Hydro-piezoelectric energy conversion

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ABSTRACT: The 21st century has seen a significant increase in interest in oceanography. Providing electricity to dispersed maritime equipment has become a crucial task because of the harsh and complicated oceanic environments. By collecting blue energy, the ocean kinetic energy harvester (OKEH) has made good progress in powering ocean sensors. This paper reviews recent advancements in the triboelectric nanogenerator (TENG), hybrid harvester (HH), electromagnetic harvester (EMH), electroactive polymer harvester (EAH), and electrical harvester (EAH). The present study examines the operational framework and output performance of the OKEH, while also highlighting the forthcoming problems and viewpoints surrounding the OKEH. This study suggests that TENG is advantageous for harvesting high entropy energy, or low-frequency, low-amplitude, random-direction wave energy-based
on the comparison of OKEHs.

Keywords: Ocean Energy Harvesting, Oceanographic Insta Oceanographic Instrumentation, Wave Energy Harvesting.

INTRODUCTION:

The technique of transforming mechanical energy, such as vibration, distortion, or other kinetic energy, into electrical energy is known as energy harvesting [1]. The use of self-power devices in healthcare, environmental monitoring, and automotive applications will ultimately rise due to the rapid advancements in wireless sensor networks (WSN) and storage power with improved efficiency solutions [2]. However, there are limitations with the power source and batteries, including bulk, weight, and limited lifespan—much shorter than the WSN life—as well as frequent battery changes and devices located in difficult-to-reach areas [3]. Because of these drawbacks, the use of

energy harvesters to power microdevices and WSNs is a viable strategy in our setting because of their tiny size, low power consumption, and unique working conditions.

One of the creative methods for gathering energy for microdevices that have been developed and put into practice is piezoelectric energy harvesting, which uses various mechanical power sources [6]. When mechanical stress is applied to some solid materials, such as crystals, ceramics, and polyvinylidene fluoride PVDF, an electric charge accumulates in these materials, which is known as piezoelectricity [7]. Many forms of energy harvesting are often possible, depending on the application and the accessibility of mechanical power sources. Mechanical energies, also referred to as random energies as they are everywhere present and have variable frequencies and amplitudes, include vibration, fluid flow, human motion, and so on [8].

The working mechanism of Rotational Piezoelectric Energy Harvesting (RPZTEH) is based on the plucking of piezoelectric for excitation. This causes piezoelectric vibration, bending, or pushing, and consequently generates voltage. Several excitation components could be used for this plucking. Researchers have employed a range of excitation components in

An extensive review of RPZTEH from the mechanical input method concept and applications is the goal of this paper. There isn't one of these reviews that is especially for rotating energy harvesters, as far as the writers are aware. The novelty of this work lies mostly in the comparison of different designs and excitation components and how they affect performance. The historical work performance and important design comparison viewpoints on the numerous mechanical inputs and applications—such as the movement of fluids (air, water), rotating vehicle tires, human motion, and other rotational operational principles—are also highlighted. Different excitation elements were discussed, including magnetic, centrifugal force, gravity, gears, mass (the mass weight acts as a force), and others. The key conclusions and operating principles of every mechanical input

investigation are thoroughly reviewed. Every one of the four mechanical.

METHODOLOGY:

The current research categorizes the comparisons of excitation elements, design, and their impact on performance into four groups based on mechanical inputs: human motion, rotating vehicle tires, fluids (air, water), and other rotational operating principles. The design, methods, wiring, mechanical inputs, and excitation type have all been thoroughly evaluated and characterized for each one. Different excitation elements, including mass, gear, magnetic, spring, centrifugal, gravity, and impact forces, have led to different classifications within the excitation type. One or more of the excitation elements may be present in each group to determine which group has the greatest impact on the improvement of rotational piezoelectric energy harvesting. Additionally covered in the design comparison is the piezoelectric rotation, which has an impact on the kind of wiring used to transfer output power. the stationary piezoelectric A rotating cantilever requires Bluetooth and/or Arduino for output power transfer, whereas a cantilever employs direct wire. For every section that comes after. The author created a summary table after each part, as shown in Tables 1, 2, 3, and 4, which includes all the details and the computed power density for relevant earlier research. The authors have also plotted each design according

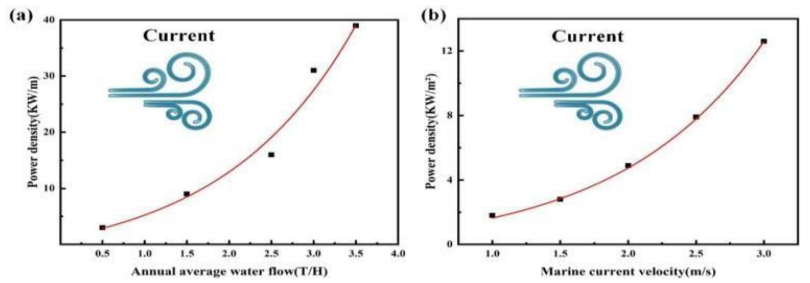

FIG. 1. Relative power density of currents with different water flow rates and without water flow rates. (a) The relative power density of ocean currents under different water flows. (b) The relative power density of ocean currents at different current velocities.

to output power density and rpm to provide a clear understanding of the optimal excitation elements and the design with the maximum power density, as shown in Figures 5, 9, 13, and 18, respectively. Figure 1 displays the schematic diagram of the methodology.

