International Scientific Conference
UNITECH`2024

REACTIONS RESEARCH OF COMPRESSION ARRAY HARVESTER

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Abstract
The current paper examines the responses of a particular type of compression array harvester to various external mechanical forces applied to it. The difference between the applied forces is that one mimics the passage of a human subject and the other the passage of an object that is in continuous contact with the array. Experimental studies are carried out to find out the differences in the electrical power produced by the two types of external forces.

Keywords: compression, harvesters, piezoelectric, energy output.

INTRODUCTION

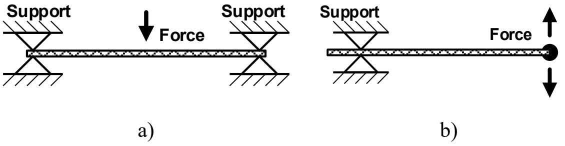
The concerns for the nowadays environmental situation predetermine the interest in the research and development of technologies that reduce pollution and increase the usage efficiency of natural resources. One of these technological directions is related to alternative low-power electrical energy sources, the so-called Energy Harvesters (EH). The physical principles and constructions used in these types of devices are diverse [1], but what they all have in common is that they use effects that are being parasitic or not affecting the basic operating processes for a given system [2].

Due to their high force-voltage ratio, piezoelectric transducers are widely used to harvest energy from external mechanical efforts in the role of energy harvesters [3, 4].

EXPOSITION

Piezoelectric energy harvesters can take a variety of structural forms, but can generally be qualified as compression-type transducers, as they all base their operation on the piezoelectric effect.

Some of the piezoelectric compression harvesters can be defined as vibrational, having a cantilever structure with one or two fixed ends (Fig. 1), the cantilever itself can have from one to several active layers (piezoelectric medium) and they are utilized for energy collecting from vibrational impacts. Vibration harvesters have well-developed theoretical models that consider the impacts on them as undamped and damped oscillations that have an almost ideal dynamic nature.

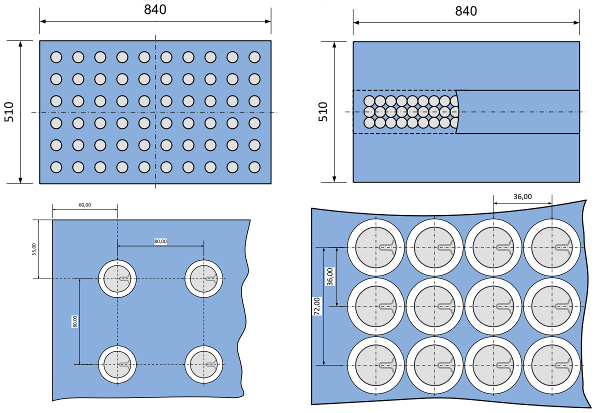


a) b)

Fig. 1. *Common structure of vibrational harvesters*

In contrast, the other types of piezoelectric harvesters do not have uniform structural features, and for each individual construction, different models specific to it should be applied.

A. Compression Array Harvester



a) Initial setup *b) Improved setup*

Fig. 2. *Array planar piezoelectric harvester*

doi: www.doi.org/10.70456/TBOF7693

To realize a compression harvester, a array-type planar configuration was chosen (Fig. 2), the matrix being achieved with multiple piezoelectric elements electrically connected in a specific way.

Piezoelectric elements are mounted on a rectangular elastic math from dielectric material and a protective cover of the same material is mounted over them. Standard piezoelectric resonators with a resonant frequency of 2,9 kHz (±500 Hz), a thickness of 300 µm and a diameter of 25 mm were chosen as the primary transducers due to their availability and relatively low cost.

A parallel electrical connection between the elements is used (shown in Fig. 3), and it is obvious that each piezoelectric element can be subjected to a mechanical load, and this will not interfere with the operation of the others. Two configurations with different active element distributions are proposed and subjected to experimental research.

