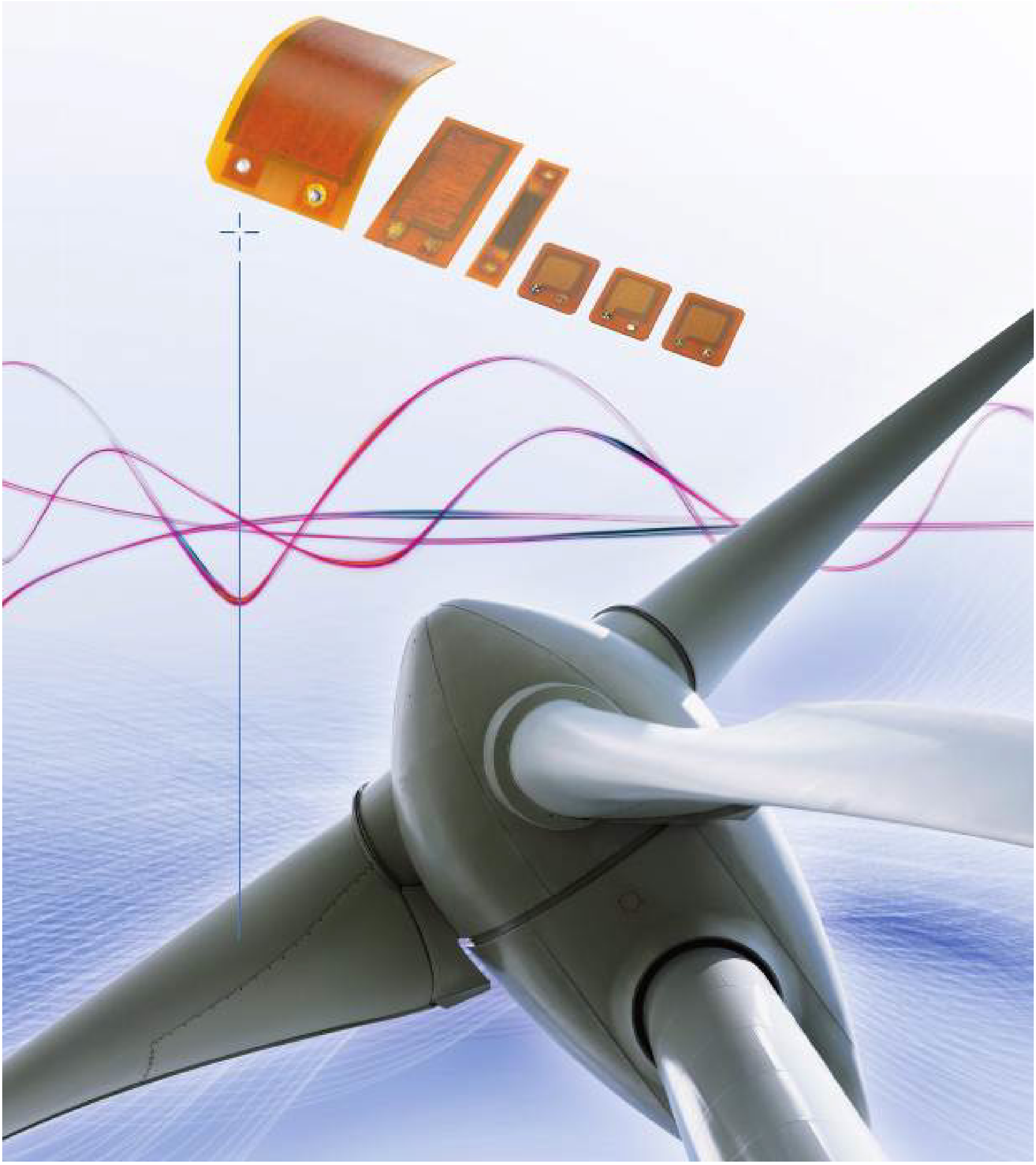
Dipl.-Phys. Birgit Schulze

Energy Harvesting Uses the Piezo Effect

DuraAct Piezo Transducer Plus Matching Electronics



PI Ceramic GmbH_Lindenstraße_07589_Lederhose, Germany
Tel. +49 36604 882-0, Fax +49 36604 882-4109 Email info@piceramic.com, www.piceramic.com

What is meant by Energy Harvesting?

