Technical Paper #4

Energystics, LTD
Advanced Energy Research and Technical Center
Room 109
Stony Brook University R &D Park
1000 Innovation Rd
Stony Brook NY 11794

Advantages of the use of Compressive Repulsive Magnetic Field Technology for power generation by linear electric generators harvesting ocean wave and other vibrational environmental energy sources:

1. Eliminates huge long coils at the end of the Permanent Magnet Array Cylinder (PMA) thereby using less expensive amounts of copper.
2. Even without the end blocking focusing magnets, there is significant reduction in end leakage of magnetic flux lines out the ends of the PMA from flux lines whose direction are parallel or nearly parallel to the long axis of the PMA cylinder simply because there are vastly less flux lines in a magnetic circuit comprising a magnetic circuit through the entire length of the PMA.
3. The use of powerful magnets may cause dangerous magnetic fields at the ends of the PMA which might be a problem for handling the Linear Electric Generator (LEG) when not in use or installed in a device. This is helped by the end blocking magnets whose fields are much smaller.
4. The use of two much smaller end focusing blocking magnets at each end of the PMA acts an excellent magnetic shielding because these two magnets are also used in the Compressive Repulsive Magnetic Field Technology (CRMFT) configuration and thus virtually all lines of force are bent backward back onto the PMA to an interior opposing pole virtually reducing magnetic flux leakage to almost nothing. Note that the flux leakage of the end focusing blocking magnets which are much smaller and are not used for power production is of no consequence and is very small in amount.
5. Further decreasing the amount of magnetic leakage into space is the fact that the end polarities of the CRMFT PMA are the same. Hence, any leakage of a flux line out one end can never return to the other end of the PMA and thus to complete the magnetic circuit which is a must, it must return to an interior pole of opposite polarity, and it would be more probable to a nearer interior pole, and thus it must cut across a coil winding. Note that the effects of #4 and #5 does make for some variation in the maximum field strength in the various compressive repulsive field regions along the axis of the PMA cylinder.
6. A high intensity and relatively uniform magnetic field is produced in a direction perpendicular to the long axis of the PMA cylinder other than for small node regions located at the direct center of an individual magnet's side.
7. The compression of the magnetic fields in regions of like adjacent poles produces a significant increase in the flux density that cuts across the coil windings in a favorable perpendicular or near perpendicular direction to the axis of the coils.
8. Although the sum total of the flux produced by the standard (NSNS) configuration is equal the sum total of the flux of an equal number of equally sized magnets in the CRMFT configuration, nearly 100% of all the flux lines in the latter come out of the circular surface of the PMA cylinder

in a direction perpendicular or nearly perpendicular to the long axis of the surrounding coils, a condition necessary for optimal maximum power output whereas in the former standard configuration, a significant number of lines of flux come out in a direction parallel or nearly parallel to the long axis of both the field coil array and the PMA cylinder which is not suitable for coil winding flux linkages and electrical power production.