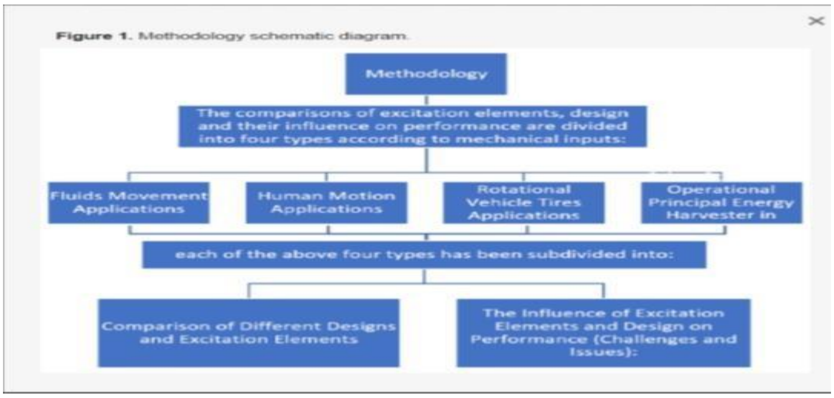

Figure 1. Methodology schematic diagram.

Materials that use piezoelectric technology:

The piezoelectric energy harvester's performance will be directly influenced by the characteristics of its material. Lead zirconate titanate is the most widely used piezoelectric substance. PZT. Piezoelectric ceramic material is rarely utilized in large strain transducers because it is brittle, relatively easy to shatter, and its high-frequency vibration environment is prone to fatigue and unsuitable for high-frequency fields. P-4, P-5, and P-8 are the most widely used PZT models. Table I provides some electrical performance parameters for PZT-42, PZT-5A, PZT-5H, and PZT-81 as examples. PVDF, or polyvinylidene fluoride, is another type of piezoelectric material.42 Despite having a lower electromechanical coupling coefficient than piezoelectric ceramics, PVDF is a semicrystalline polymer with sheet crystals inserted in the amorphous phase. is frequently used to capture human motion energy because of its excellent flexibility, resilience to aging, and extended service life under alternating loads.

However, because of its expensive cost, complicated production process, and relatively poor piezoelectric coefficient, it is not suited for large-scale energy collecting. Table II contains the performance metrics for a popular PVDF.

The internal piezoelectricity of the crystalline region is caused by the strain-dependent polarization intensity of the crystalline region, which is governed by the electrostriction effect and residual polarization.44 MFC, or piezoelectric fiber composite material, is robust and flexible, appropriate for curved structures, and capable of operating in both d33 and d31 modes. Compared to PZT, it has a lower output current and capacity.45,46

As a result, It has extensive application in the automotive, aerospace, and health monitoring sectors. It is not appropriate for large-scale paving, nevertheless, because its production costs are considerable and its piezoelectric coefficient does not surpass PZT in terms of piezoelectric power output. The typical piezoelectric characteristics of MFCare given in Table III

TABLE I. Typical piezoelectric properties of different PZTs.

Model	Dielectric loss ($\tan\delta$)	Electromechanical coupling coefficient (k_{33})	Dielectric constant (ε_{33}^T)	Piezoelectric strain constant (d_{33}) (C/N)	Piezoelectric voltage constant (g_{33}) (V m/N)
PZT-42	0.3	0.6	1400	300	32×10^3
PZT-5A	2	0.78	1700	450	21.5×10^3
PZT-5H	2.3	0.65	4500	670	16.8×10^3
PZT-81	0.3	0.6	1700	300	27×10^3

TABLE II. Typical piezoelectric properties of the common PVDF.

Parameters	Symbols	Value	Units
Piezoelectric strain constant	d_{31}	23	(10^{-12}) C/N
	d_{33}	−33	(10^{-12}) C/N
Piezoelectric voltage constant	g_{31}	216	(10^{-3}) V m/N
	g_{33}	−330	(10^{-3}) V m/N
Electromechanical coupling factor	k_{31}	12%	...
	k_t	14%	...

TABLE III. Typical piezoelectric properties of the common MFC.