The term Energy Harvesting is popularly used when electricity is generated from sources such as ambient temperature, vibrations or air flows. Since there are now electronic circuits whose power requirement is of the order of milliwatts, even though its energy yield is relatively low, energy harvesting with piezo-based solutions is always of great interest in situations where electricity cannot be supplied via power cables and one wants to avoid batteries and the maintenance effort required.

Energy harvesting can be based on a number of physical effects. Photovoltaic cells are one option, as are thermoelectric generators which generate electrical energy from temperature gradients.

It is also possible to receive and energetically use the energy from radio waves via antennas, as is the case with passive RFID tags, for example. Piezoelectric crystals are also ideal for energy harvesting. They generate an electric voltage when force is applied in the form of pressure or vibrations, i.e. they use the kinetic energy available in their environment.

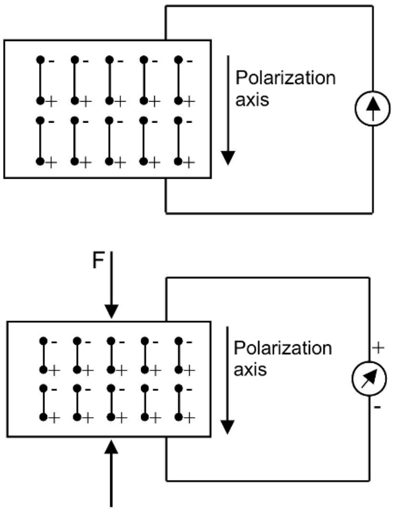


Fig. 1 Energy generation using the piezo effect (Physik Instrumente (PI))

Energy Generation with the Piezo Effect

When a piezo crystal mechanically deforms as a result of a force applied with tension or pressure, charges are generated which can be measured as a voltage on the electrodes of the piezo element (Fig. 1**Fehler! Verweisquelle konnte nicht gefunden werden.**), a phenomenon known as the direct piezo effect.

This method of charge generation is familiar from gas ignition systems to generate the ignition voltage, for example. The charge generated (Q) can be described by the mathematical expression below:

$Q = d \times \Delta F$

The charge constant d (ratio of charge generated to force applied) in this equation is a material-specific constant of the order of 10^{-10} C/N.

It therefore quickly becomes apparent that the quantity of charge generated is relatively low. This aspect places high demands on mechanical systems and electronics in order to “harvest” the optimum amount of energy.

A Complex System

A universal energy harvesting solution does not exist, because the energy excitation conditions differ from application to application. To dimension such a system correctly, all important boundary conditions must be known and taken into account. Take the energy source, for example:

One needs to distinguish between continuous and pulsed motions. The requirements of the electric load must also be taken into consideration, of course: The important parameters here include the voltage required, the power and the input impedance, i.e. capacitive or resistive.

It is then possible to use this data to design and dimension the transducer including the mechanical system. Here, PI Ceramic can contribute its years of experience and comprehensive know-how in the design of custom-engineered solutions, which benefit very different sectors of industry.

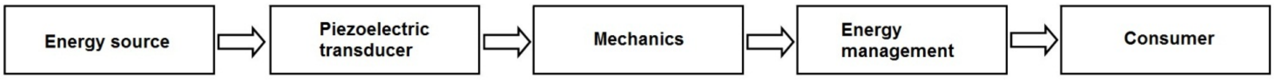


Fig. 2 Design of an energy harvesting system (Physik Instrumente (PI))

Typical Applications for Piezo Energy Harvesting

There are many applications where the energy generated by energy harvesting from the environment is sufficient and can be used in a worthwhile way.