9. There are no long regions relatively void of magnetic flux along the side of the PMA cylinder with the CRMFT whereas there are with the standard configuration, and whatever the small amount of flux is present, their direction is parallel to the long axis of the coil array and PMA cylinder, and only lie adjacent to the cylinder surface – thus they are useless for electrical power generation.
10. There is no significant eddy or hysteresis energy losses anywhere in the magnetic assembly as there are no large ferromagnetic flux focusing structures present that move relatively to the linear motion of the magnets.
11. The magnetic field focusing is done by the magnets and the pole pieces themselves with no heavy ferromagnetic structures to do this.
12. There are no Lenz Law back EMF forces produced in the pole pieces because they do not move relative to the motion of the magnetic field.
13. There are no back EMF forces generated from the magnet motion other than in the coils themselves as there are no bulky ferromagnetic structures surrounding the coils in an attempt to focus and concentrate the flux around the coils as in conventional generators.
14. In the conventional configuration, as you stack the number of magnets to a larger and larger number, the incremental field strength at the ends of the magnets becomes smaller and smaller until after about configuring a PMA of about 10 magnets, there is virtually no further gain to increase the PMA length with more magnets. In the CRMFT configuration, the number of lines of force leaving the side of the PMA cylinder is more or less constant except for small node areas at the midpoint of an individual magnet's thickness, and the average amount of flux per unit length along the entire cylindrical surface remains fairly constant no matter how many magnets are added making for PMA lengths that can be meters long. This is very advantageous to wave energy converters (WEC) employing LEG's where large wave energies can be absorbed and converted with long PMA cylinders. The technical reason for this is that in the standard configuration, as the length of the PMA long axis increases, magnetic circuit consisting of the path of the flux through the interior of the PMA and the return path through air (which is of low magnetic flux permeability or permanence) becomes longer and longer between the two end poles increasing the reluctance of a good portion of the magnetic circuit there thereby reducing the flux density and total flux going from the end N pole to the end S pole. Contrast that with the CRMFT array in which repulsive pole regions of the PMA cylinder prevent any flux lines from traveling through the interior of the PMA. Instead, the magnetic circuits are all local coming out of one N pole repulsive region and quickly back into the adjacent S pole repulsive region and so forth. Thus no matter how many extra magnets are added and how long the LEG is, the return air path of the flux will always be both shorter, relatively the same or almost the same length and the length of the PMA or number of magnets used will have no significant effect on the flux output average per magnet and will have no decreasing effect on the benefit of adding additional magnets to the PMA length. Another way of putting it, the Permanence Coefficient goes down as the standard PMA grows in length and number of magnets, and stays constant in the CRMFT PMA no matter how long it is and how many magnets are added.
15. The CRMFT array is very scalable both in terms of going from using very small rare earth magnets to extremely large magnets and the number of magnets may be at a minimum one pair to a maximum of many hundreds of magnets with no theoretical maximum, only limits subject

to safe handling, assembly, wave size, and structural stability of the LEG itself (not the PMA itself which can be made quite stable even with huge diameter and length scaling). Thus the CRMFT array can be used from miniature structures for tiny environmental vibrational energy harvester generators to moderate structures such as buoys to grid scale power generating WEC's.

16. If the PMA is in a neutral position relative to the coils (i.e. a wave node), a small wave that moves the PMA a short distance in the conventional configuration will produce no power as the vertical oscillation of the magnets will be completely within the "dead zone" interior region of low magnetic flux density that occurs along most of its length at all points except at the ends. In contrast, with the CRMFT array, the smallest ocean wave vibrational disturbance will produce electrical power.
17. The use of pole pieces and the compression of magnetic fields together from repelling adjacent magnetic poles significantly increases the measured magnetic field intensity (B) that occurs If the along the long axis of the PMA as the lines of force exit perpendicularly from the cylindrical surface. In the lab this was measured to be on the order of 80 to 90% (5500 Gauss (G) or 0.55 Tesla (T) to 9700 G or 0.97 T) with magnets and pole pieces of thickness 2 to 1 respectively. If this effect is maximized using optimally predicted effective ratios of magnet thickness to pole piece thickness depending upon the application, the B magnetic field intensities can be increased for the magnets we used in the research PMA's (2" in diameter 1" thick NdBrFe rare magnets and 2" in diameter 0.5" thick 1018 steel pole pieces) from about 5500 G (0.55 T) to about 18000 to 20,000 Gauss (1.8 to 2.0 T), an up to 400% gain, with the limit being set only by the magnetic saturation permeability of the steel pole pieces.
18. The pole pieces at as magnetic lenses that direct the flux back onto the coil windings working in concert with the other design factors that do this.
19. Normally, the severe repulsion of the repelling like polarity magnetic fields (which are stabilized by a patent pending structural assembly array and assembly process) would repel the magnetic flux back into the interior of the magnets located at the repulsive magnetic field regions. This effect is extremely delirious and should not be allowed to happen as it would happen if there were no pole pieces used at all. If this situation in fact does occur, the magnets will be slowly but progressively demagnetized with time as the repulsive magnetic force will act as a coercive magnetic force operating in a direction opposite to the original force of magnetization of the magnets. This effect is neutralized by using pole pieces which because of their much greater permeability pulls the flux lines into them and away from the magnet interior pole regions. Until the pole pieces are saturated, they can prevent this effect from happening. Thus again, the optimal design of the CRMFT PMA is such that the ratio of the magnet thickness to the pole piece thickness results in the pole pieces being saturated. If one goes beyond that, even with the pole pieces, the magnetic repulsive field between adjacent magnets will not be able to be confined to the pole pieces and the magnets could be eventually demagnetized. One can either limit the size of the magnet thickness or increase the thickness of the steel pole pieces to keep the pole pieces in magnetic saturation. Note that low carbon steel rather than iron or other types of steel are used because of its superior high permeability and saturation characteristics.
20. Because the magnets travel through the surrounding coils rather than adjacent to them as in some other WEC's powered by LEG's we have another factor that causes virtually all of the flux lines generated by the PMA to intersect the coil windings and produce power.
21. The PMA's themselves are scalable in arrays to produce 3 dimensional "crystalline like" matrices because of the unique geometrical and pole configuration. This structure has been patented.
22. So far, we have been discussing the CRMFT in terms of wave energy converting LEG's. All generators can be used as linear motors and the characteristics of this magnetic array need yet to be explored for use in rail guns, linear servo mechanisms and actuators etc.