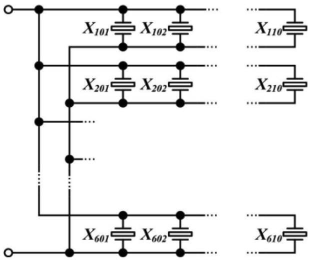


Fig. 3. *Electrical connection between elements*

The experimental studies were performed only on the active part of the compression piezoelectric harvester in order to clearly show its action and possible behavior, i.e. experiments have not been performed on the servicing circuit.

Additionally, a full bridge rectifier and capacitive elements are added to the schematic of the experimental circuit (Fig. 4), the diodes are of the 1N4148 type, and the capacitive elements have the following values $C_1 = 1$ µF and $C_2 = 10$ nF. The capacitor is chosen to have a standard capacitance of 1 µF and the resistor R_L was initially chosen to have a standard value of 1 MΩ.

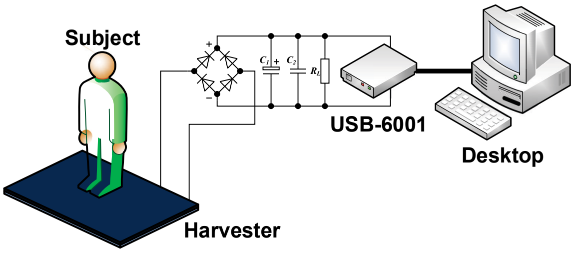
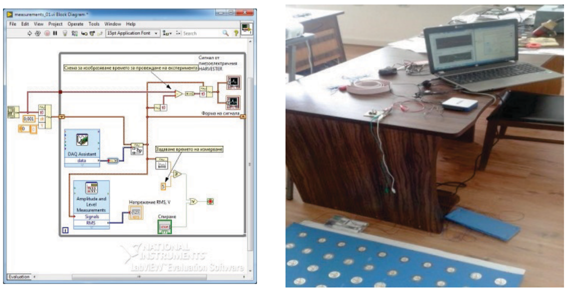


Fig. 4. *Experimental circuit*

This large value was chosen considering that, in principle, piezoelectric elements have a low current density, and in order not to have a rapid discharge of the capacitor, it is preferable to use a high-resistance load. NI (National Instruments) USB-6001 DAQ measurement board is used to monitor the dynamic composite. The measurement is performed through the LabView 2023 software environment (Fig. 5), the data obtained are in RMS voltage values.



a) Block-diagram *b) Experimental setup*

Fig. 5. *Experimental setup for the harvester*

Experiments were conducted to mimic the passage of pedestrians, and each subject was previously measured for shoe size and weight, respectively. Subjects are ought to make as many passes as possible along the length of the pad in 5 s while reading the RMS voltage signal in this time interval, with ten such measurements performed for each subject.

B. Improved Configuration

The initial experiments were performed on a planar array with relatively large distances between the active elements (Fig. 2,a), which lead to relatively small acquired energies. Obviously, reducing the distance between the active elements should increase the energy yields, thus experiments are performed on an array with minimum distances with the same subjects (Fig. 2,b). During the experiments, the electrical loads (R_L) are changed in order to check their influence on the acquired power.

From the partial data (*Table 1* and *2*) for one of the subjects, it can be seen that the improved harvester structure has a higher energy yield.