Although small button cells have quite long useful lives nowadays, it may make sense to avoid batteries nevertheless, because it is too much effort to test and change them when the load is installed in a location which is inaccessible or difficult to reach. Energy harvesting solutions can then be the means of choice, despite their complexity. A typical example for this is so-called health monitoring on the rotor blades of wind turbines.

Further interesting fields for energy harvesting are data monitoring and transmission in heating and air conditioning technology. If vehicle vibrations are used for energy generation, products can be continuously monitored during transport without the corresponding sensors having to be connected up or equipped with batteries. This is useful if temperatures have to be recorded inside closed containers, for example. Rain sensors can be powered via energy harvesting in the windscreens of vehicles, and the energy requirements of wireless ZigBee networks can also often be covered by “harvesting” energy in the environment.

Highly Versatile and Durable Patch Transducers

In principle, every piezoceramic component or every piezo actuator can be used for energy harvesting. By converting mechanical vibrations of a few kilohertz into electric voltage, a few milliwatts of power can be generated, and this can be supplied to electrical components, e.g. processors, sensors or mini-transmitters.

Order Number	Operating voltage [V]	Min. lateral contraction [µm/m]	Rel. lateral contraction [µm/m/V]	Blocking force [N]	Dimensions [mm]	Min. bending radius [mm]	Piezo ceramic height [µm]	Electrical capacitance [nF] ±20%
P-876.A11	-50 to +200	400	1.6	90	61 × 35 × 0.4	12	100	150
P-876.A12	-100 to +400	650	1.3	265	61 × 35 × 0.5	20	200	90
P-876.A15	-250 to +1000	800	0.64	775	61 × 35 × 0.8	70	500	45
P-876.SP1	-100 to +400	650	1.3	280	16 × 13 × 0.5	-	200	8

Piezo ceramic type: PIC 255
Standard connections: Solder pads
Operating temperature range: -20 to 150°C

Fig. 3 The table shows the technical data of different piezo transducers (Physik Instrumente (PI))

A particularly practical solution is the durable, laminated DuraAct transducer which PI Ceramic provides in a wide range of standard designs (Fig. 3 and Fig. 4).

Fig. 4 Highly versatile and durable patch transducers (Physik Instrumente (PI))

A DuraAct patch transducer consists of piezoceramic plates or films which are embedded in a polymer together with their contacts. This mechanically preloads the brittle ceramic while electrically insulating it at the same time. The mechanical preloading extends the loading limits of the ceramic so it can also be applied to curved surfaces, for example. At the same time the compact design including the insulation makes it easier for the user to handle; it is even possible to embed the patch transducer in a composite material.

The patch transducers ideally have a symmetrical structure, i.e. when the transducer is bent, the same quantity of charge with opposite sign is generated on both electrode surfaces; it would not be possible to measure a potential difference. This makes it necessary to bond the transducer onto a substrate (e.g. aluminum, CRP or GRP material), thus producing the conventional bender structure. Charges can now be generated by fixing the bender at the edge and displacing it, the charges being proportional to the stresses or strains introduced into the ceramic to a first approximation.

A test provides information on how the thickness of the ceramic affects the energy harvesting characteristics. To this end, the DuraAct transducers were bonded to CRP strips and fixed on one edge. A rotating eccentric disk displaces the bender transducer.

With this set-up it was thus possible to realize the reproducible fixing and excitation conditions necessary for the direct comparison of transducers (variation of frequency and displacement).

Power Output as a Function of Load Resistance

Moreover, it is possible to compare how the CRP bender structures and the various DuraAct transducers (P-876.A11, -A12 and -A15) bonded on CRP behave at different load resistances and the same excitation conditions (frequency: 1 Hz, displacement: 5 mm). The AC voltage from the generator was rectified by a Graetz full wave bridge rectifier and smoothed with a capacitor (10 µF). The power output was then determined for every type of DuraAct at different load impedances.

This showed that every transducer in the test had a different electrical load range with optimum power output (Fig. 5). The bender structure with the DuraAct P-876.A12 provides the greatest power output under the boundary conditions stated. This demonstrates very well that optimum power output always requires an optimized transducer design with corresponding power adjustment.

