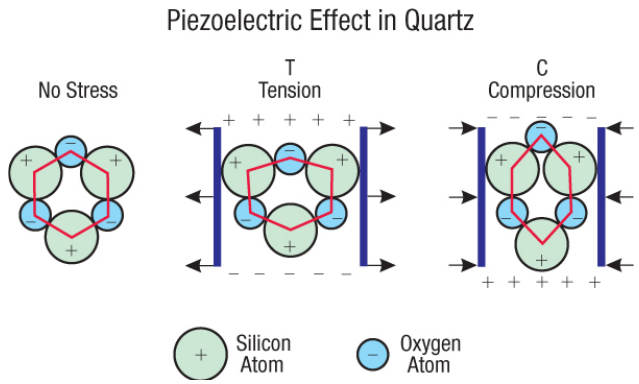
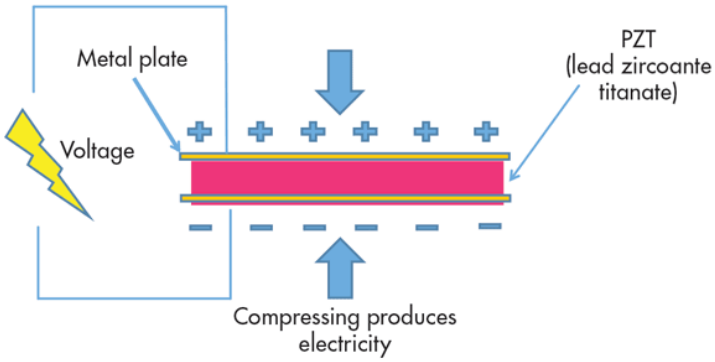
What is Piezoelectricity?

Piezoelectricity is literally translated as electricity as a result of pressure. The word "piezo' is a derivation from the Greek word "piezin", which means to press. [2]The discovery of piezoelectricity occurred in 1880 by the sibling duo of Pierre and Jacques Curie where they discovered that applying pressure to crystals e.g. quartz generated electrical charges on the surface of these materials due to the direct piezoelectric effect.

Piezoelectricity is a unique property for certain materials, and it exists due to the structure of crystals which is not symmetrical, but exists in an electrically natural balance, yet when mechanical pressure is applied, to a piezoelectric material, the structure deforms, and the atoms are rearranged into a structure where they conduct an electrical current. This is applicable vice versa as well, where if an electric current is applied to a piezoelectric material, then the crystal will convert electrical energy into mechanical energy by expanding, although this property is not used for piezoelectric sensors in roads.



The diagram illustrates the piezoelectric effect in the natural compound of silicon dioxide, where when mechanical energy is applied then the material compresses or expands and converts mechanical energy into electrical energy.
Source: https://www.autodesk.com/products/eagle/blog/piezoelectricity/



Source: https://www.autodesk.com/products/eagle/blog/piezoelectricity/

The direct piezoelectric effect is referred to as when mechanical energy is applied to a crystal. As this diagram above illustrates, the crystal is placed between two metal plates where there is no stress on the material and the material is in perfect electrical natural balance. Mechanical pressure is applied to the material through the metal plates, which means the electric charges are pushed to an out of balance position and excess charges are formed on

[2] Available: https://www.etymonline.com/word/piezo- [2022 March]

opposite sides of the crystal face, with one side being positive and the other negative. Electric charges are collected on the metal plates which are used to produce and send an electric current through the circuit. [3]

There are natural piezoelectric materials including Quartz as mentioned above and even sugar cane crystals. However, study into Piezoelectricity led to the development of man-made materials including lead zirconate titanate (PZT) which for the same applied mechanical pressure produces more voltage, thus making it economically more viable. Although, an issue with using PZT is that it is toxic, and thus more research is being carried out into potential bio-piezoelectric materials. For road power generation, cement based piezoelectric materials can be used which are made of pre-embedded piezoelectric ceramics.

Study and Research into Piezoelectricity

An Israeli company, Innowatech, had been trialling the development of these piezoelectric sensors outside Tel Aviv, where they used IPEG (Innowatech Piezo Electric Generators) which had been planted 6 cm under the road level and at a 30 cm apart, proving that Piezoelectric sensors are a promising alternative for energy production that engineers must consider. The energy harvested is stored in the electronic capacitors of the storage system. The company argues that these are a future source as they are easy and inexpensive to install. The actual method would involve the sensors embedded between the roads' normal layers which could work with layers of asphalt, concrete or composite concrete or even a mix. Although some may argue that the costs of adding the sensors is very expensive thus making it inefficient, but it may be that the costs are substantially less than that of wind or solar energy systems as the new sensors could be laid when new roads are laid or even when regular maintenance costs are occurring, according to the Innowatech company. The company states that "Innowattech's solution is capable of producing significant amounts of electricity" in terms of energy this is "about 400 kWh from a 1 km stretch of generators along the dual carriageway (assuming 600 vehicles go through the road segment in an hour)", as the company observes. This would be sufficient energy to power 600-800 homes.[4] This is coming from a relatively old article from 2009, thus newer improving and developing technology carried out by engineers will be able to develop on this and provide even more energy. One important note that should be considered is that Innowatech placed the piezoelectric sensors in a position very close to the pavement, in that any slight movement would be easily detectable, and cause the deformation of the crystal, producing a current.