Parameters	Symbols	Value	Units
Piezoelectric strain constant	d_{31}	−171	(10^{-12}) C/N
	d_{33}	374	(10^{-12}) C/N
	d_{15}	585	(10^{-12}) C/N
Piezoelectric voltage constant	g_{31}	−11.4	(10^{-3}) V m/N
	g_{33}	24.8	(10^{-3}) V m/N
	g_{15}	38.2	(10^{-3}) V m/N
Electromechanical coupling factor	k_{31}	0.34	...
	k_{33}	0.71	...
	k_{15}	0.6	...

Piezoelectric effect :

In construction, a piezoelectric device can be employed as a driving and sensing element simultaneously. Whenever a piezoelectric substance is distorted, a voltage may be produced; also, when a voltage is supplied to a piezoelectric material, the piezoelectric material's shape may be altered. Utilizing the positive piezoelectric effect, piezoelectric elements can be employed to create power generation or detecting apparatuses.

Figure 5 (b) illustrates the phenomenon known as converse piezoelectricity, which occurs when a voltage is given to one of a

piezoelectric element's two sides. When piezoelectricity is reversed, mechanical energy can be produced from electrical energy by the piezoelectric material.

The piezoelectric trap can function in three different ways: d31, d33, and d15 modes.13. Two numbers are contained in the subscripts: the first indicates the piezoelectric material's polarization direction, and the second indicates the applied field or force. Though it is challenging to use in practice, the d15 mode has the best energy capture efficiency theoretically. captures vibration energy in a certain mode. Generally speaking, cantilever beam constructions use the d31 mode because it can create larger deformation with less external force and enhance energy capture efficiency. It is also straightforward to process and the system's inherent frequency is lower, making low-frequency resonance easier to produce setting. Under strong stresses, higher energy capture efficiency is achieved.

III. OCEANIC FLUID ENERGY HARVESTING TECHNOLOGIES: A SIMPLE CLASSIFICATION

A. Utilizing the VIV concept for energy harvesting

Energy usage through the capture of kinetic energy produced by ocean currents has gained popularity as a research field in light of the increased availability of renewable energy. Using piezoelectric methods like vortexinduced vibrations (VIV) and flutter-induced vibrations (FIV), ocean current energy can be harvested, according to several research that have been published. Nonetheless, the ocean is full of current energy. Examples include waves that cause the water to flow and the dominant wind that blows across the sea surface, pushing the saltwater along with the wind and moving the upper layer of seawater downward. Owing to the conditions in the water, several researchers. Flow-induced motion (FIM) has been applied to PEH in the ocean by certain researchers because of the ocean's unique environment. Included in FIM are FIV and VIV an efficient energy harvesting excitation system. When harvesting ocean current energy using the VIV mechanism, the Karmen vortex street effect is typically utilized (when a steady inflowing current, under specific conditions, bypasses some item, a double A Karmen vortex street is created following a non-linear movement, and a row of linear vortices with opposite rotational directions and regular configurations are regularly shed on both sides of the item.

1. Harvesting energy from streams that flow in parallel

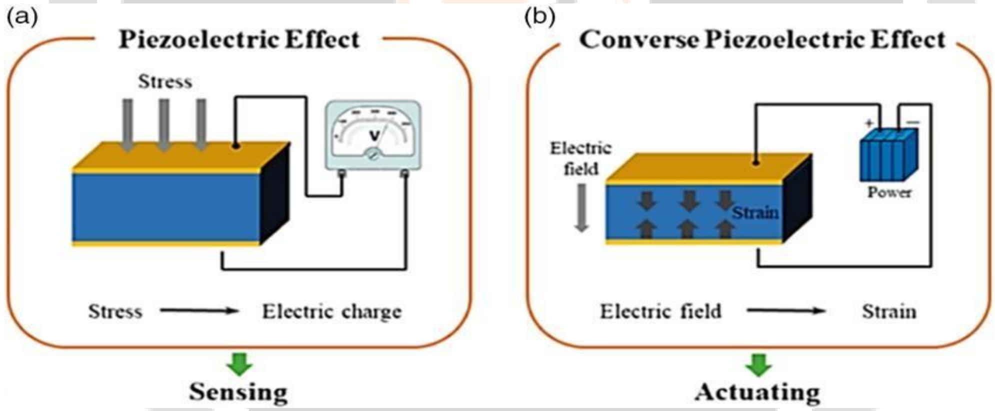

FIG 5: Piezoelectric effect. (a) Positive piezoelectric effect. (b) Converse piezoelectricity

The power generating unit or piezoelectric cantilever beam of the piezoelectric energy harvester (PEH) is positioned horizontally within the water stream, which is utilized to force the power generating unit to move or to deform the unit due to the impact of the water stream, completing the power generation process.59–61 An experimental investigation of the motion, drag, and vortex shedding patterns of the elastically mounted cylinder was carried out by Wang et al.62. It discussed how the cylinder at various heights above the flat wall affects the VIV received in a transverse direction. It has made a significant contribution to the use of VIV for sea current energy harvesting by PEH in the future.

