Micromachines **2013**, *4*, 168-196; doi:10.3390/mi4020168

OPEN ACCESS

micromachines

ISSN 2072-666X

www.mdpi.com/journal/micromachines

Article

Review on Electrodynamic Energy Harvesters—A Classification Approach

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Received: 29 December 2012; in revised form: 20 January 2013 / Accepted: 22 January 2013 / Published: 29 April 2013

Abstract: Beginning with a short historical sketch, electrodynamic energy harvesters with focus on vibration generators and volumes below $1\,\mathrm{dm}^3$ are reviewed. The current challenges to generate up to several milliwatts of power from practically relevant flows and vibrations are addressed, and the variety of available solutions is sketched. Sixty-seven different harvester concepts from more than 130 publications are classified with respect to excitation, additional boundary conditions, design and fabrication. A chronological list of the harvester concepts with corresponding references provides an impression about the developments. Besides resonant harvester concepts, the review includes broadband approaches and mechanisms to harvest from flow. Finally, a short overview of harvesters in applications and first market ready concepts is given.

Keywords: review; electrodynamic energy harvesting; electromagnetic linear generators; power MEMS

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1. Introduction

Energy harvesting, a term that was originally used in a publication about the photosynthesis of light in 1966 [1], is nowadays understood as the conversion of ambient energy from the environment to electricity at small scale. Environmental energy sources, such as radiation, motion, or heat, of course have always been available. However, due to several developments, energy harvesting became a hot research topic in the 1990s and still is.

- The increasing efficiency of electronic components and circuits allows the use of low-power sources. Today, many sensors consume only between 0.1 to a few microwatts [2], a $1\,\mathrm{MHz}$ microprocessor can work with a milliwatt power and in standby mode survive with only a microwatt [3].
- Cost reductions and improvements in mass production technologies enabled manufacturers to implement more and more electronics and sensors into products and created new markets [4]. Famous examples are tire pressure monitoring [5] or consumer electronics that are increasingly equipped with sensors and wireless functions.
- The trends towards process automation, intelligent logistics, safety and comfort require more and more electronics for data acquisition, processing and communication [6,7]. The effort to connect the growing number of electronic devices and sensors increases dramatically. For example, disregarding installation costs, just replacing the connecting wires for sensors and switches in new and refurbished buildings can save $10,000\,\mathrm{t}$ of copper in Germany per year [8].
- The demand for flexibility and the increasing number of mobile applications require wireless solutions for power supply. A good indicator for this development is the market for GPS-circuits that grows more than 7% per year [9].
- The costs for battery supply, especially maintenance costs to exchange discharged batteries, make energy harvesters an attractive alternative. Simple calculations show that at a comparable volume harvesters can provide the energy of a battery within weeks to months [10].

This review focuses on electrodynamic energy harvesting from vibrations and provides an overview about research fields and questions that have been studied during the past 15 years. The paper gives an update to previous reviews [11–14] and, in contrast, discusses literature from a different point of view. By highlighting and classifying selected harvesters from literature the variety of answers and solutions is sketched. As electrodynamic energy harvesting has taken the step to first commercial products, explicit applications have been collected. An extended chronological table with published harvester concepts is added. As it requires a broader discussion of the theoretical background, the comparison of the output power of electrodynamic is not included in this paper.

2. Historical Sketch on Electrodynamic Energy Harvesting

The fundamentals of electrodynamic energy harvesting have been discovered nearly two centuries ago. The observation of the force (later named Lorentz force in honor of Hendrik Antoon Lorentz) generated by a magnetic field on moving charge carriers is attributed to Hans Christian Ørsted (1920) [15,16]. In 1821 Michael Faraday invented the electric motor by setting up his experiment with a permanent gyration of a current carrying wire in a magnetic field [16,17].

With the law of induction found by Faraday in 1831 [18] it was possible to explain the conversion from mechanical to electrical energy and vice versa. The energy harvesting mechanism is based on the change of the flux linkage in the harvester coil due to an ambient excitation of the harvester. According to the law of induction, a voltage is induced, and energy is partly supplied to an attached load and partly dissipated due to the coil resistance. The equivalent energy is extracted from the excitation due to Lorentz force. With the Maxwell equations, first comprehensively published in 1865 [19], the analytical description was given.

Many generators based on the rotating principle have been built. Already in 1831 Joseph Henry developed the first linear generator [15]. However, the primary need for rotating machines can be considered as reason for the low attention of linear generator concepts until the mid 1990s. Then, starting with the larger efficiency of electronic circuits and the increasing number of applications, research on linear generators for power generation, now called energy harvesters, has been kicked-off. Beginning with the Seiko AGS Quarts Watch sold since 1988 [20,21] and the publication of Williams and Yates in 1995 [22], research groups all over the world published several hundred papers on energy harvesting and more than a hundred on different prototypes.

Research and development in electrodynamic energy harvesting has been oriented to a broad variety of questions, firstly, to enable to harvest from practically relevant vibrations and, secondly, to harvest as much power as possible. Besides, three main groups of questions driven more by intellectual curiosity can be identified.

Harvesting principle: How can different motions be used or made usable to harvest from? Which physical phenomena can be utilized for harvesting and what are their harvesting mechanisms? Which design approaches can help to adapt to different operating conditions and excitation profiles and to extract the maximum power? **Fabrication and materials:** Which design opportunities and limitations result from the diverse fabrication processes and applied materials? What are the trade-offs between fabrication costs and, e.g., the output power? **Suitability for application:** Which requirements result from the environment? In which applications are harvesters beneficial compared with other solutions? How does the harvested power impact the excitation? Which power management is required to supply an application and to deal with situations of low harvested power?