The Piezoelectric effect is sensitive to changes in weight, motion, and vibrations. This was tested in a practical experiment by Rutgers Institute of Engineering[5], where this was tested both physically and through simulations. They found that the energy output increased with an increase in the loading frequency and load magnitude. In simple terms, this means that the energy harvesting performance of the generators with the crystals was mainly affected by the vehicles weight, speed and the number of vehicles passing over the sensor.

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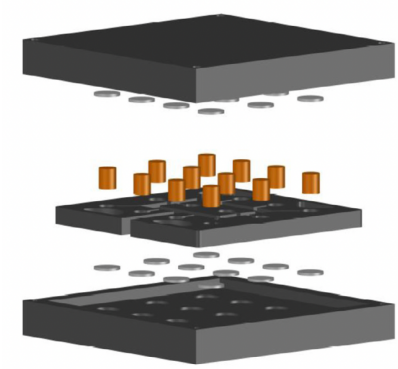
[3] Cesca Fleischer (2016) "How Piezoelectricity Works [Online]" Available: https://www.autodesk.com/products/eagle/blog/piezoelectricity/ [2022 February]

[4] Tessa Henderson (August 4, 2009) "Energy Harvesting Roads in Israel [Online]" Available: https://www.offgridenergyindependence.com/articles/1589/energy-harvesting-roads-in-israel [2022 Feb]

[5] Multiple Authors (May 11, 2018) "Laboratory Testing and numerical simulation of piezoelectric energy harvester for roadway applications" Available: https://www.sciencedirect.com/science/article/abs/pii/S0306261918307335 [2022 Marhc]

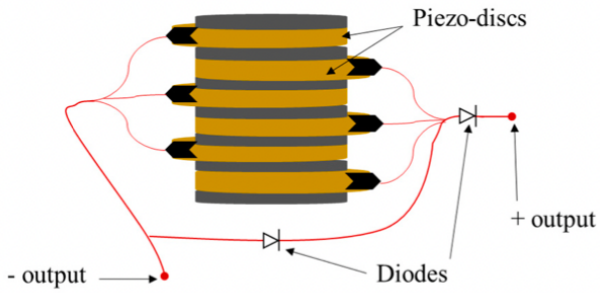
Prototypes

Another name for a type of piezoelectric sensor would be PEH i.e. Piezoelectric Energy Harvesters. The PEH would be embedded within the pavement surface, but not enough research has been carried out yet on which material would be more suitable for building the actual road. The PEH would be made of 12 piezoelectric units with the circuit boards and other components including packaging. This model would include the units stacked on top of each other in parallel.



Inner Structure of PEH
Source: https://www.sciencedirect.com/science/article/pii/S199668141630195X

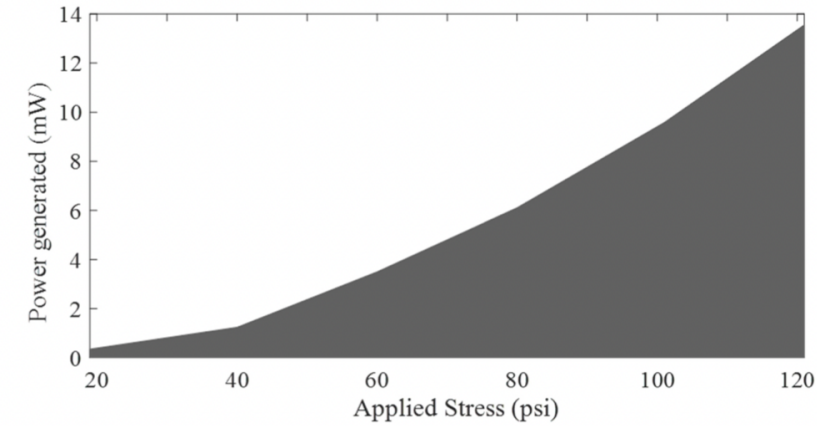
Another such prototype is the HiSEC (Highway Sensing and Energy Conversion).



Source: https://www.mdpi.com/2071-1050/10/2/383

As the diagram above illustrates, the HiSEC model consists of three piezo discs stacked in parallel with two diodes. For this particular model, the curve below shows that the "responsive power generation of the HiSEC device increases gradually as the load/stress is increased". [6] It is plotted in mW against psi (pound per square inch).