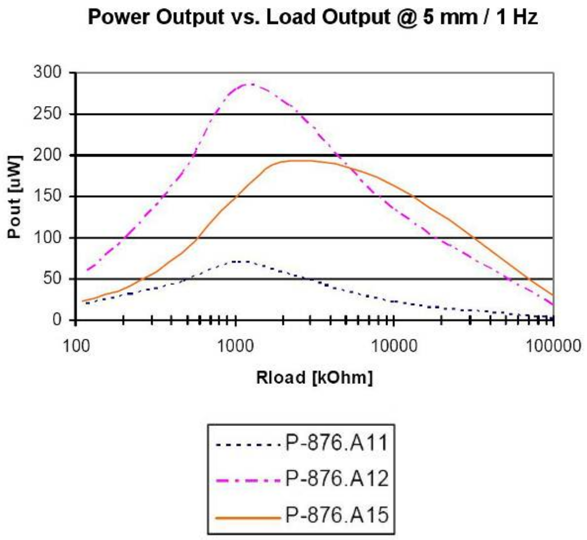


Fig. 5 Power output as a function of the load resistance (Physik Instrumente (PI))

Power Output as a Function of the Excitation Conditions

The other results of the investigation are restricted to the bender structure with the DuraAct P 876.A12 patch transducer.

Figure 6 shows the power output as a function of the displacement. The power output is crucially determined by the mechanical deformation of the bender structure. The larger the displacement, the greater the charge and power generated. It is therefore particularly important to analyze the energy sources available and to develop a mechanical design adapted to them which allows optimum conversion of mechanical energy into electrical.

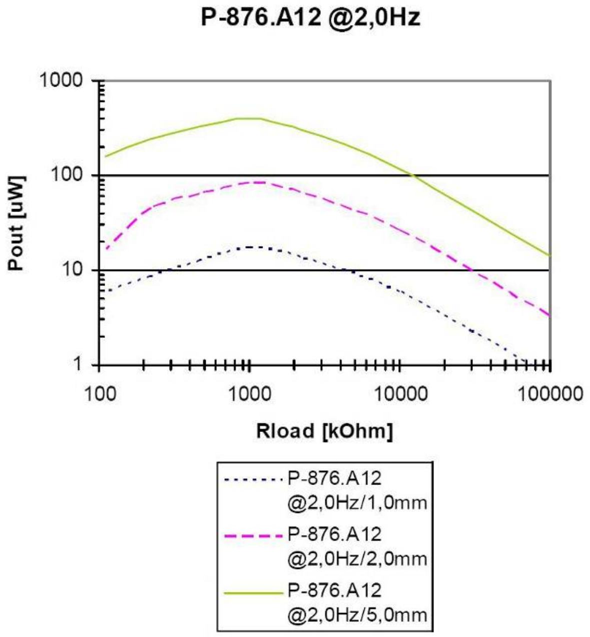


Fig. 6 Power output as a function of the excitation conditions (Physik Instrumente (PI))

The frequency of the excitation also has a direct effect on the power output. As Figure 8 shows, there is an almost linear relationship between power output and excitation frequency. It is also possible to see a shift of the optimum load range to smaller values at higher excitation frequency.