3. Review on Published Prototypes

To review and discuss the differences of electrodynamic harvesters in terms of excitation type, boundary conditions, magnetic and mechanical design as well as manufacturing aspects, symbols are introduced to classify the harvesters. To illustrate the diverse categories of harvesters, representative designs are displayed in figures 1–6 on pages 172, 174, 176, 178, 180 and 182, and numbered for later reference. For a better overview the figures are partly cut, re-arranged, re-sketched and re-labeled. The average power and RMS load voltage of the harvesters at the frequency of maximum power are cited together with the corresponding sinusoidal excitation acceleration peak or flow rate. A comprehensive summary of prototypes from literature is attached in Table A1 in Appendix A. The copyright notices and reprint permissions can be found in Appendix B. Hybrid concepts of integrated electrodynamic and piezoelectric harvesters such as [23,24] are not included in the discussion.

3.1. Excitation and Motion

3.1.1. Excitation Type

vibration
flow
rotation

Harvesters have been designed for different kinds of motion of the energy source. The prototypes, such as (1–17,18–23,28–30), directly harvest from a vibrational source. Due to the vibration, an internal mass is directly excited to change the flux linkage in a coil. In contrast, harvesting from flow usually requires a mechanism to generate the internal motion. Harvester (26) contains a piece disturbing laminar flow. The created vortex causes a beam to oscillate and harvest energy. The Humendinger wind-belt (27) uses a ribbon flattering in air flow and harvests energy from its vertical motion. Equal to the principle of a classical windmill or turbine, such as harvester (24), flow can be converted into a rotational motion. From a rotatory motion one can, of course, directly harvest with a classical generator. In case the harvester cannot be mounted to the shaft, Toh *et al.* investigated harvesting from the rotation of a pendulum that is eccentrically fixed to the shaft [25].

3.1.2. Direction of Excitation

1D one-dimensional excitation
2D two-dimensional excitation
3D three-dimensional excitation

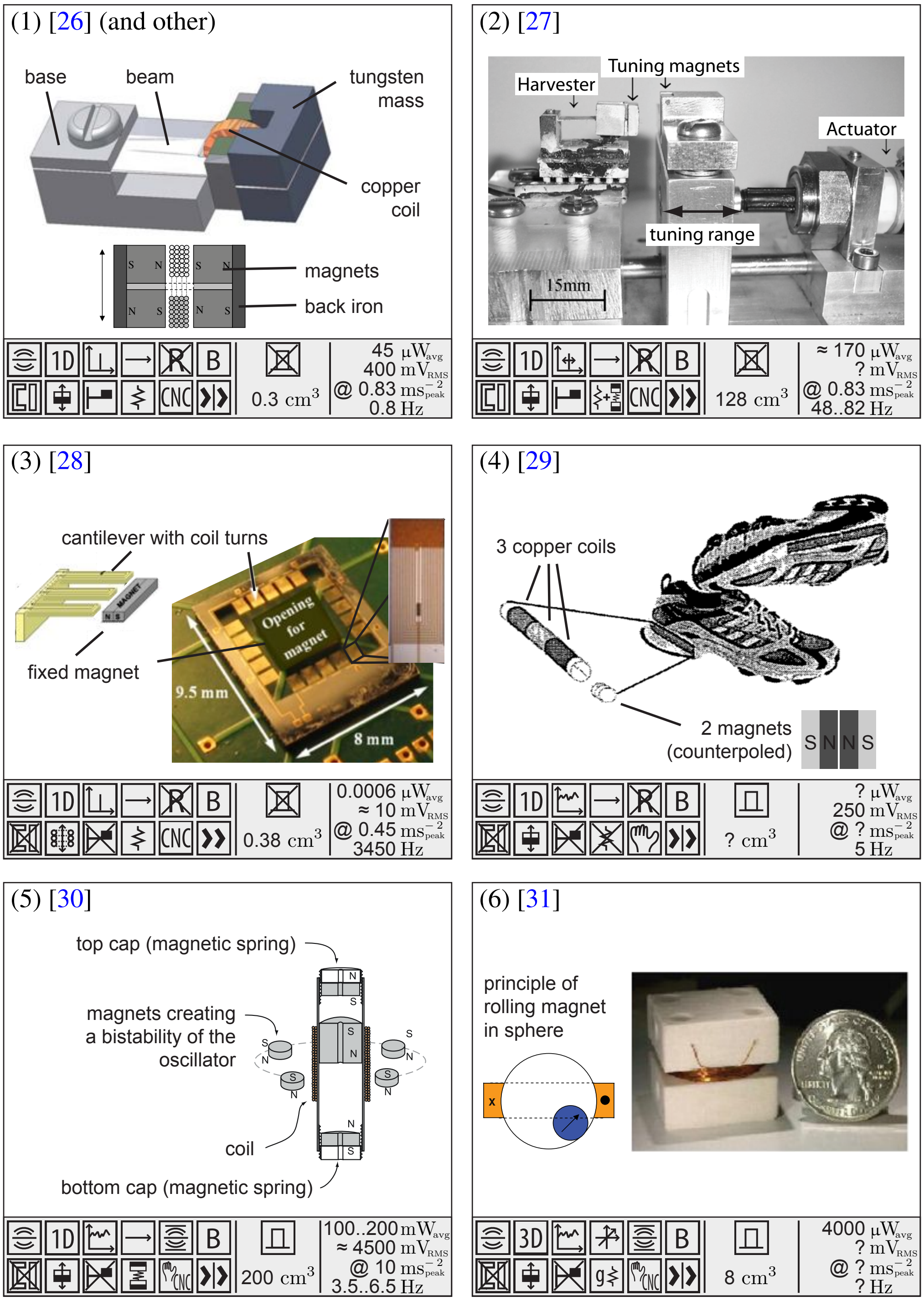
Most harvesters have been designed to harvest from one-dimensional motions. At vibrations with a preferred direction, the simpler design and potentially higher electrodynamic coupling can be exploited. In fact, many vibrations are multidirectional and a multi-domain harvester could be beneficial. Several principles such as harvesters (7–8,14,16) can also be used for two-dimensional harvesting. Although with limited electrodynamic coupling in the third dimension, (6) is the first and only three-dimensional design.