Cao et al.63 created an ideal piezoelectric beam geometry and used it with magnetic excitation in low-flow waters. They fitted the PEM with a continuous variable-width piezoelectric cantilever beam supporting a cylindrical blunt body, and they thoroughly investigated the impact of fringe and width ratio on the voltage of collecting. The outstanding energy harvesting performance for low-velocity water flow thus produced the ideal structure. They proved that 19.9 V was the highest root-meansquare voltage and that 19.9 V was the rootmean-square voltage per unit area.

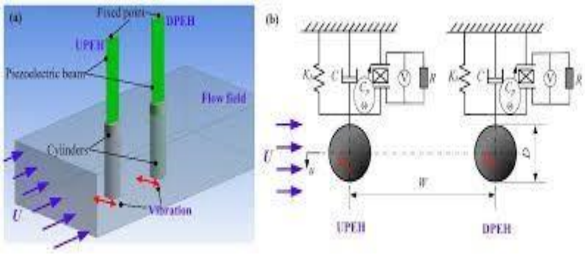

FIG. 7. Schematic diagram of two tandem PEH systems by reproduced with permission from Song et al., Micromachines 12(8), 872 (2021). Copyright 2021 Multidisciplinary Digital Publishing Institute (MDPI). (a)Threedimensional system. (b) Equivalent model of two tandem PEHs.

0.07 V/mm2, respectively, at 0.6 m/s of flow rate. The ideal triangle beam is enhanced by the use of magnetic excitation, increasing it by 127% in comparison to a traditional Without any magnetic excitation, a constant-width beam vortex-induced vibration piezoelectric energy harvester (VIVPEH). New small-scale hydropower technology has been developed by Wang et al.gadget that uses a current to harness the energy of a Karman vortex street behind a blunt body. The Karmen vortex street in the generator flow channel of the structure causes pressure oscillations that periodically bend the piezoelectric film, which Elevates the voltage Na et al.65 studied a piezoelectric energy harvesting apparatus based on continuous fluctuations. To verify the power generation and charging according to real sea conditions, and unit time, the device's ability to charge microelectronic gadgets and obtain electricity in the center of the ocean's continual turbulence was shown. For the steady and effective harvesting of rotational mechanical energy, Zhao et al.58 presented a hybrid piezoelectrictriboelectric nanogenerator.

Experimental results showed an output power gain of 10% over the prior PEH. The PEH for energy harvesting from a parallel-flowing stream is displayed in Figure 6.

2. Using vertically running streams to gather energy

Large-scale power generation is typically accomplished by hydroelectric power systems, however, the cost and time involved tremendous costs are connected with producing power on such a grand scale.67, 68, For obtuse body piezoelectric cantilever beams, Sun et al. developed three segmental distribution parameter models.69. The half-cylinders lift and vortex are shown to be bigger than in the other two scenarios, and its pressure and velocity differential is shown to be more significant. To capture the energy of the vibrations in water flow, Song et al.70 built a PEH that is placed in series. Fig. 7 displays the structural diagram.

suggested a directed-adaptive PEH with guided wings to address the Karmen vortex phenomenon. The performance of this PEH in the changeable direction flow environment is shown for the velocity range of ocean currents. A shear PEH that harnesses pressure. It was Wang and Liu who developed water flow.701

The maximum generated voltage and instantaneous power of the device are around 72 mVpp and 0.45 NW, respectively, according to measurements made in the pressure chamber under different pressure variations. Table IV provides the various VIVPEH settings.