23. The CRMFT PMA has so far been discussed as being used as the rotor in an LEG with the Field Coil Array (FCA) being used as the stator. The PMA and the FCA can be interchanged to the stator and the rotor respectively with no change in function.
24. Because one can use long CRMFT PMA's in wave energy conversion as well as any other vibrational energy harvestable source of energy, as the size of the PMA increases relative to the height of the wave, the efficiency of the energy conversion will increase toward a theoretical 100% subject to all of the other physical constraints that would put a limit on the conversion efficiency but it is clear that very high efficiencies can result.
25. The shape of the CRMFT PMA is conducive to its use in long strips or geometrical arrays to disperse wave energy for the protection of coastal beaches and structures with electrical energy as a useful byproduct. A patent has been granted for these structures.
26. When compared to the Halbach magnetic array in which the total flux of magnetic field as on the top of the array is twice the flux that would be on either side of a NSNS standard conventional permanent magnet array with very little flux on the bottom side of the array (assuming rectangular magnets), the CRMFT is superior because all of the flux is compressed into a perpendicular or near perpendicular direction of the motion of the magnets and the long axis of the coils, and this compression causes flux densities in the region of the coils to be much higher than would be seen in the Halbach array (estimated at least to be 400% with magnets capable of being used in the lab, twice that of the Halbach array). Note that many of the flux lines in the Halbach array flow parallel to the long axis of the PMA and the coils and thus many of the flux linkages are in effective for producing power. For that reason, the Halbach array is not used for electrical power production.
27. In the conventional magnet stacking of alternate poles, the air gap between the innermost coils and the outer surface of the PMA is critical – the larger the gap, the greater the diminution of the magnetic field intensity crossing the inner coil windings and the less the power output. Furthermore, the further the radial distance from the PMA outer curved surface, the greater the component of the magnetic field parallel to the long axis of the PMA (which produces less power as there are less flux winding linkages created) and this problem because more critical very quickly with the coil thickness (outside diameter minus the inside diameter) as it is the radial component of the magnetic field perpendicular to the long axis of the PMA that cuts across the full thickness of the coil that creates the maximum number of coil flux linkages that produces the maximum power output. Because the magnetic fields are compressed and then focused by the magnetic pole pieces to such an extent that virtually all of the magnetic field lines emanating from the curved cylindrical surface of the PMA are in the radial direction perpendicular to the PMA long axis, and because the very great proportion of the field stays radial and perpendicular to that axis, the size of the air gap is no longer that critical as the number of flux linkages for a surrounding coil remains the same no matter what the size of the air gap (that is a reasonably sized air gap from a fraction of a mm. to several mm, depending upon the diameter of the magnet and the degree of magnetization of the magnet). Hence the PMA rotor stator sliding mechanism and interaction can be built more economically to a less critical precision and dimensional tolerance.
28. Because in the CRMFT configuration, the compression of the magnetic fields cause virtually the entire magnetic field as it leaves the cylindrical surface of the PMA to be perpendicular to the long axis of the PMA, and it to stay perpendicular to the long axis for quite some radial distance out. As a result, the field lines begin to diverge toward the direction parallel to the long axis quite a distance away and they immediately begin to point again back to the perpendicular direction as the field lines travel the short magnetic loop quickly to the adjacent magnetic poles instead of pursuing wide air spaced magnetic loops as per the conventional configuration. As a

further result, even if the coil thickness is considerable, the direction of the magnetic field lines throughout the coil thickness is perpendicular to the long axis of the FCA (which is parallel to the long axis of the PMA) which produces the maximum flux winding linkages and power production. The thickness of the coils used with the conventional configuration has to be sharply limited, a limitation that does not occur with the CRMFT configuration.