3.1.3. Excitation Form

single frequency vibration
vibration with frequency variation
broadband vibration

The excitation form or frequency spectrum is one of the main drivers for the broad variety of designs. To harvest from a single frequency, *i.e.*, a harmonic vibration, resonant harvesters such as (1,12–17, 18–23,26,28–30) have been developed. They allow to harvest high power but only from a narrow-band excitation. In case this frequency varies, tuning concepts such as (2) adapting the spring stiffness to the actual frequency have been applied. The simplest way to harvest not only at varying frequency but also from broadband vibrations is to use multiple oscillators with different resonant frequencies such as (3). Another option is to harvest with a single oscillator and its multiple resonance modes (16) or

Figure 1. Electrodynamic harvester prototypes (1)–(6) reprinted from [26–31].



super-harmonics [32]. Energy from broadband motions can also be harvested with a rolling or sliding mass but no spring forces (4,6). An opportunity that goes back to the SEIKO AGS Kinetic Quartz Watch [20,21] is a pendulum harvester principle (7,8). The pendulum, once completely rotating, is capable to sustain the rotation at a certain range of accelerations and frequencies and able to harvest broadband under certain ambient conditions. Furthermore, nonlinear spring forces can be utilized. A stiffening or softening characteristics of the spring [33] or a mechanical bistability (5) helps to increase the bandwidth under certain boundary conditions. The approach of using a low frequency oscillator to excite a high frequency vibration (frequency step up) between coil and magnetic field by touching (10) or magnetically attracting (9) a second oscillator was implemented to harvest from broadband vibrations. However, for the excitation the low-frequency oscillator needs to reach a certain displacement that at higher frequencies requires strong accelerations. Finally, as the harvester is a coupled system of energy storages where the energy flow between the mechanical, magnetic and electrical domains defines the frequency behavior, it is possible to tune the frequency behavior on the electrical side [34]. For a comparison of broadband harvesting approaches, the reader should refer to [35].

3.1.4. Internal Motion of the Harvester/Principle of Changing Flux Linkage

- continuous rotation
- oscillatory linear/trajectory
- pendulum motion with optional rotation
- other

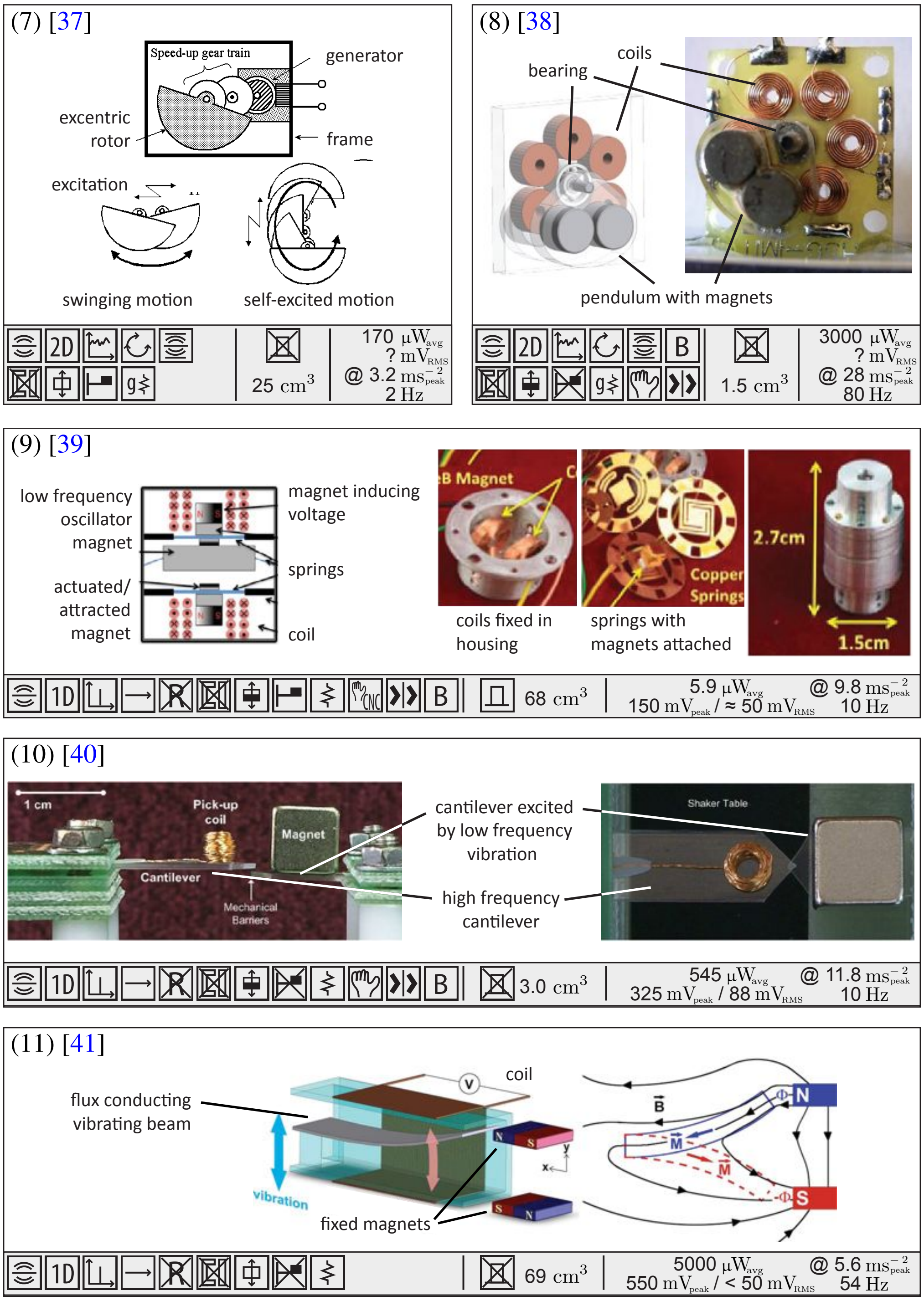
With respect to the internal motion, harvesters can be divided into four types. First, rotation devices that feature a continuous internal rotation between the magnetic field and the coil (25). Second, devices with an eccentric mass, which allows an oscillatory motion (7,8) and, under certain conditions, a rotatory motion. Third, devices that harvest from a linear or trajectory-kind relative motion (1–5,9–17, 18–23,26,28–30). Fourth, harvesters with an internal motion that is not described by the first three types (6). The advantage of a rotational motion is that generator concepts have been investigated for a long time. Such as the pendulum harvester, the concept allows simple and cheap design with high coupling (e.g., the well-known one of a hub generator [36]). An equivalent has not been found for linear harvester concepts. In fact, the internal motion is not limited to a rotation, pendulum or defined trajectory. Free motions might feature the lowest coupling but allow multidimensional harvesting.