B. Harvesting energy using the FIV principle

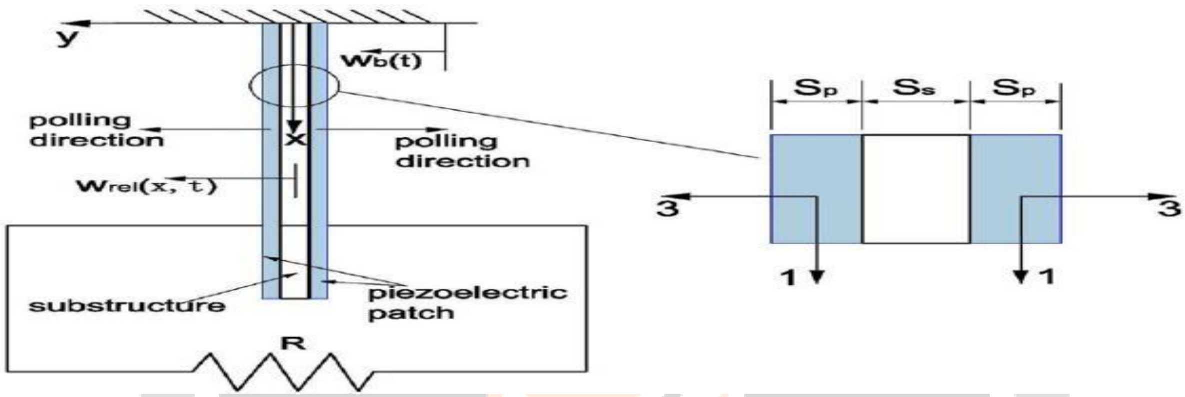

FIG. 8. The structure of a vertical cantilever column with piezoelectric

The power produced by the impact of the water flow is transferred through vibration in the FIV energy harvester, allowing the creation of periodic movements. From an energy perspective, WKPEH is situated in the flow field for periodic oscillation and harvesting. As a result, the flow rate greatly affects the WKPEH's output performance. As a result, the majority of research began to alter the mass block's shape. According to the findings, the proposed energy harvester's micro-hydro experimental prototype can assess the water flow rate. Based on the longitudinal wave motion of water particles, Xie et al.60 created a wave energy harvester, as seen in Fig. 8. With the practical sea wave, a power value of up to 55 W can be achieved.

The parameters for the wavelength, wave height, and sea depth are 2, 2, and 15 meters, respectively. To enhance low current and decrease high impedance, Woo et al.76 created a piezoelectric energy harvesting system for water waves.

Impedance matching is made simple and requires no additional impedance conversion circuitry due to the experimentally demonstrated low and constant internal impedance, which is independent of both strain and frequency. Two piezoelectric beams and two cylinders are features of a unique piezoelectric energy harvester that Gu et al.90 suggested.

In Figure 8(b), the structure prototype is displayed. Finding the right match between the cylinder's diameter and resistance allowed for the extraction of additional electrical energy. It can produce up to 21.86 µW of output power. An underwater PEH based on propellers was reported by Kim et al. 91. Comparing the finished PEH to the traditional flutter-induced vibrations piezoelectric energy harvester (FIVPEH), it is significantly more efficient and able to light up 972 LEDs.

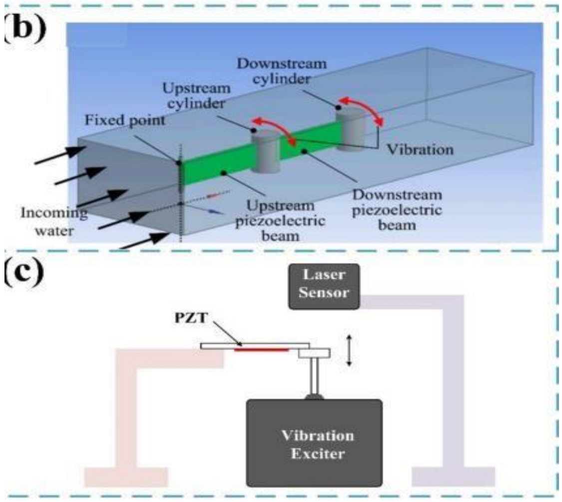

FIG. 8. The structure of a vertical cantilever column with piezoelectric. (a) Reproduced with permission from Xie et al., J. Sound Vib. 333(5), 1421–1429 (2014). Copyright

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Applications of Fluid Motion

This section presents a comparative analysis of research that has employed fluid as a mechanical input source for RPZTEH, such as wind, air, or water. These two categories are split up based on the excitation components. For every study, their power density, design, and methods have been published.

3.1. Examining Distinct Designs and Excitation.Components

First off, research on RPZTEH using air (wind) as a mechanical input source has been published. Figure 2a illustrates how Stamatellou & Kalfas [29] used air swirling as an excitation element alone to produce a turbulent flow field and collect energy. The positioning and orientation of the piezoelectric can be changed to maximize output power using the piezoelectric mounting mode. Since the PZT does not spin with the system, a power density of 0.031 µW/mm3 was obtained from a 37 mm PZT at 300 rpm in a collection time of 20 s cycle duration without the need for a slip ring or any output power transmission.

