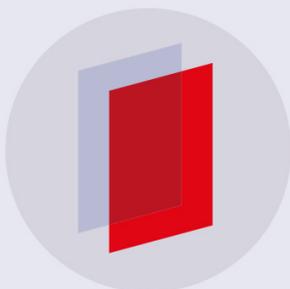


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To cite this article: J Kunz *et al* 2018 *J. Phys.: Conf. Ser.* **1065** 202008

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# An Automated measurement system for measuring an overall power efficiency and a characterisation of piezo harvesters

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**Abstract.** Systems for measurement power characteristics of piezo harvesters in dependence on a frequency and a load resistance are not commonly used due its complexity. Therefore, the parameters are usually measured manually near its resonant frequency. In some cases, it is convenient to measure the characteristics in a broader range of parameters. Then, in order to achieve more precise results and effective measurement we decided to develop our own measurement system. The system controls an effective value of vibrations, sets a frequency and a load resistance for measuring a power generated by a piezo harvester and measures a tip displacement of the harvester. These quantities are used for a characterisation of piezo harvesters. Moreover, the voltage and current on vibration exciter are measured to evaluate the overall efficiency of the harvester. The system was tested on a harvester MIDE PPA-1001 for various added weights and vibration levels from 0.1 to 0.5 g. The measured data analysed and the efficiency was calculated as a ratio between a vibration power consumed by the harvester and its electrical output. The evaluated overall efficiency varies between 10 and 15 % nearby its optimal working conditions.

## 1. Introduction

Energy harvesting is an emerging area, due to availability of ultra-low power electronics, which can be powered from the harvested energy. This together with a wireless data transfer makes the electronics completely wireless and maintenance free, which is a great combination for autonomous devices. [1] The energy can be harvested from f.e. mechanical vibrations, where piezo harvesters are used. [1; 2]

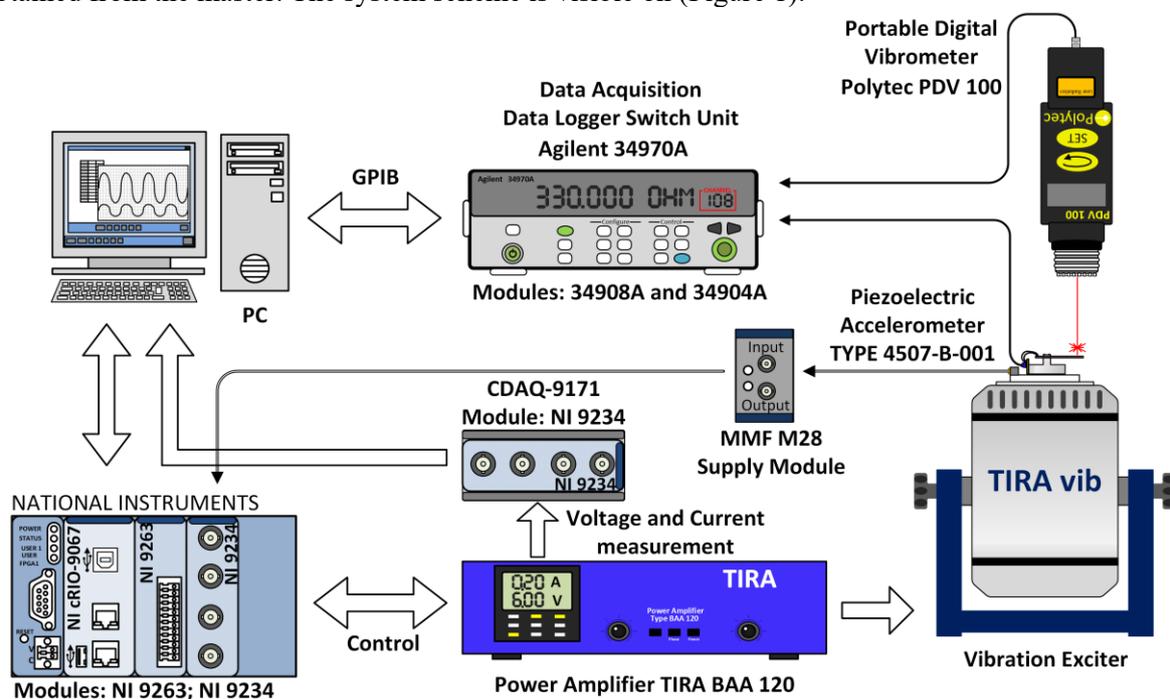
To achieve a maximum efficiency a proper harvester has to be selected in dependence of the vibration characteristics and desired functionality. For this reason, piezo harvesters have lots of parameters which has to be measured. [2] Unfortunately, the parameters are usually describing the best available case, however that case is unreachable in practice due real, non-optimal, operating conditions. For this reason, it is useful to measure the harvester parameters nearby its ideal conditions. This measurement will generate a lot of data and will last quite a long time, so it is convenient to use an automated measurement system. Similar system is described in [3] where dedicated equipments are used. In contrast, our system is based on a multipurpose hardware. Furthermore, the system is able to find a harvester resonance frequency using a chirp sine and moreover, it is able to measure the overall efficiency of the harvesters.