3.2. Operating Conditions

3.2.1. Volume & Aspect Ratio

- no housing
- open housing
- closed housing
- closed housing including electronic circuit

Figure 2. Electrodynamic harvester prototypes (7)–(11) reprinted from [37–41].



The prototypes in literature exhibit a wide range of volumes. The published values include different parts of the harvester, some only the oscillating parts, some additionally the volume penetrated by the oscillator, some the clamping, some a closed housing and some even the electronics. For a better comparison the reviewed prototypes are provided with the estimated comprising cylindrical or cuboid-shaped volume, which includes all harvester parts, a possibly existing electronic circuit as well as the volume penetrated by moving harvester components. The symbols denote whether a closed or open housing is enclosed. One can find devices with more than a hundred cubic centimeters (5,22,23,26), designed for output power in the milliwatt range as well as microdevices with less than a cubic centimeter (1,3,12,13,15,17,20,21,25,29) for microwatt power.

All these harvesters feature different aspect ratios with respect to the direction of excitation. Harvesters with aspect ratios in the range of 1 (1,22,23) benefit from the easier design of the magnetic circuit. Flat harvester designs with a low aspect ratio are mostly driven by planar fabrication technologies (12–15,17). From the motivation to replace batteries, harvesters in battery size have been built (19).

3.2.2. Weight

The total weight of the harvester can be important in applications, for example, when energy from human walking, in aeronautics or in vehicles should be harvested. Although investigations on the energy balance for harvesters used in vehicles or aircrafts have not been published yet, some authors used a minimum harvester weight as design criterion [42–44].

3.2.3. Output Voltage

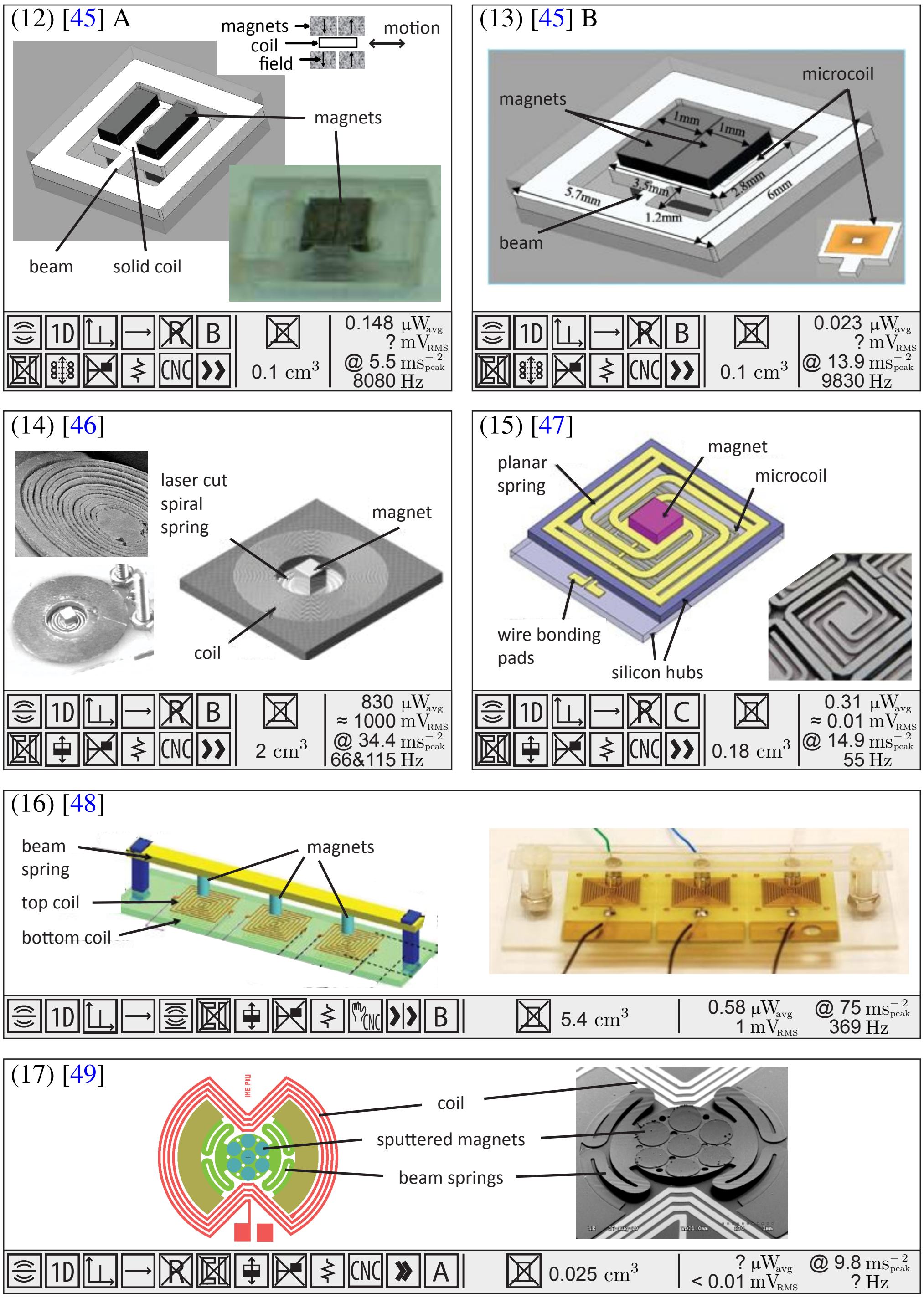
The output voltage of a harvester depends of various parameters. To realize one of the standard voltage levels $1.2/1.8/2.4/3.3/5\,\mathrm{V}$ of electronic circuits, the harvester AC output voltage needs to be rectified and controlled. Especially in miniaturized harvesters voltage levels are very low. The minimum value of approximately $0.3\,\mathrm{V_{DC}}$ required by boost and step-up converters that multiply the voltage is often not reached. As a solution, a nonlinear spring force in combination with an inhomogeneous magnetic field has been applied to generate voltage peaks (11). Alternatively, thin microfabricated coils (13,15) or thin wires with some ten micrometer thickness have been used (1,20). The latter is mainly limited by the capability of wire handling and bonding and with introduction of the fully automated wire bonding process in harvester (29) provides promising opportunities.