[6] Naveen Kumar (2015) "Energy Collection via Piezoelectricity" Available: https://iopscience.iop.org/article/10.1088/1742-6596/662/1/012031/pdf



Source: https://www.mdpi.com/2071-1050/10/2/383

Often, it is argued that these piezoelectric sensors are meant for a micro-scale, however using a large-scale harvester in frequently used roadways is possible, as shown by the Department of Electrical Engineering at Hanyang University and the Korea Institute of Civil Engineering and Building Technology, where they designed an energy harvester that used piezoelectric cantilever beams[7], which are structural elements that are supported in one end and free at the other end and can be exposed to vertical loads.[8] Another case that should be considered is the traffic conditions; traffic over a prolonged period of times could create the opportunity of electricity production at a macro-scale.

Storage

There can be different methods that can be used for the storage of the electricity produced, and two of these possibilities include storage using a capacitor or a rechargeable nickel metal hydride battery. Advantages of using a capacitor are that it allows immediate access to stored energy while the circuit set up using a NiMH battery would be quite simple, preventing the dissipation of more power, since there are fewer components. In addition, the use of a capacitor would mean that the piezoelectric component would have to constantly produce electrical energy, since it is not able to store power, like batteries are able to.

Moreover, a few issues that must be tackled by engineers whilst considering the use of the road energy through piezoelectricity would be the storage of the electricity produced; would this occur underground? How would the electricity be properly transmitted across for businesses and households to use? A solution for this would be switching the electricity system to completely underground transmission; instead of overhead power cables carrying electricity, these too could be built underground.

Globally, with an increasing frequency of erratic weather systems, this may be an optimum solution anyway, as in the UK itself, there have been an increasing number of power cuts due to storms. These could be avoided with the underground system. Often the question then posed is the threat with the frequency of heavy flooding increasing as well, and the answer is that underground cables and the sensors would both be expected to meet rigorous operational standards, where if flooding occurs, water would not be able to permeate the many layers of

[7] Many authors (August 3, 2016) "International Journal of Hydrogen Energy" Volume 41, Issue 29, Pages 12563-12568 Available: https://www.sciencedirect.com/science/article/abs/pii/S0360319915316694
[8] Neenu S K (October 11, 2020) "Everything you should know about cantilever beams [Online]" Available: https://theconstructor.org/structural-engg/cantilever-beams/167474/ [2022 March]

insulation. More research could be carried out on how road harvesting energy would work in areas prone to earthquakes.

Environmental Impacts

There are many future benefits of using road energy-harvesting; it could potentially be used as a source for roadway lighting. Another idea that could be developed through the use of piezoelectricity in roads would be a radical concept which is necessary for the future, in terms of dealing with concept change; namely, the concept of sector coupling or cogeneration. This would involve combining two different sectors such as electricity production and transportation and, in this case, piezoelectricity energy harvesting can be combined with the usage of electric cars which would further benefit the environment. This would decrease the use of non-renewable resources and lead to decreased CO2 emissions, as in itself piezoelectricity is supposed to be zero GHG (Green House Gas) emissions, which means less contribution of GHG to climate change, and thus the use of this energy could minimise global warming, therefore mitigating climate change, by stabilizing the climate.

The process of the sector coupling would simply work as a matter of interdependence; after the initial propagation of the electric cars, the electric cars would drive across roads, creating piezoelectricity when driving over the sensors and this would mean that the electricity harvested through the sensors could be used to charge the cars, creating a self-relying system within itself. Another advantage that piezoelectricity provides in stark comparison to other renewable resources which often depend on the weather such as wind or solar, is its reliability; as long as cars are driven across roads, there should not be a shortage of electricity. Furthermore, another benefit of road harvesting piezoelectric technology is that unlike other renewable sources, including solar and wind, no extra space is required; it would be built into existing roads, or into roads that would anyways, regardless of the technology have been made for transport. On the other hand, solar and wind energy harvesting both require excessive land and space, which can be a limiting factor in their use.

Due to this being a relatively new idea and concept, the scope of research in terms of its energy usage and storage is quite insufficient, as well as study on actual practicality is currently limited, although on current theoretical basis, it appears to be quite an effective practical solution. Although there is currently limited study, it could be used as an area where a thorough research can be carried out in the coming time.

Conclusion

To conclude, piezoelectricity appears to be an appealing opportunity with a high potential to become one of the most suitable methods of energy harvesting in the future, because of it having it being environmentally friendly and reliable. It could be a part of one of the types of energy used in the concept of energy diversification, combining it with other forms of energy harvesting such as hydro-, solar, tidal, wind and geothermal in certain locations, to create a stable system that does not rely on non-renewable, GHG emitting fuel sources. The current issue that is possibly prohibiting the promotion of this source of energy harvesting in comparison to other modern green technologies is that there is a lack of testing and practice. What engineers must now do to mitigate climate change is to further study into this field and how this could be commercialized on a mass scale i.e. its generating capacity, and also be equally profitable economically.

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