Technical Publications

Capacitive Energy Conversion

Practical Devices

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ISSUE RECORD

23/4/22 Section added to discuss possible construction methods
18/4/22 Corrections to formulae
16/4/22 Additional details of disk-type and cylindrical geometries
15/4/22 Initial issue

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SUMMARY

This report considers the different mechanical configurations that may be considered in exploiting the theory presented in the Energy Theory report in this series.

PRACTICAL DEVICES

The value of a capacitor is determined by three things at any instant:

- The common area of the plates
- The distance between the plates
- The permittivity of the intervening material (dielectric)

This is explained in detail in the Energy Theory report.

The implications are that the required variation in capacitance can be achieved by varying any or all of these factors. Looking at these in more detail we can consider the practical implications of each.

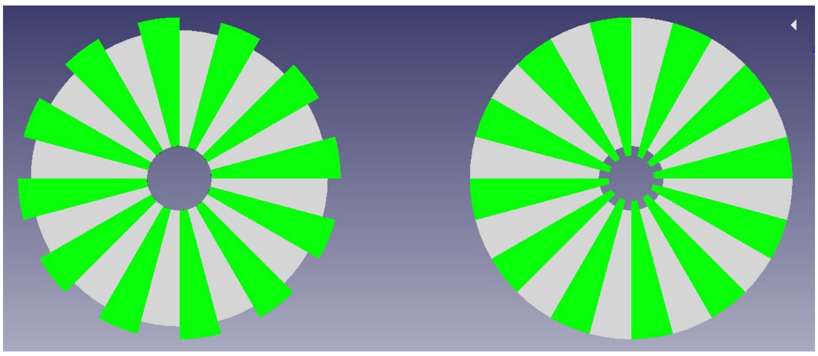
Changing the common area

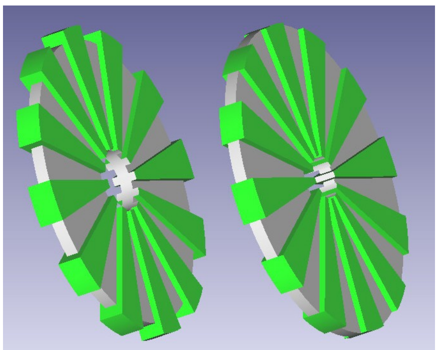
The common area can be changed either by sliding the plates relative to each other, or by rotating them in some way. It hardly needs to be stated that for a practical device this mechanical process needs to be repeated, perhaps very quickly, in order to create a continual supply of electrical energy.

To this end, **a flat, sliding construction** will require reciprocation which would require kinetic energy to be exchanged, and may be difficult to manage with overall efficiency. The amount of kinetic energy would depend on the mass of the moving plate(s) and the speeds involved. The efficiency can be improved with some sort of rotating crank and con-rod construction, but this may prove to be inefficient through the number of moving parts and bearings involved.

A flat, rotating construction would seem more efficient as mechanical energy would be maintained, subject to any friction and viscous effects from intervening gas or fluid. This could take the form of concentric, flat, fan-like discs that alternately overlap and separate as one rotates. If these are “stacked” concentrically on a common shaft the effective area can be multiplied at will at the expense of overall thickness. The discs would need to be very close, and to avoid friction a gas dielectric would perhaps be required. The effects of viscose drag would need to be considered, but at first sight, this might seem a feasible option, subject to the proviso that the available mechanical energy is provided in rotating form.

A guide to a possible configuration for a rotating design is shown here. Only the discs are shown, as the required splined tube and shaft designs can easily be deduced.





The “stack” comprises two alternating disk designs that have matching raised segments and are made of a conducting material. In this example each segment is 15 degrees wide with 15 degree gaps. But so long as the gaps are no wider than the raised segments other angles can be used. One disc type has the segments projected outside the perimeter, where they engage in slots in a surrounding tube. The other type has the segments projected towards the centre, where they engage in splines on a

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shaft. Therefore, as the shaft and the tube vary in relative angle the discs pass over each other and the capacitance between them varies.

The capacitances (as discussed in the Theory section) can be calculated as follows. It is assumed the splines and gaps are equal in angle.

$C_0 = (2N-1)\pi(D^2-d^2)e/8t_0 + (2N-1)\pi(D^2-d^2)e/8(t_0+2t_1)$
$C_1 = (2N-1)\pi(D^2-d^2)e/4(t_0+t_1)$

d is the inner diameter of the discs
D is the outer diameter of the discs
N is the number of stacked discs (gives 2N-1 facing surfaces)
t_0 is the minimum distance between facing splines
t_1 is the depth of the splines
e is the permittivity of the intervening material (a gas is a likely candidate for reasons explained earlier)

This change in capacitance is repeated each time the splines align, so a charge is harvested as many times per rotation as there are splines. These calculations can be used to calculate the power transfer per spline of rotation according to the equations discussed in the Theory section.