3.2.4. Robustness

none
temperature tolerant
shock resistant
temperature and shock resistant

The tolerance of a harvester for ambient temperatures can be important for its lifetime. Magnetic materials degenerate above their Curie temperature. Due to its high energy product NdFeB is mostly used to maximize the output power of harvesters. The strongest commercially available material, NdFeB N52, should not be used above $80\,^{\circ}\mathrm{C}$. For applications with temperatures above, authors had to use alternative materials such as SmCo (25). Besides magnetic degeneration, the ambient temperature can additionally affect the harvester characteristics, *i.e.*, the frequency response, due to thermal expansion of mechanical components. Therefore, (23) includes compensation mechanisms.

Figure 3. Electrodynamic harvester prototypes (12)–(17) reprinted from [45–49].



In many applications harvesters have to withstand excitation peaks or shocks. In fact, every design can withstand a certain excitation level. However, additional design features were implemented to make a harvester more robust. Overloading at stable excitations with slowly changing magnitude can be prevented by tuning a harvester out of resonance (2). At quickly changing or random excitations a pendulum harvester (7,8) is a solution, because the pendulum itself limits the amplitude. Another option is a design such as (16). Here, the tensile stress in the two-sidedly clamped beam prevents a large amplitude and fatigue as well as overloading. Additionally, spring-like mechanical (18) or magnetic (5) end stops can be beneficially utilized.

Note, preferably the symbols for temperature and shock resistance would state the particular limit values. As these have rarely been reported, the symbols are only used as an indicator for higher robustness.

3.3. Internal Design Aspects

3.3.1. Magnetic Design

without back iron
back iron without relative motion of magnetic components
relative motion between magnetic components

In addition to the design aspects discussed in the previous sections, the design of the magnetic circuit is a key feature of the harvester. The simplest design is a simple magnet (3,5,8–10,14–16,19–21). Guiding the magnetic flux with the help of multiple magnets (12,13) and additional back iron parts (1,2,23,26,28–30) enables to increase the magnetic flux density. Hereby, the output power is increased and the magnetic field outside of the harvester reduced. The latter can be important, e.g., to minimize external forces on the magnetic circuit. Usually one prevents a relative displacement between magnetic components to avoid hysteresis loss and magnetic retention forces. However, in (11) the relative displacement is utilized.

3.3.2. Mechanical Design

moving magnetic circuit
moving coil
moving separate mass

no additional mass
additional mass

mechanical spring
magnetic spring
spring force due to gravitation
no spring

Figure 4. Electrodynamic harvester prototypes (18)–(23) reprinted from [50–55].

Optimization of the output power has driven the creativity for the mechanical design, as well. For reasons of component sizes, fabrication, wire bonding, *etc*., either the coil (3,12,13,18), the magnetic circuit/ the magnets (1,2,4–6,8,10,14–17,19–21,23,28–30) or a separate mass (7,9,11) has been used as oscillator. An additional mass was used to increase the quality factor of the oscillation (1,2,18). Mostly, mechanical beam or membrane springs have been used to mount and guide the oscillator (1–3,9–17, 18–21,23). When counter magnets or even no spring forces are applied as magnetic springs, the oscillator has to be guided, e.g., in a tube (4,5) or sphere (6).