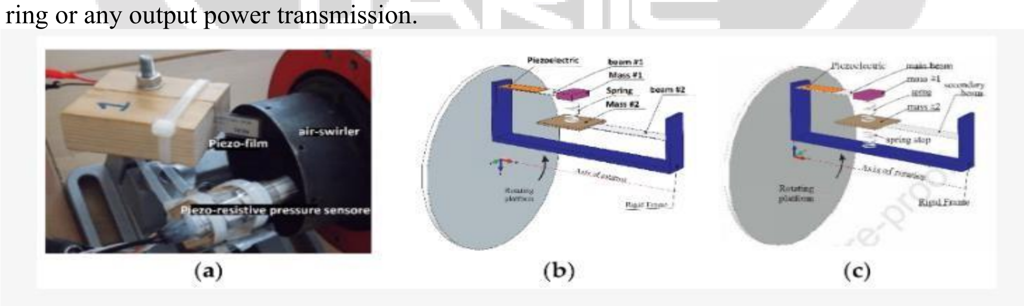

Figure 2. (**a**) Simultaneous measurement of the pressure and piezoelectric film output voltage [29]; (**b**) View of rotating energy harvesting system [55]; (**c**) View of enhanced energy harvester [74].

Comparably, using a beam, spring, gravity, centrifugal forces, and two masses as excitation factors, Febbo et al. [55] carried out a revolutionary design alternative to a basic PZT beam that fixed the beam to a hub, as illustrated in Figure 2b. The power density is within the range of 0.079–0.32 µW/mm3. To prevent slide rings, power transfer is accomplished using an acquisition system (Arduino). To increase power, future work may employ two PZTs since they have two beams; moreover, a durability test will help extend the harvester's lifespan.

In addition to the two-flexible beam and the spring connecting the two dense masses, as seen in Figure 2c, the same authors improved their model [74] by including a single-side spring stop. With a rectified output power density of 0.31–2.59 µW/mm3 at 50–150 rpm, this design produces more power than the previous one.

The contact force of this device was maximal at the lowest rotation speed, which makes it novel. This led to its proposal as a substitute for low excitation frequency generated power. Y. Yang and colleagues [30] have employed impactinduced resonant technology to achieve an effective excitation vibration mode for piezoelectric beams. According to the harvester-based knowledge design, resonance could be triggered by an effect in any operating environment. Figure 3a illustrates a configuration consisting of twelve PZT beams and a seven-ball. At 200 rpm and 20,000 ohms, the harvester power density was 1.3 µW/mm3. This power can be used in a WSN by storing it in a capacitor; however, the WSN needs to rotate with the system or incorporate an additional output transfer device, such as a slip ring.

Furthermore, using two piezoelectric beams composed of free-standing bi-morph thick film and a windmill with a free-spinning fan, Bai & Havr [66] investigated an air-flow energy harvester. All components were manufactured and constructed. At 750.6 rpm fan rotation speed and 87 Hz magnetic force frequency, the maximum power density is 0.058 µW/mm3. The harvester can be further optimized by being designed to be smaller and more compact, which is thought to be necessary for traditional wind turbines.

A wide-band piezoelectric energy harvester was also built and optimized by RezaeiHosseinabadi et al. [65] to obtain the greatest energy possible by employing magnetic and mass as excitation forces. PZT makes up the prototype, which vibrates as a result of interactions between the magnetic link to the piezoelectric beam and the permeant magnetics in the tiny turbine. The best output power density was discovered to be 0.59 µW/mm3, and as the PZT does not rotate, standard wiring was utilized to transfer output power without the requirement for a

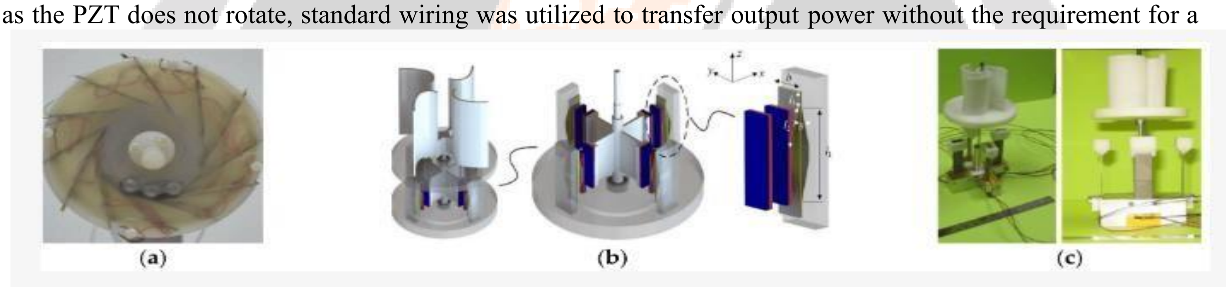

Figure 3. (**a**) Piezoelectric windmill diagram shows piezoelectric bimorphs arrangement [30];
(**b**) Schematic illustration and working mechanism of the investigated Magnetically Coupled Piezoelectric Wind Energy Harvester (MPWEH). The symmetrical opposite magnetic arrangements [75]; (**c**) Prototypes of nonlinear wind harvester: configuration of tangential design and configuration of radial design [52].

slip ring.