The optimum angles would depend on the anticipated rotation speed and the recovery time of the electronics, as a pulse is generated each time the segments become fully engaged (in this example twelve times per rotation, so at 50 rpm the pulse stream would be at 600pps or about 1.6ms intervals). It would seem best to use many thin segments for a slow-rotating device, as it would magnify the pulse rate and reduce the charges and voltages required for a given output. For fast-rotating devices it would seem best to use fewer segments to reduce the pulse rate if the electronic response time requires it.

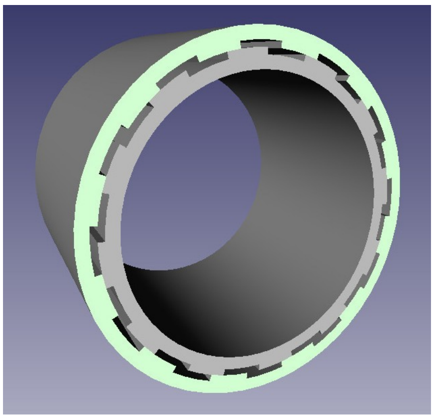
As explained in the Theory section, the battery characteristics may limit the maximum efficient charge transfer rate, and this may then require increased “dead time” with larger gaps between segments; this, however will limit the total capacitance and reduce the power yield. Further consideration needs to be given to how the segment angles are optimised for any particular application.

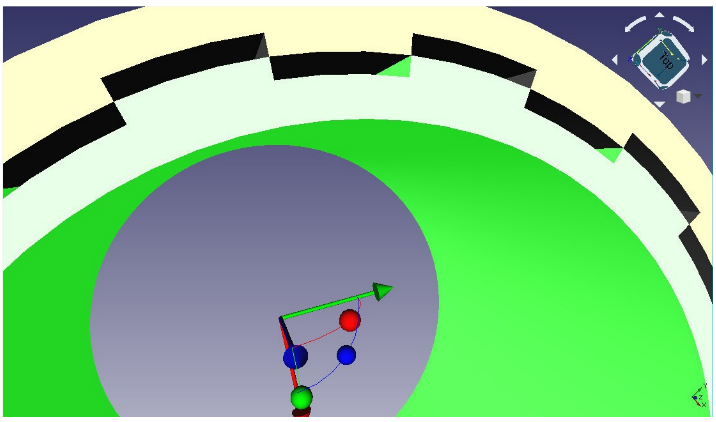
The shaft and the tube need to be electrically isolated, and there needs to be a strong electrical contact between the discs and either the tube or the shaft. The spaces between the segments can be infilled with a low-permittivity insulating material to provide a smooth overall contact surface. Also, the gaps between the discs needs to be very closely controlled, and this may present a problem with sufficiently accurate alignment along the splined tube and shaft. Perhaps shims could be used, but this needs to be investigated further.

The electrostatic connections are made through the tube and the shaft. This necessitates having some sort of slip ring for one or the other, depending on whether the tube or the shaft is intended to rotate. However it would be possible to split whichever is the stator and take the connections to the two ends of it without needing connection to the rotor.

A cylindrical construction, in which inner and outer cylinders, each with raised, axial nodes or splines, rotate with similar effect to the blades of the fan construction. This would have similar advantages and limitations to the rotating discs option, and can be similarly considered as a feasible option.

A guide to a possible configuration for a cylindrical design is shown below. The diagrams show the situation with the splines partially overlapping, and with them completely misaligned.





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The device consists of an inner and an outer tube, each made of conducting material. The matching surfaces are splined so the capacitance between them varies as one or the other rotates. The splines run the length of the tubes, and the capacitances (as discussed in the Theory section) can be calculated as follows. It is assumed the splines and gaps are equal in angle.

$C_0 = L\pi de/2t_0 + L\pi de/2(t_0+2t_1)$

$C_1 = L\pi de/(t_0+t_1)$

d is the matching diameter of the tubes
L is the length of the tubes
t_0 is the minimum distance between inner and outer splines
t_1 is the depth of the splines (the same for both tubes)
e is the permittivity of the intervening material (a gas is a likely candidate for reasons explained earlier)

This change in capacitance is repeated each time the splines align, so a charge is harvested as many times per rotation as there are splines. These calculations can be used to calculate the power transfer per spline of rotation according to the equations discussed in the Theory section.

In this example each spline is 15 degrees wide with 15 degree gaps, but so long as the gaps are no wider than the splines other angles can be used. The optimum angle follows the same considerations as for the rotating disc construction *q.v.*

The tubes need to be electrically isolated, and the spaces between the splines can be infilled with a low-permittivity insulating material to provide a smooth overall matching surface. Also, the gap between the inner and outer splines needs to be very closely controlled, and this may present a problem with sufficiently accurate surface preparation and alignment.

The electrostatic connections are made through the tubes. This necessitates having some sort of slip ring for one or the other, depending on which tube is intended to rotate. However it would be possible to split whichever is the stator and take the connections to the two ends of it without needing connection to the rotor.

Changing the distance between the plates

This distance can be changed by some sort of reciprocal action, or perhaps by something related to swash plates.