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The efficiency of conversion between harvester vibration and electrical power output can be found in [4; 5]. However, the overall efficiency, which means the efficiency of energy conversion between ambient vibrations and the electrical power output is still an open issue, so it is convenient to measure it automatically.

## 2. Automated measurement system

For measuring the characterisation and the efficiency of piezo harvesters we have built an automated system. We have used an equipment from National Instruments and other, which is commonly in a lab. The software is written in LabVIEW 2015 and it is separated to two sections. One section, a master, is measuring the harvesters. Whereas the other, a slave, which runs on Compact RIO 9067, is performing a vibration control. The vibrations are measured using accelerometer B&K 4507, generated via TIRA BAA 120 amplifier and controlled to a constant RMS value, which is together with the actual frequency obtained from the master. The system scheme is visible on (Figure 1).



**Figure 1.** Schematics of the automatic measurement system for characterisation of piezo harvesters and measurement of their efficiency.

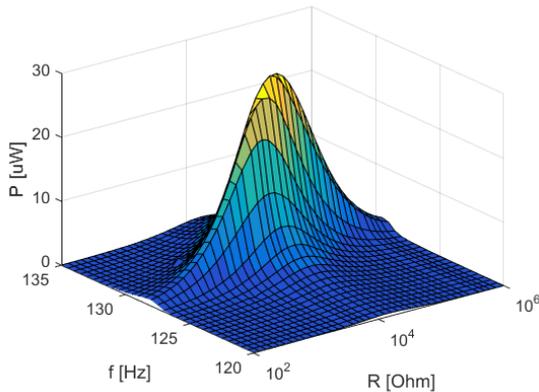
The master is communicating with an Agilent 34970A, where a velocity of the harvester's tip using an interferometer and a generated power on selected load resistance are measured. To set a proper resistance, for a power measurement, two 34904A matrix switch modules are used. One matrix switch contains 9 resistors, which can be combined parallelly to achieve the desired resistance.

## 3. Measured data

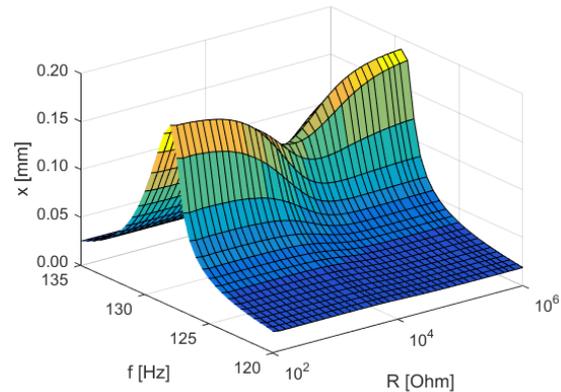
Once the measurement system was completed we started to collect data on a piezo harvester MIDE PPA-1001. [6] We measured its power (Figure 2) and displacement (Figure 3) in dependence on the frequency of vibrations and the load resistance. Both were chosen near the optimum. This was done for different vibration amplitudes (from 0.1 g to 0.5 g) and different added weights (from 0 to 518 mg).

On the figures (Figure 2, Figure 3) is clearly visible that when the delivered power is maximal, the amplitude of the harvester vibration decreases in comparison with a different load on the same frequency. This is so, because when the circuit has the lowest impedance then the maximal power is delivered and according to [2] the vibration decreases.

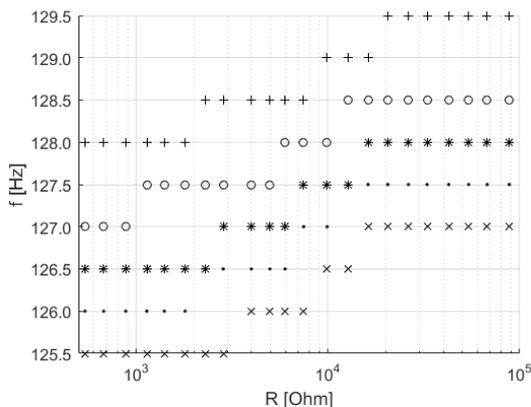
Similarly, the frequency, where maximum power is delivered, is increasing with increasing load resistance. This is also explained in [2], however they calculated it only open and short circuited harvester, so according to (Figure 4) we can assume, that their calculations can be interpolated to calculate the best combination of the frequency and the load resistor to achieve a maximum delivered power.