29. The cylindrical cross-section, though not required, in most cases is used as the optimal configuration of the CRMFT PMA as it results in totally uniform and symmetric radial feels emanating out of the entire cylindrical surface of the cylinder.
30. If two identical magnets are placed in the conventional NS attachment configuration, the total space occupied by the flux lines will be significantly greater than the same two magnets forced together in the CRMFT mode. The total amount of magnetic flux will be equal in either case, but in the CRMFT configuration, that flux will occupy a smaller volume, and hence, the average magnetic field intensity in the region near the magnets where power producing coils would be located will be greater.
31. Using materials with a higher magnetic saturation than 1018 low carbon steel will lead to even higher magnetic field compression and intensity.
32. Measurements with and without the end deflecting magnets using a gauss meter has shown that with the size PMA being used (3 magnet pairs, 2" diameter and 1" thickness magnets), measurements indicated a 20% increase in the intensity of the peak magnetic fields when the end deflecting magnets were used. This is over and above the estimated 200% increase in efficiency of magnetic flux cutting across a given amount of coil windings as compared to the standard NSNSNS configuration.
33. If we use just the PMA without the end deflecting magnets, it is estimated (and this will be shown hopefully analytically by the computer simulation) that there is a significant loss of magnetic flush for small PMA's and therefore, the end deflecting magnet is much more significant for small PMA structures. The explanation is as follows: If each magnet produces N total magnetic lines of flux, the PMA as a whole produces nN total flux where n = the number of magnets in the PMA. However, flux only escapes into space and does from the N pole end of the PMA, goes into space with most of this flux not intersecting the coils because their direction is parallel to the long axis of the PMA and when they do curve around to return to a S pole in the interior of the PMA, it is way beyond the location of the coils. Thus this represents magnetic flux leakage which impairs the efficiency of the generator. The amount of leakage remains the same no matter how long the PMA is and how many magnets are used, because unlike the conventional configuration of NSNS where all the flux comes out the end of the PMA, in the CRMFT configuration only the flux from the end magnet comes out as flux loops in this configuration is only to the adjacent poles and not out into space except for the end magnet. The use of end deflecting magnets is critical for short small PMA's such as wrist watches, personal energy harvesters, buoys, etc but less critical for larger PMA's such as Wave Energy Converters. Reason: (A semi-analytical explanation) If the minimum sized PMA using 2 magnets produces a total amount of flux of 2N, and let's assume that 50% of the flux emanating out of the end magnet that is lost is N/2, the % loss of flux of the system is (N/2)/2N or 25% which is significant. However, if the PMA has 10 magnets, n=10, the total flux is 10N, the amount lost to space at the ends is still only N/2 (as opposed to 50% of 10N or 5N in the conventional configuration), the percentage leakage is (N/2)/10N or only 5% and an end deflecting magnet is not really necessary to prevent flux leakage and its effect on the power generation is nil (though an end deflecting magnet is still useful to help in braking the PMA with the end braking magnet). It is this arrangement of magnetic fields that is responsible for an estimated 200% improvement

in the magnetic flux coil winding linkage for magnets and coils of a given size of the NSSNNSSN CRMFT versus the standard older NSNSNSN technology.

34. While the CRMFT causes virtually all of the magnetic flux lines to curve around to the interior of the PMA cutting across the coil windings producing power, some of the lines further away from the PMA may curve around in such a manner that the radial component of the magnetic field perpendicular to the axis of movement and long axis of the PMA (the only component of the field that produces power in the coil windings) may less than and even small relative to the tangential field component(parallel to the direction of motion and long axis of the PMA) in the vicinity of the winding which produces no power and wastes magnetic flux reducing the efficiency of conversion. The ratio of the perpendicular component to the tangential component can be enhanced at points further out from the PMA in the outer windings of the coil by surrounding the coils with a thin circular sheet of very high permeable magnetic shielding sheeting .