A reciprocal action would suffer similar kinetic disadvantages as discussed for sliding plates. But it has the advantage that the mechanical energy can be provided by linear pressure and without rotating components. It could perhaps be placed in a tidal basin and respond underwater to the varying tidal pressures without obstructing the movement of ships or fish, and where the rate of movement, and corresponding kinetic energies, are very small. This has been the subject of research into using MEMS[1] as body-implanted devices to power life-signs monitoring or drug dispensing without needing to charge batteries. These devices seemingly do not need to be particularly efficient, so the models developed are not intended to be scalable even to domestic supply levels. However the applicability to pressure-related energy sources may make this type worth considering

A rotating action could be achieved by a swash plate construction, where a disk is canted at an angle on a rotating shaft, and acts on a ball bearing that oscillates another, non-rotating plate along the same shaft. This sort of construction is used by many applications, but is not known for being mechanically efficient, having several moving parts and lubricants. But it has the advantage of operating from a rotating mechanical source and is therefore a possible competitor to established devices.

Changing the dielectric

The dielectric is a physical material, so two principal options present themselves: either move the dielectric or move the plate(s). In any case the dielectric needs to be a very good insulator and have a breakdown voltage compatible with the requirements of the operating charges.

When choosing a dielectric material liquids are unlikely to suitable because of the viscous drag that would consume mechanical energy and create unwanted heat; and solid dielectric material would create friction in relative movement, and would need some sort of lubricant or air gap. Also, as shown in the list below, materials with high permittivity can be expensive to obtain and use.

The following gives some relevant examples:

1 Micro Electro-Mechanical Systems. Some research papers are available on the internet.

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Air	1
PTFE	2.1
Glass	4.7
Aluminium oxide	9.5
Strontium titanate	310

It must also be considered that two capacitors in series provide less capacitance than either of them individually, thus:

$C = (C_1+C_2)/(C_1*C_2)$

So, for a given area, a small air gap (which may be required to reduce friction, but constitutes a series capacitor) can easily cancel the advantages of a high permittivity dielectric. This effectively renders moving the dielectric relative to the plate(s) unlikely to be an efficient option.

While at first sight it seems impractical to use this approach, a design that changes the common area, as discussed above, would require some sort of protection against short-circuiting the plates, and a high-permittivity but robust dielectric material may be required as an insulating coating. For this purpose, aluminium oxide may be a good candidate if the conducting plates are themselves aluminium, which is a good electrical conductor and otherwise possibly a suitable material.

CONSTRUCTION

For the cylindrical rotating devices, several construction options can be considered. The feasibility of each, as described below, depends on the size of the devices and the volume of production (e.g. the trade-off between tooling and labour).

It is important to consider that the gaps between the splines do not need to have curved bases to follow the cylindrical shape if they have small angular widths and the depth of cut at centre is adequate; this allows for easier machining if the basic shapes are not cast beforehand. However, sharp corners arising from rectangular cuts may lead to longitudinal fractures if the metal is not thick enough or well supported externally.

Casting

For large devices it may be best to cast the cylinders to the rough overall shape and finish them to the required precision by milling or reaming.

Extruding

For smaller devices in production it may be feasible to extrude the cylinders to the required splined shape and finish them to the required precision by milling or reaming. This would require investment in setting up a foundry for extruding the required shapes but may be economic overall.

From stock

Stock tubing of the required size and thickness (preferably extruded, as rolled steel may be subject to stress distortion) can be milled to the required shapes.

Fabrication

For low-volume production, where the cost of special extrusions may not be feasible, fabrication could be considered. If the splines are made separately (e.g. from stock strip metal) they would need to be fitted very securely to the cylinders (which could also be stock material). They would also need to be reamed or milled to finish to the required curved surfaces.

In principle this method detracts from the essential simplicity of the designs, and could add substantial costs in a production situation.

Mixed materials

Only the splines need to be made from conductive material. Therefore a possible construction would use non-conducting material, such as a hard plastic that can be inexpensively moulded, and metal strips bonded for the conducting surfaces. The assembly would need to be milled or machined to provide the precise surface profiles, and the splines would need to be reliably connected at their ends through collars or endcaps.

If non-conducting material is used between the splines this will modify the “low” capacitance C_1 (refer to the equations, above). This capacitance may then become significantly lower if it depends principally on edge-effect capacitance between splines instead of t_1 as previously described. This could result in magnifying the available energy transfer for each pulse.

3D printing

For experimental purposes the parts could be made using additive technology, but the time taken renders this unlikely to be suitable for production except in rare, specialised applications. It may be possible to print in plastic and coat the surfaces with conductive paint.

Inlaying

If a basic splined structure is made from non-conducting material (e.g. moulded plastic), the conducting surfaces can be inlaid in the gaps between the splines. They will need to be somehow connected together at their ends and may need to be reamed or milled to get the required surface accuracy, as described for mixed materials. But this would have a similar electrostatic effect as described for mixed materials, and may make construction easier than bonding the strips independently.

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