On the other hand, Zhao and colleagues [75] introduced a novel approach to RPZTEH that solely utilizes magnetic coupling and force amplification techniques for excitation. They maximized the effective force and greatly decreased the resistance torque by positioning the magnets in a symmetrical opposite manner, as shown in Figure 3b. The experimental findings demonstrate that it can operate continuously for almost 12,000 seconds at wind speeds between 3 and 10 m/s. Its greatest power density was 3.3 µW/mm3. One could characterize this gadget as having higher resilience and a wide speed range for wind energy harvesting.

Çelik et al. [54] have presented a configuration that involves the use of magnetic force for excitation. The configuration comprises a PZT layer with dimensions of 70 × 32 × 1.5 mm and a harvester that is 30 cm long, with a propeller diameter of 16 cm, from the propeller to the tail end. When simulated in a dynamic regime, the system's highest power density is 4.76 µW/mm3 at 600 rpm. This work verified that chaotic and regular dynamics could be harvested at various rotation speeds by a piezoelectric harvester with a magnet at its tip. Furthermore, Karami et al. [52] used only magnetic excitation to construct a built-in wind generator that may provide electricity to sensor nodes in hard-to-reach or remote areas during periods of low wind speed. As seen in Figure 3c, two configurations—one tangential and the other radial—have been constructed. At 200 rpm, 16 Hz, and a 25 mm magnetic gap, the greatest output power density measured is 15.5 µW/mm3. The new nonlinear PZT wind turbine presented in this work has a low wind speed startup and can generate enough power to run a standard WSN.

An alternative approach is the mathematical modeling of an energy harvester by Nezami et al. [76], which uses centrifugal forces, mass, and gravity for excitation. In big applications, such as wind turbine blades, the harvester can use two magnets and a small desk to transform the slow mechanical rotation into PZT vibration. When the

disk motion alternates between bouncing and passing, it reaches a chaotic state between 35 and 45 rpm, at which point the output power becomes noticeable. The power density is 2.83 µW/mm3, and since the PZT spins with the system, a slip ring was employed to transfer it.
As an alternative, Nezami et al. [76] have proposed mathematical modeling of an energy harvester that uses centrifugal forces, mass, and gravity for excitation. With two magnets and a modest workstation, the harvester can transform sluggish mechanical rotation into PZT vibration for big applications, such as wind turbine blades. The output power increases significantly in the 35–45 rpm range when the disk motion alternates between bouncing and passing in a chaotic manner. A slip ring was employed to transfer the 2.83 µW/mm3 power density since the PZT spins with the system. The research that reports on the usage of water as a mechanical input source for RPZTEH is provided below. In addition to direct impact, there is an indirect method of harvesting energy from raindrops by employing a PZT turbine or watermill with magnetic force for excitation. Raindrops' kinetic energy is proportional to their square of velocity since their greatest speed is attained well before they touch down. Therefore, there is no difference in the amount of power harvested from rainfall at ground level versus at higher elevations. In addition, a water tank situated on an elevated platform can be utilized to gather rainwater. The PZT turbine arm could receive the gravitational energy from the raindrops [39, 40]. The PZT will bend and gather energy as a result of the turbine rotating. By applying a greater force to PZT in this manner than a single raindrop would at any given time, it will be able to collect more energy. This harvester's typical energy output is predicted to be between 10 and 100 W/cm3
[40].

Additionally, Cho et al. [37] constructed a hydro-electromagnetic and piezoelectric energy harvester to supply power to the smart type of water meter system by using magnetic force On the other hand, An et al.'s study suggests using a unique vortex-induced PZT energy converter (VIPEC) to capture ocean kinetic energy in an underwater setting [32]. Figure 4b shows the components of the harvester, which include a hinged plate linked to

and water flow for excitation. This paper presented a turn-buckle water wheel made of stainless steel with two magnets and a 90 mm diameter, as Figure 4a illustrates. The piezoelectric harvester's greatest root mean square output power density at 10 kΩ was 0.6222 µW/mm3. The water leak detector in the water leak warning system will be powered by piezoelectric power harvesting. Future research can focus on the threshold voltage detector as a major concern.

