The Kinetic Energy Potential of Pressurized Natural Gas Wells

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It has long been known that there are substantial quantities of kinetic energy that can be derived from the pressure of natural gas wells. However, prior art kinetic energy conversion methods have not proven to be cost effective or efficient for the following reasons: (1) the reliance on rotating turbine style equipment of which the blades are not usually fabricated to withstand the extreme pressure associated with natural gas wells; and, (2) rotation creates centrifugal forces that become greater with increased velocity, which imposes limits on the velocity at which turbine units, electrical generators, and alternators may operate; and, (3) turbine units are designed for very specific pressure ranges and even relatively small pressure variations can cause the need for blade changes and larger pressure changes generally result in the entire failure of operation of the turbine; and, (4) the high pressure, dual phase discharge from natural gas wells comprises methane gas and other corrosive gases, most often quantities of oil, water, sand and other debris that quickly erode rapidly rotating turbine blades; and, (5) turbine units are subjected to severe "end-thrust" forces, which result in the turbine, while rotating at high velocity, being pushed to one side in the direction of the shaft penetration of the housing with great force. Fluids exert pressure equally in all directions. An area equal to the displacement of the shaft has no external opposing force to the internal pressure of the pressurized fluids within the turbine housing; therefore, a force equal to the cross sectional area of the shaft times the pressure in pounds per square inch pushes the turbine to one side.

This presentation discloses a method whereby end thrust that is roughly equivalent to the use of positive displacement pistons within a cylinder is used to facilitate the harnessing of the kinetic energy potential of pressurized natural gas wells via a linear alternator that is driven back-and-forth by a pneumatic ram with the aide of a driver in order to generate electrical power.

I. Background Discussion

Harnessing the enormous kinetic energy potential of the high-pressure multiphase flow of pressurized natural gas wells is certainly not a new idea. However, the success rate using rotary turbine style equipment that was originally designed for operation at constant pressure with clean, single-phase dry gases has historically been very low.

Changes in output pressures over time are a persistent problem in geothermal power generation and is a major challenge in harnessing the kinetic potential of natural gas wells. It is

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well known that gas wells continue to drop in pressure as the amount of gas within the reservoir decreases on a continuous basis, which makes the use of pressure sensitive turbines extremely problematic. Geothermal steam wells also experience substantial pressure drops. For example, the Geysers Geothermal Field is one of the oldest and grandest geothermal sites resources in the world that has produced vast quantities of high quality dry steam over the years, which has unfortunately resulted in a substantial loss of steam pressure. Turbines that were originally designed to operate using approximately 150 psi of steam pressure will not operate today as the pressure in some wells within the field has drops to as low as 80 psi. Adjusting the pitch of the blades of a turbine to operate at the lower pressure at the Geysers can cost over a million dollars and if the pressure drops substantially again the turbine will again fail to drive an electrical generator.

The use of linear power equipment is herein proposed as a means to harness the kinetic energy of natural gas wells that produce mainly dry methane gas, geo-pressure water gas wells that produce mainly high pressure water, low pressure gas wells with a high water cut that possess heat capable of generating kinetic energy, using a proprietary method of injection of liquid phase low-boiling-point-liquid, such as propane at depth within the well bore.

The volatile liquid is rapidly boiled to a high pressure vapor by direct heat exchange within the well bore by the thermal energy contained in the water in order to gas-lift the water containing small amounts of oil and gas from the well water at high pressure; and, thereby creating substantial quantities of kinetic energy. Linear power equipment may also be used to harness the kinetic energy of hot dry steam produced by geothermal wells or kinetic energy generated by high temperature geothermal water wells via injection of a liquid phase low-boiling-point-liquid.

Linear power equipment may also be beneficially used in association with agriculture and aquaculture interests. For example, the City of Calistoga, CA and the greater Napa Valley, which are at the heart of the California wine country, have hot water readily available through out the area at extremely shallow depths with temperature ranges often approaching 300 degrees F. Shallow large diameter geothermal wells with nearby injection wells being at a different depth could be inexpensively drilled into this hot liquid resource; thereby, providing an entirely renewable energy source. Fish farming often requires hot water in order to facilitate faster growth for the fish and to assure survival of warm water species during cold winter seasons. Power can be generated with heat rejected to aquaculture ponds and tanks.