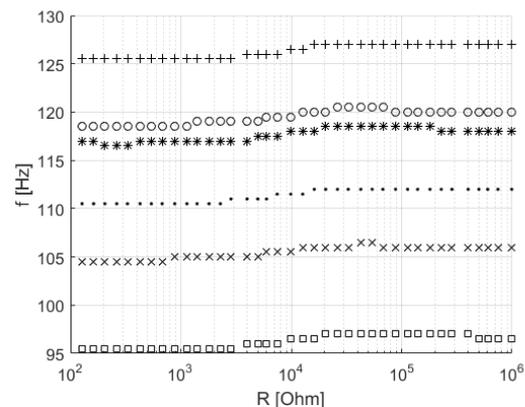
**Figure 2.** Electric power generated by a harvester PPA-1001 on sinusoidal vibrations with acceleration  $a = 0,1 g_{rms}$  and no added mass on the harvester.



**Figure 3.** A harvester PPA-1001 displacement amplitude in dependence on sinusoidal vibrations with acceleration  $a = 0,1 g_{rms}$  and no added mass on the harvester.



**Figure 4.** Parameters, a frequency and a load resistance, of the maximum electric power generated by harvester PPA-1001 for different levels of sinusoidal vibrations,  $0,1 g_{rms}$  (+),  $0,2 g_{rms}$  (o),  $0,3 g_{rms}$  (\*),  $0,4 g_{rms}$  (·),  $0,5 g_{rms}$  (x), and no added mass.



**Figure 5.** Parameters, a frequency and a load resistance, of the maximum electric power generated by harvester PPA-1001 for different added masses, no load (+),  $69 mg$  (o),  $109 mg$  (\*),  $209 mg$  (·),  $331 mg$  (x)  $518 mg$  (□), and vibration amplitude  $a = 0,5 g_{rms}$ .

#### 4. The conversion efficiency

Many work has been done to increase a conversion efficiency between the vibrating harvester and the usable electric power. [4] However, the efficiency between ambient vibration and harvester was not much discussed, perhaps due to other inapplicability of the ambient vibration. However, it is quite important to know how much energy the harvester consumes from outside to produce desired electrical power. For these reasons, we decided to calculate the overall efficiency between the input power and the electric power output.

The input power was calculated as a difference between real powers of the vibration exciter with and without mounted harvester. Both powers were calculated from the actual current and voltage powering

the exciter. Both quantities were measured on the monitoring outputs of the power amplifier to minimize the errors. As the harvester itself weights only 2,8 g and the moving mass of the exciter weights more than a kilogram, we can assume that the additional weight of the harvester mounted on the exciter does not cause additional power losses in the exciter. For that reason, the calculated power difference is exactly a power input to the harvester. The power output from the harvester is simply the power measured on the load resistance.

The harvester efficiency was measured near the resonant frequency and the optimal load resistance for acceleration  $a = 0.5 g_{rms}$ . The efficiency varies between 10 and 15 % in dependence on the load resistances and frequencies. The theoretical efficiency is limited due to losses in the system. [7] Considered these limitations the theoretical efficiency should be more than 25 %, so there the actual efficiency can be almost doubled.

## 5. Conclusion

In this paper, we introduced an automatic measurement system for measuring parameters of piezo harvesters. The system is programmed in LabVIEW and is based on National Instruments hardware, together with Agilent 34970A, which allows dynamic changes of a load resistance by setting a different parallel combination of preset resistors.

Using this measurement system, we measured the parameters of a piezo harvester PPA-1001 for different accelerations and added weights. From these data is visible how the maximum output power is dependent on the frequency and the load resistance for different accelerations (Figure 4) and added weights (Figure 5).

Moreover, from the data it is possible to calculate an overall efficiency of the harvester. The efficiency near the resonance varies between 10 and 15 %, whereas the theoretical one should be at least 25 %. Increasing this efficiency will be challenging, however it could significantly improve the total energy generated by piezo harvesters.

## Acknowledgments

The authors gratefully acknowledge financial support from the Ministry of Education, Youth and Sports under projects No. LO1210-"Energy for Sustainable Development (EN-PUR)" solved in the Centre for Research and Utilization of Renewable Energy. This research was carried out under the project CEITEC 2020 (LQ1601) with financial support from the Ministry of Education, Youth and Sports of the Czech Republic under the National Sustainability Programme II.

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