3.4. Fabrication & Development Stage

3.4.1. Fabrication and Assembly

manual
partly manual
computer controlled

non-integrated
semi-integrated
integrated

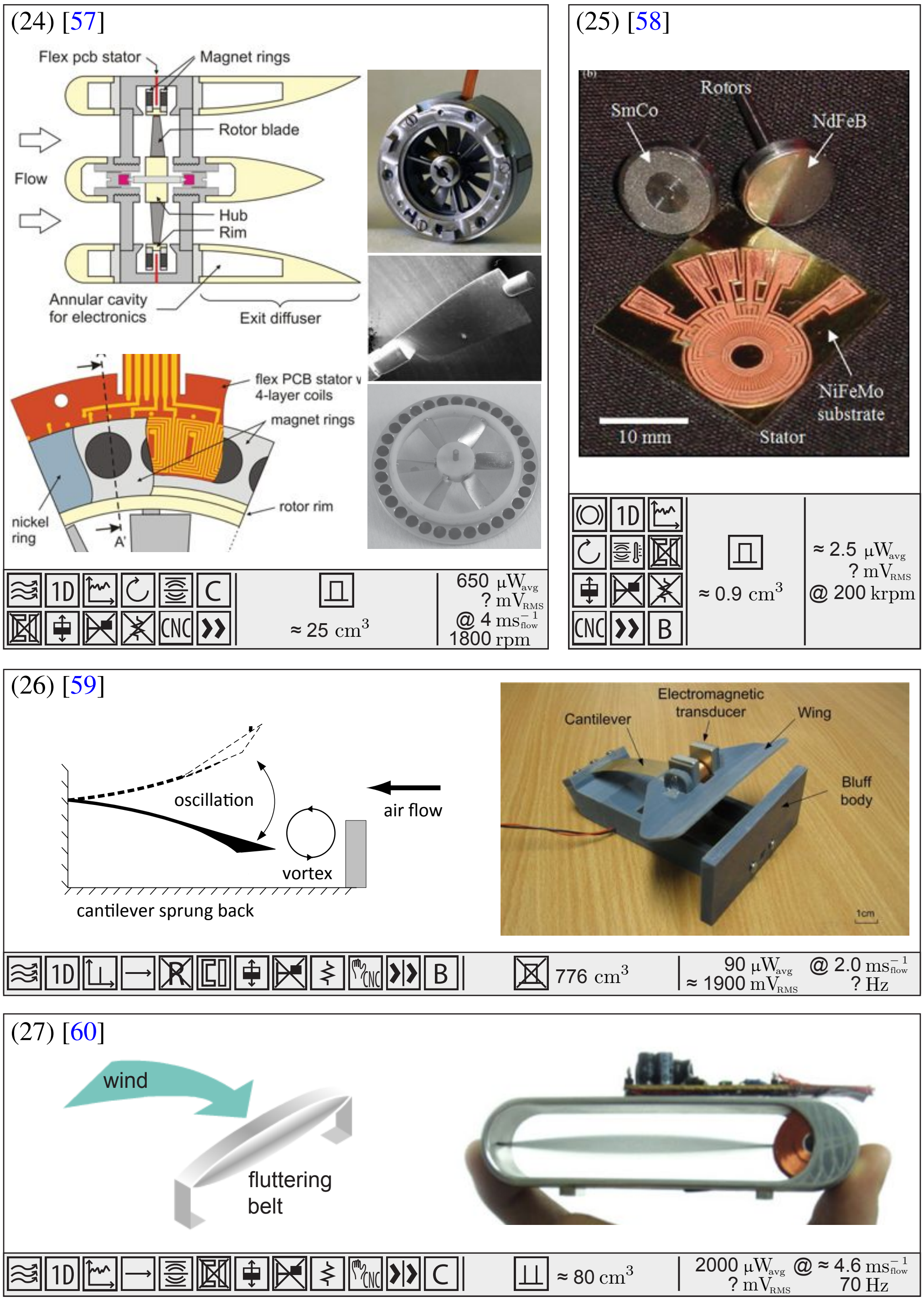
Besides the design, the fabrication process and its tolerances determines opportunities and limitations for the harvester design and characteristics. Some main drivers are the design freedom, tolerances and costs. The fabrication should be divided into the fabrication of harvester parts and the assembly. In research, many parts have been fabricated by hand. In fact, computer controlled processes such as CNC machining (1,2,9,18,23,28–30), rapid prototyping (6), lithography (3,12,13,15–17,20,24–25), or laser cutting (9,14,19) often help to quickly fabricate and to reduce costs and tolerances. Still, one main issue for minimum tolerances often is manual non-integrated assembly. Approaches for a semi-integrated fabrication are a PCB-based (14) or MEMS-based (12,13,15,17) concept. However, due to the challenge to integrate the fabrication of the magnetic circuit, permanent magnets often are attached separately. With the semi-integrated harvester concept (13) it was possible to reach very low tolerances as the manual assembly was limited to the uncritical stator part. Harvester (17) was the first fully integrated MEMS harvester and, although still with an disadvantageous magnetic design, points out the opportunities in microfabrication (for the challenge of integrated fabrication of permanent magnets refer to [56]).

3.4.2. Development Stage

A laboratory A-sample
B probably reproducible B-sample
C reproducible commercial C-sample

The fabrication is closely connected to the development stage of a prototype. Some publications provide data based on single measurements of a laboratory sample. With A-samples such as (10,14,16,17,25,29,30) the measurements of a sample are reproducible but the reproducibility of the prototype and its behavior (e.g., when reassembled or rebuilt) is not clear. In case the reproducibility of the prototype is probable, a harvester is listed as B-sample here (1-9,11-13,15,18-21,24-26,28). Finally, there are C-samples such as (22,23,27), which are well reproducible and are or can be used commercially.

Figure 5. Electrodynamic harvester prototypes (24)–(27) reprinted from [57–60].



4. Prototypes in Applications

During the last years different harvesters have been designed for a range of specifically selected applications.