Table 1: *Partial data from initial harvester setup*

R_L, kΩ	**1**	**2,4**	**5,1**	**7,5**	**10**	**51**	**75**	**100**
№	Subject Mass: 60 kg; Shoe size: 38							
1	0,0039	0,0136	0,0299	0,562	0,638	1,722	1,925	2,517
2	0,0091	0,0318	0,0698	0,587	0,705	1,684	2,006	2,468
3	0,0109	0,0380	0,0836	0,599	0,768	1,766	1,841	2,425
4	0,0121	0,0422	0,0929	0,613	0,702	1,806	1,966	2,517
5	0,0135	0,0471	0,1036	0,548	0,843	1,734	1,923	2,449
6	0,0169	0,0590	0,1297	0,531	0,836	1,772	2,091	2,507
7	0,0162	0,0565	0,1243	0,526	0,726	1,694	1,847	2,463
8	0,0154	0,0538	0,1182	0,486	0,773	1,713	1,816	2,417
9	0,0109	0,0380	0,0837	0,581	0,827	1,791	1,933	2,462
10	0,0205	0,0716	0,0929	0,563	0,799	1,827	1,872	2,378
U_{RMS}, V	0,0129	0,0452	0,0929	0,5596	0,7617	1,7509	1,922	2,4603
P, mW	**0,03328**	**0,17005**	**0,33819**	**8,35072**	**11,6037**	**12,0222**	**9,85089**	**12,1062**

Table 2: *Partial data from improved harvester setup*

R_L, kΩ	**1**	**2,4**	**5,1**	**7,5**	**10**	**51**	**75**	**100**
№	Subject Mass: 60 kg; Shoe size: 38							
1	0,0568	0,133	0,415	0,831	0,955	2,354	2,914	3,824
2	0,0490	0,129	0,482	0,869	1,059	2,471	2,867	3,762
3	0,0553	0,228	0,561	0,914	1,102	2,518	3,008	3,751
4	0,0583	0,318	0,437	0,881	1,077	2,483	2,931	3,851
5	0,0636	0,295	0,462	0,846	0,961	2,441	2,892	3,767
6	0,0362	0,265	0,483	0,807	0,997	2,564	3,057	3,807
7	0,0545	0,047	0,638	0,764	0,93	2,433	2,871	3,835
8	0,0762	0,310	0,632	0,893	1,037	2,391	2,956	3,773
9	0,1187	0,434	0,828	0,915	1,141	2,279	3,011	3,716
10	0,1497	0,348	0,574	0,903	0,962	2,451	2,973	3,748
U_{RMS}, V	0,0718	0,2507	0,5512	0,8623	1,0221	2,4385	2,948	3,7834
P, mW	**1,0317**	**5,2386**	**11,9152**	**19,8283**	**20,8938**	**23,3188**	**23,1752**	**28,6282**

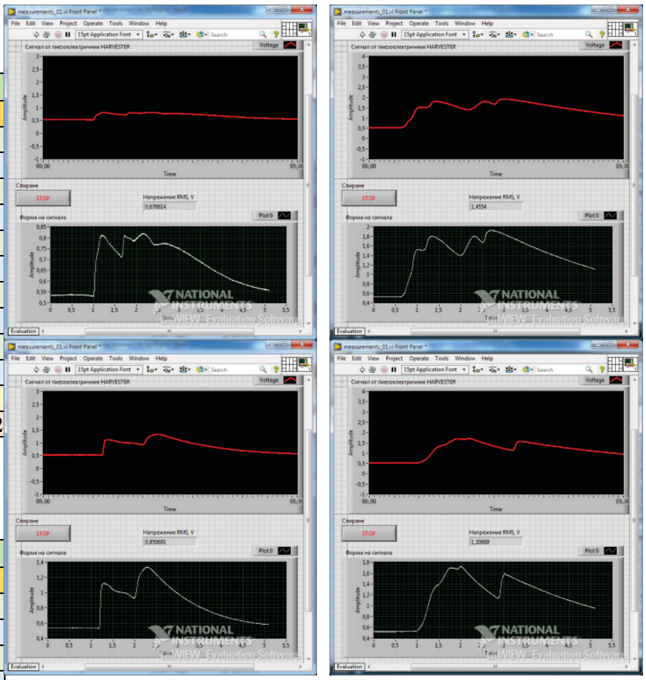
Table 3: *Comparison between the harvester setups*

R_L, kΩ	**1**	**2,4**	**5,1**	**7,5**	**10**	**51**	**75**	**100**
Setup	P, mW							
First	**0,03328**	**0,17005**	**0,33819**	**8,35072**	**11,6037**	**12,0222**	**9,85089**	**12,1062**
Second	**1,0317**	**5,2386**	**11,9152**	**19,8283**	**20,8938**	**23,3188**	**23,1752**	**28,6282**

The improved variant of the compression piezoelectric harvester is more efficient due to the reduced passive area between the elements (increased number of active elements per unit area), but for the same area, the harvester needs more active elements, which increases the cost. But in both cases, the electrical energy that can be obtained from both structures is relatively small.