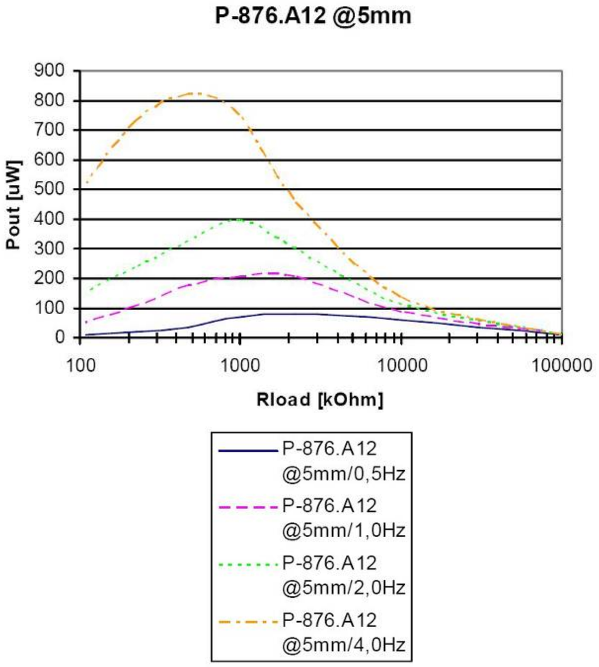


Fig. 7 The relationship between power output and excitation frequency is almost linear (Physik Instrumente (PI))

Matching Electronics

The test electronics available for piezo energy harvesting include a rectifier with downstream storage capacitor and load switch. They can process alternating and continuous input voltages. The electronic circuit decouples the load (i.e. the consumer) from the generator and the energy can be collected and stored over a long period.

For the charging process of the storage capacitor the open-circuit voltage of the generator must be higher than VHigh.

When the voltage level VH is reached after a charging time t_1+t_2 the discharge process (supply to a load, t_3) begins. If the voltage available decreases to the value VLow, no further power output is possible, the storage capacitor must be charged up again (Fig. 8).

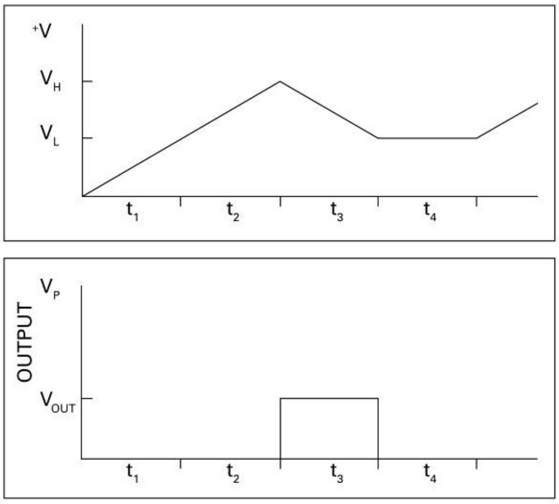


Fig. 8 Energy is only supplied between the voltage levels V_H and V_L (Physik instrumente (PI))

Energy can therefore only be supplied between the voltage levels VH and VL:

$$W_{el} = \frac{C}{2}(V_H - V_L)^2$$

If one varies the capacitor, it is possible to match the electronics to the power requirement of the load. The output voltage of the test electronics can be flexibly adjusted between 1.8 and 5 V. Due to the repeating phases of “charging” (w), “storing”, “energy output”, “charging” this solution is particularly suitable for applications which do not have a continuous power requirement, e.g. in wireless sensor networks where the charge is generated and stored in measurement breaks and the energy is retrieved for the measurement and data transmission.

If the piezo transducer, the mechanical system and the electronics are matched to each other so as to take account of the application-specific boundary conditions, piezo-based energy harvesting can be a practical way of supplying energy in many other applications as well.

Conclusion

The results here show as an example how ambient energy can be converted to electrical energy and then be used to supply a corresponding consumer under specific conditions.

There is no general energy harvesting solution that serves all purposes. The design of the piezoelectric transducer, the electronics and the kind of excitation used substantially determine the outcome and need to be matched individually for a certain task.

More information on DuraAct piezoelectric patch transducers is available at:

www.piceramic.com

Author

Dipl.-Phys. Birgit Schulze, Product Manager at Physik Instrumente (PI) GmbH & Co. KG.

About PI Ceramic

Since 1992, PI Ceramic (PIC) has been developing and manufactur-ing piezo ceramic materials and components for standard and OEM solutions: piezo components, ultrasonic transducers, actuators and system solutions. The PICMA® multilayer actuator technology, which received an award for its reliability, is one of many inventions of PIC. PI Ceramic, a subsidiary of Physik Instrumente (PI), is locat-ed in the city of Lederhose, Thuringia, Germany.