The probably best known harvester is the device of EnOcean GmbH [61] that is usually installed into light switches. The device harvests energy for sending three radio telegrams when the switch is pressed and allows a plug-and-play switch design. A study by the group of Beeby has shown that an energy harvesting latch can be used to power monitoring and safety systems in doors [62]. This harvester was operated when the door handle was pushed or the door shut. Another harvester has been developed in his group to harvest from air flow in air ducts [27]. Cymbet [63] harvested from air flow that was said to be typical in buildings. The power was suitable to measure the flow rate and transmit data to a receiver nearby.

The resonant-type PMG17 [55] or PMG27 [64] of Perpetuum Ltd. [7] (founded by Beeby *et al.*) are designed to fulfill industrial standards. Devices are certified for fabrication (RoHS—EU directive for the restriction of use of hazardous substances in electronics), waste and recycling (WEEE—EU directive for collection and recycling) and usage in hazardous environments (ATEX—EU directive allowing usage in an explosive atmosphere). They feature a temperature compensation to operate between $-40\,^{\circ}\mathrm{C}$ and $80\,^{\circ}\mathrm{C}$, use standard electrical connectors and harvest several milliwatts from many machines, e.g., in industrial or transportation applications. With the VEH460 [65] Ferro Solutions, Inc. builds a harvester for similar applications.

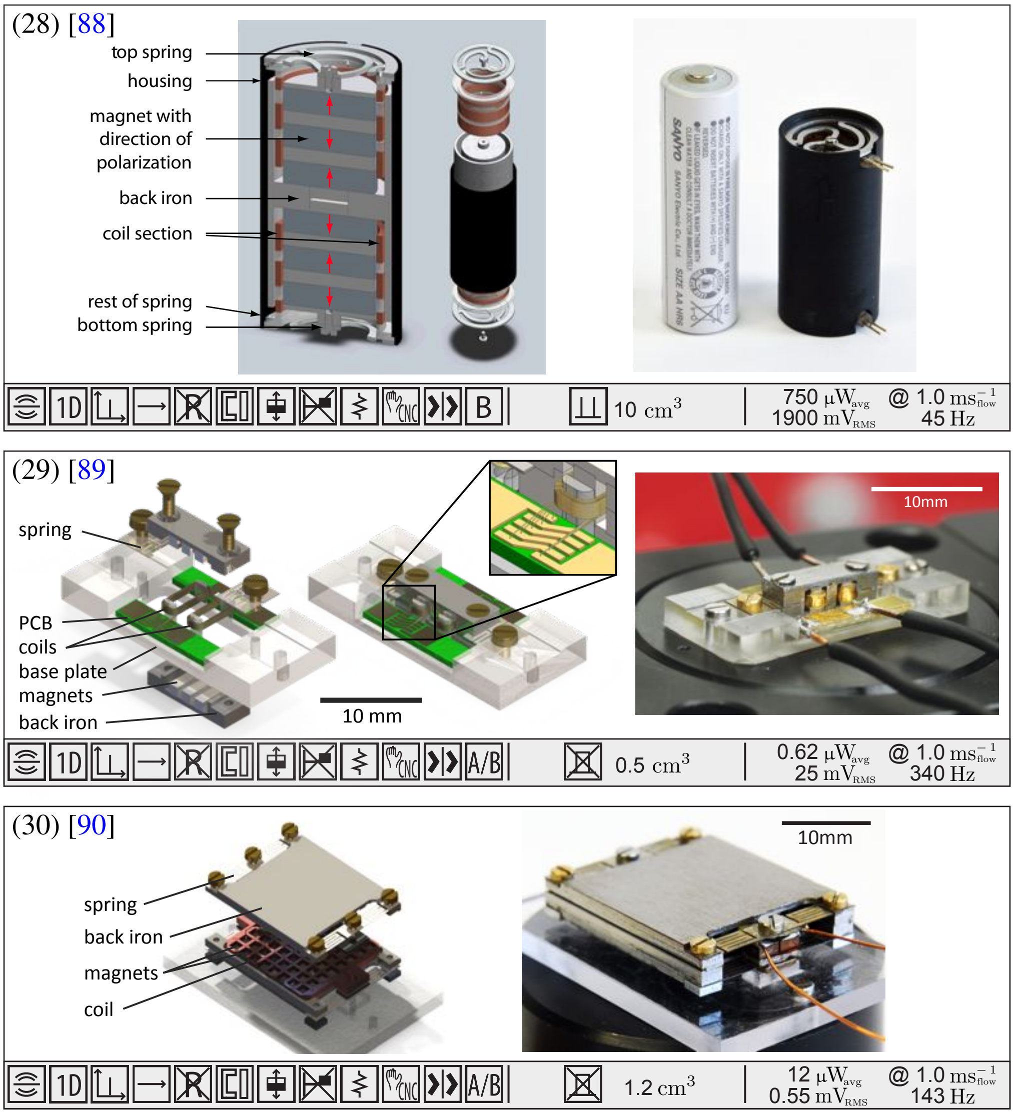
To power remote controls, Brother Inc. demonstrated a harvester in size of a AA battery probably featuring a design similar if not equal to harvester (22) [66]. Several authors published body worn [44,67–69] or implantable [70] prototypes, and prototypes to be integrated in a shoe [29,43] to harvest from human walking. A commercially available example with the form of a stick that can be put into a backpack is the nPowerPEG [71].

Electrodynamic harvesters were also designed for structural monitoring applications, e.g., by powering wireless sensor notes for transmission, temperature and acceleration monitoring on bridges [72,73]. A study about a harvester mounted to a car engine shows that enough power can permanently be harvested to supply different condition monitoring sensors [74].

Additional application-ready systems of harvesters can be found, which, in contrast, have not been designed for or tested in a specific application [51,75–82].