C. Continuous impacts on the harvester

In the previous experiments on the compression piezoelectric harvester, pedestrians were used to generate the harvested energy. Due to the peculiarities of the human movements (the gait), specific features are observed in the profile of the extracted energy (Fig. 6).



a) Subject mass: 90 kg
Shoe size: 43

b) Subject mass: 98 kg
Shoe size: 45

Fig. 6. *Peculiarities in pedestrian gait*

An experiment is proposed in which this feature is excluded, and the array structure is continuously subjected to load during the study as furthermore the mass parameters of the effecting device are changed.

The measurements are carried out as follows: the impacting object is initially placed outside the active part of the harvester array. At the beginning of the experiment, the mobile object is moved along the active part of the array within 5 s, the movement being carried out in both directions along its length (Fig. 7). For each different mass load, ten experiments are done and then the data are averaged (Table 4). Presumably the continuous influence over the harvester should be more effective than pedestrians at relatively equal masses.

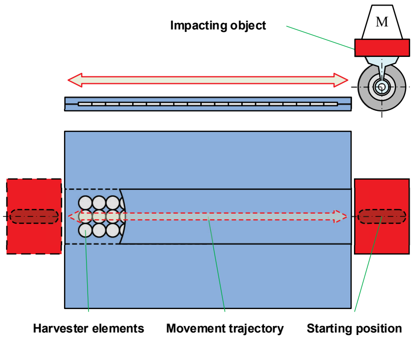


Fig. 7. *Continuous impact on the harvester*

The obtained data shows that when the mass of the impacting object increases, the amount of acquired energy increases (Table 5) which is in the frame of the expected results.

Table 4: *Partial data for 48,05 kg mass*

R_L, kΩ	**1**	**5,1**	**7,5**	**10**	**33,78**	**51**	**75**	**100**
№	Object Mass: 60 kg							
1	0,0259	0,1193	0,1490	0,1924	0,5177	0,7149	0,7529	1,2247
2	0,0253	0,1240	0,1476	0,2027	0,4461	0,7784	0,7677	1,0870
3	0,0199	0,1125	0,1532	0,1762	0,4809	0,7138	0,7893	1,0949
4	0,0255	0,1182	0,1716	0,2101	0,5180	0,6957	0,8322	1,0579
5	0,0295	0,1036	0,1547	0,1781	0,5004	0,6509	0,9670	1,0308
6	0,0205	0,0934	0,1336	0,1991	0,4782	0,7994	0,9713	0,8566
7	0,0169	0,1214	0,1584	0,2198	0,5189	0,6227	0,9585	1,0189
8	0,0252	0,0849	0,13101	0,2231	0,5033	0,7625	0,8236	0,9365
9	0,0247	0,1110	0,1272	0,1960	0,5150	0,6464	0,88964	1,05988
10	0,0172	0,1190	0,1682	0,2168	0,4105	0,7194	0,7262	0,9402
U_{RMS}, V	0,0259	0,1193	0,149	0,1924	0,5177	0,7149	0,7529	1,2247
P, mW	**0,1064**	**0,4809**	**0,5956**	**0,8116**	**1,4151**	**1,9792**	**1,9169**	**2,1249**

Table 5: *Data for different masses*

R_L, kΩ	**1**	**5,1**	**7,5**	**10**	**33,78**	**51**	**75**	**100**
Mass	P, mW							
15,45 kg	0,00948	0,05051	0,07757	0,14154	0,16137	0,23849	0,17864	0,23932
25,25 kg	0,02424	0,13401	0,14502	0,24761	0,48169	0,55335	0,53226	0,59824
38,25 kg	0,06301	0,27178	0,38937	0,48919	1,02833	1,07553	1,29870	1,37068
48,05 kg	0,10643	0,48094	0,59562	0,81157	1,41514	1,97918	1,91688	2,12492

Contrary to expectations, continuous impacts did not lead to a sharp increase in the amount of energy acquired, especially compared to the results of pedestrians with a mass close to that of the impacting object (Table 6 and Fig. 9).