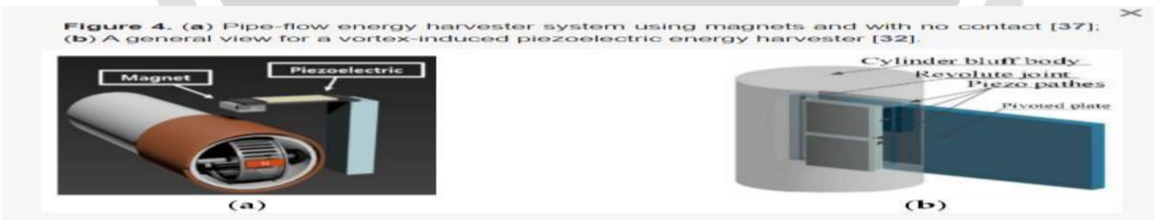

Figure 4. (**a**) Pipe-flow energy harvester system using magnets and with no contact [37]; (**b**) A general view of a vortex-induced piezoelectric energy harvester [32].

the harvester's tail, a cylinder, PZT patches, and a storage circuit. When 10 kΩ of resistance is used, the maximum output power density of 0.035 µW/m3 is achieved. Underwater mooring cables and other Underwater Mooring Platforms (UMPs) are a good fit for the VIPEC due to their straightforward construction. The possibility of energy harvesting from the mechanical buckling of Ionic Polymer-Metal Composites (IPMC) caused by a constant fluid flow was also evaluated by Cellini et al. [77]. A paddlewheel, two (IPMC) fixed at both ends and a slider-crank mechanism make up the harvester. As the flow speed changes from 0.23 to 0.54 m/s and the shunting resistance varies from 1 to 1000 Ω, the experimental findings show that the IPMC output power ranges from 1 pW to 1 nW. Although the concept is unique, it has to be made more compact and have a higher output power.

3.2. Excitation Elements and Design's Effect on Performance (Difficulties and Issues)

Variable factors, which are separated into input, output, and comments, have been compared, as Table 1 illustrates. As indicated in Table 1, the following factors generally affect the output power of piezoelectric energy harvesting: frequency (rpm), piezoelectric size, dimension, and material type; resistance; and whether or not the piezoelectric rotates. Additionally included in this table are output power and power density. Although the design is influenced by the excitation elements, Table 1 illustrates how the design affects the output power density for the identical excitation elements. Although other studies also employed PVDF and PZT composite, PZT was the primary material used in the RPZTEH.

CONCLUSION:

Based on its excitation factors, design, and impact on performance, this paper examines the latest studies and research in rotational piezoelectric energy harvesting. A variety of energy harvester types are typically available, depending on the intended use and the accessibility of mechanical power sources. Although other studies also employed PVDF and PZT composite, PZT was the primary material used in the RPZTEH. Mechanical energies, also referred to as random energies as they are ubiquitous and have variable frequencies and amplitudes, include vibration, fluid flow, human motion, and so forth. The low rotational frequency of human motion and other rotating mechanical power sources prevent them from reaching the piezoelectric resonance frequency.

As a result, researchers are now working on frequency up-conversion and bandwidthbroadening strategies. The evaluation of excitation components and the design of their impact on performance for diverse mechanical Inputs are classified into four categories based on mechanical inputs: human motion, rotating vehicle tires, fluids (air, water), and other rotational operational principles.

There are two components to the fluid power source: air (wind) and water (rain). Very high wind-speed planes have not yet been created, despite several outstanding achievements for air or wind and the use of different kinds of excitation elements. More studies can also be conducted in more traditional locations, including the air inside an air conditioning tunnel or the exhaust from air conditioning units. Few experiments have been done with rain or water flow as the input power source, however, the power density is poor. This review revealed that a smaller, more compact design can attain a greater output power density by using magnetic and gravitational forces as excitation elements.

As rotational input mechanical power sources for human motion, various excitation elements have been employed for frequency upconversion and output power increase. However, the low frequency of this power source and the requirement for a small, light harvester are the primary causes of concern. To widen the bandwidth and so harvest more power in different speed ranges, numerous studies have employed innovative designs with a variety of excitation elements. Furthermore, given that PVDF materials are flexible when it comes to the movements of human body parts, more compact designs must be made using them. Further practical trials are required to determine its viability for everyday human use. This review revealed that utilizing magnetic and gravitational forces as excitation factors in small, compact designs can result in better output power densities.

There are a variety of designs that have been utilized to employ vehicle tires as mechanical input power sources; some require sizing the object to fit within the tire, while others must undergo a field test on a functioning vehicle. But, creating a prototype that can gather sufficient power in the wideband frequency range—especially when the vehicle is moving slowly—is our primary priority. Using centrifugal and gravity forces as excitation elements with a small, compact design that fits easily in a vehicle tire were found to be able to obtain better output power density, according to this review.

Studies that employ the gear as an excitation element for frequency up-conversion are scarce. Its output power does, however, reach a sufficient level for a wide range of applications. Additionally, it can be raised by only using more gear teeth or a higher piezoelectric number. Further research can be conducted to decrease the contact between the piezoelectric and gear teeth or to use magnetics to create a contactless system that would boost the piezoelectric output power and lifetime while also reducing the size of the gear harvester. This review revealed that a smaller, more compact design utilizing a gear, gravitational springs, and magnetic forces as excitation elements can result in a better output power density while reducing friction between the gear teeth.

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