To any of these harvesters an electronic load circuit is attached that rectifies and controls or manages the output voltage. Meanwhile, lots of specific research was done on these electronic circuits. Some solutions are reviewed in [83–86]. Rectification can be done with a full bridge rectifier or voltage doubler, both passive with diodes or actively with switched transistors. The efficiency depends on the leakage currents and internal resistances. For voltage regulation buck-boost-converters such as the TI6120x from Texas Instruments are state-of-the-art. With the help of a resonating MHz-circuit the harvester voltage is chopped and the voltage peaks generated by the inductor of the resonating circuit are used to charge a capacitor. In a second step the load voltage is controlled to the required level. The efficiency of a buck-boost-converter depends on the harvester output voltage as well as the load current and can reach values of up to more than 90%. Besides the total efficiency of the rectifier and voltage control, the power transfer from the harvester to a load or buffer is important. Similar to an ideal voltage source that supplies most power into a matched load, the input resistance of the electronic circuit has to be adapted. Researchers at IMTEK developed a rectifying and voltage controlling circuit that adapts its input resistance for maximum power transfer [87]. This circuit still requires a second harvester to provide a reference signal. The next generation, which is currently under development, uses a maximum power point tracking component making the reference harvester obsolete.

Figure 6. Electrodynamic harvester prototypes (28)–(30) according to [88–90]-



5. Conclusions

After 15 years of research a huge variety of electrodynamic harvester concepts was investigated. To serve for a broad range of volumes (<1 cm^3 to >100 cm^3), form factors (cylindrical, cubical, *etc.*), excitation accelerations (<0.5 ms^{-2} to >100 ms^{-2}) and excitation frequencies (≈1 Hz to >1 kHz), many different design approaches and fabrication technologies have been chosen and tested. Solutions for narrow- and broadband vibrations as well as flow were found. It has been proven that electrodynamic harvesters are capable of supplying low-power electronics, and first commercial products are available on the market.

However, despite the extensive research and promising results, some challenges still remain. First, an integrated manufacturing of harvesters at millimeter to centimeter scale as well as microprocessing of magnetic circuits for smaller harvesters would help to improve harvester tolerances and overcome current design limitations. Second, the comprehensive optimization, especially by considering the damping phenomena, would allow to increase the harvester power or generate the same power within a smaller volume or at weaker excitations. Finally, a detailed comparison of the harvester performance is missing. A benchmarking approach considering the physical impact of the boundary conditions would help to identify promising harvester designs. A first attempt to address this challenge of benchmarking is within our current research focus.

A. Table of Prototypes

Table A1. Extended chronological list of the harvester concepts from literature. A design number "(?)" denotes that the prototype of one of the corresponding references was included into the discussion of the previous section.

No.	1st Reference	Properties according to Section 3	Comments & additional references
	[91]	1D CNC B	[92]
(14)	[93]	1D CNC B	[46,94,95], see also [77]
(1)	[96]	1D CNC B	[26,78,80,81,97–102]
	[103]	1D	
(7)	[104]	2D g	[37]
(19)	[77]	1D CNC B	[51], adapted from [93]
	[105]	1D	
	[106]	1D B	[70]
(13)	[107]	1D CNC B	[45,108], adapted from [98,109,110]
(4)	[29]	1D B	no power measurements
	[111]	1D B	[112,113]
(12)	[109]	1D CNC B	[45,98,110,114,115], see also [107,108]
	[116]	1D CNC B	[117]
	[118]	1D CNC B	
	[119]	1D CNC B	[120–122]
	[108]	1D CNC B	[107], adapted from [98,109,110]
	[123]	1D CNC B	
	[124]	1D CNC B	[125]
(8)	[38]	2D g B	[125]
	[126]	1D A	
(27)	[60]	1D CNC C	
	[127]	1D CNC B	[42,128–133]
	[134]	1D CNC B	
	[135]	1D CNC B	
(15)	[136]	1D CNC C	[47]
	[54]	1D	
(6)	[137]	3D g CNC B	[31]

Table A1. *Cont .*

No.	1st Reference	Properties according to Section 3	Comments & additional references
(25)	[58]	1D CNC B	
	[138]	1D CNC B	
	[69]	1D B	
(18)	[50]	1D CNC B	
	[68]	1D CNC B	
	[25]	1D CNC C	[139–142]
	[143]	1D CNC B	[144]
	[24]	1D CNC B	[145–147]
	[74]	1D CNC B	[82,148–151]
(2)	[152]	1D CNC B	[27,153,154], adapted from [96]
	[155]	1D B	[88,156]
(9)	[39]	1D CNC B	[72]
	[157]	1D CNC B	
(20)	[52]	1D CNC B	
	[158]	1D CNC B	
(24)	[159]	1D CNC C	[57]
	[160]	1D CNC C	
	[161]	1D CNC B	[162]
(23)	[55]	1D CNC C	
	[64]	1D CNC C	
	[163]	1D CNC B	[32,164,165]
(3)	[28]	1D CNC B	[111]
	[23]	1D B	
(22)	[65]	1D C	
(16)	[48]	1D CNC B	
(11)	[41]	1D	
	[166]	1D CNC B	[2]
	[162]	1D CNC A	
(5)	[30]	1D CNC B	
(21)	[53]	1D CNC B	
	[167]	1D CNC C	
	[168]	1D CNC B	
	[90]	1D CNC B	
	[89]	1D CNC B	
(17)	[49]	1D CNC A	

Table A1. *Cont* .

No.	1st Reference	Properties according to Section 3	Comments & additional references
(26)	[59]		
	[169]		
(10)	[40]		
	[170]		
	[171]		

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Acknowledgements

The authors would like to thank the DFG for funding the graduate school 1322, Micro Energy Harvesting. Additionally, the first author thanks the Foundation of German Business (sdw) for his scholarship.

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