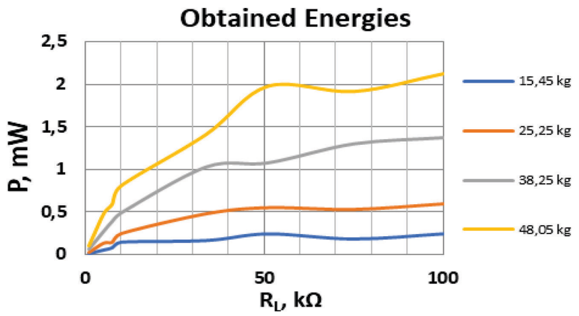


Fig. 8. *Obtained energies from the harvester*

Table 5: *Result comparison*

Maca	**R_L, kΩ**	1	5,1	7,5	10	51	75	100
60 kg	**P, mW**	**1,0317**	**11,9152**	**19,8283**	**20,8937**	**23,3187**	**23,1752**	**28,6282**
48,05 kg	**P, mW**	**0,1064**	**0,4809**	**0,5956**	**0,8116**	**1,9792**	**1,9169**	**2,1249**

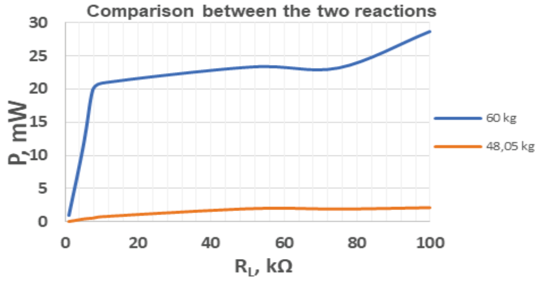


Fig. 9. *Comparison between the results from person with 60 kg mass and object with 48,05 kg mass*

It is also interesting to note the results for the 75 kΩ load in the both type of studies, where a deviation from the assumed behaviour of the piezoelectric harvester is noted.

D. Assumptions regarding the two types of influence

The interrupted action of the human gait should be noted with pedestrians triggering the harvester. This is related to the peculiarities of human biomechanics when walking, which are distinguished from a simple repetitive impact on the plane of motion.

Another thing not taken into account in the study is the inertial influence exerted by the dielectric pad on the mechanical forces applied to the harvester. Research of this kind had not been conducted.

CONCLUSION

The following conclusions can be drawn from the research:

The proposed improved design of the piezoelectric planar harvester proves its advantage in terms of the acquired energy (Table 3), although it will lead to a sharp increase in the number of active elements and, accordingly, the economic cost of the harvester.

Two types of impacts were studied on the proposed harvester: an intermittent action corresponding to a human walking through the active part of the harvester and a continuous impact imitating the passage of some vehicle. The stated hypothesis that the continuous mechanical impact on the piezoelectric planar harvester will lead to an improvement in the energy harvesting process compared to that of a human passage, was not justified. This may be due both to the failure to take into account some of the influencing factors, and to the incorrect setup of the experimental set.

The range of experiments conducted should be expanded to more thoroughly study the influence of the electrical load (R_L) as well as the dielectric substrate.

Funding: This research was funded by the European Regional Development Fund under the Operational Program "Scientific Research, Innovation and Digitization for Smart Transformation 2021-2027", Project CoC "Smart Mechatronics, Eco- and Energy Saving Systems and Technologies", BG16RFPR002-1.014-0005.

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