II. Kinetic Energy

Kinetic energy is the energy that a body of mass in motion possesses. Once in motion the inertia of the mass resists any change in its motion. The greater the mass (more weight) and the faster the velocity; the harder it is to change the direction of the motion or to bring the body of mass to rest. In order to harness the kinetic energy of a body of mass in motion, a resisting force, such as a turbine or a piston within a cylinder, is used to decrease the rate of motion of the mass. In the process the kinetic energy of the mass in motion is transferred to the resisting force at a rate equal to the amount of change in motion caused by the resistance. The greater the change in motion the greater the amount of kinetic energy harnessed by the turbine or piston.

All renewable sources of kinetic energy, such as wind power, geothermal steam, water currents, wave action, water being released by a hydroelectric damn, etc., exert a force in a straight line. The pressurized gas generated by organic Rankine power cycles also exerts a linear force.

Kinetic Energy equals one-half of the mass times the velocity squared.

Written as: $KE = {}^{1}/_{2}mv^{2}$

Importantly, the velocity of the body of mass is squared in the formula, which means that the energy level of the mass in motion grows exponentially with increased velocity. In example, the kinetic energy of wind power that was formulated from the above kinetic energy formula is the cube of the velocity or two (2) times two (2) times two (2) equals eight (8). The kinetic energy availability of wind blowing at fifteen (15) miles per hour is only one-eighth ($1/8^{th}$) of the amount of energy available in thirty miles (30) per hour wind. The amount of power that may be produced by wind blowing sixty (60) miles per hour is eight (8) times more powerful than the power generated by thirty miles (30) per hour wind. However, the energy level of one hundred and twenty (120) miles per hour wind is sixty-four (64) times greater than the energy level of thirty (30) miles per hour wind and is five hundred and twelve (512) times greater than the available kinetic energy level of fifteen (15) miles per hour wind, which explains the tremendous power and highly destructive nature of hurricanes and tornados that have very high kinetic energy levels due to their velocity.

The hydrostatic pressure of water behind a damn increases in response to increased depth. However the pressure at depth of the static water behind a damn does not have as much useable power as the kinetic energy of the mass of liquid in motion. The function of the "penstock" for hydroelectric power plants is to convert hydrostatic pressure into velocity. The penstock increases the kinetic energy of the water by accelerating the flow of water. This is accomplished by applying a force (hydrostatic pressure) to the water over a distance, while gradually decreasing the diameter of the pipe, which further increases the velocity of the water (Bernoulli's principle) as it must flow through a more confined smaller cross sectional area. The increased velocity results in an increase in the level of kinetic energy of the water before it reaches the turbine; and, thereby more electrical power may be generated by the process of using pressure as a force to accelerate a body of high mass water to considerable velocity.

Likewise, high-pressure gases have the ability to accelerate high mass liquids to substantial velocity via gas-lift pumping in order to produce more net output power. High-pressure gases can be attained by injection of liquid phase low-boiling-point liquids into hot water in a closed cycle using direct heat exchange deep within the well bore. The thermal energy contained in the water boils the liquid phase low-boiling-point-liquid into high-pressure vapor, which accelerates the flow of high mass liquids, such as water and oil, from the well at significant pressure, wherein the high kinetic energy level of the heavy liquids as well as expansion of the high-pressure vapor power a prime mover with far greater power.

III. The Enormous Kinetic Energy Potential of Natural Gas Wells

The following chart below is a partial reproduction of the original spreadsheet calculations performed by Dr. Michaedides of Tulane University for Robert Hunt in regard to

calculating the kinetic energy potential of natural gas wells having high-pressure and high flow rates. The full calculation modeled additional pressure ranges and flow rates. However, any range of conditions may be input into the spreadsheet for immediate calculation. This portion of the chart shown herein clearly and dramatically demonstrates the tremendous potential of high-pressure, high flow rate natural gas wells through out the US, Canada, and the rest of the world to generate many millions of megawatts of electrical power.

Linear Power, Ltd.'s Kinetic Energy Linear Alternator

Kinetic Energy Potential of High-Pressure High Flow-Rate Gas Wells for Producing MW's of Electricity

Computation of the ideal power produced by pressurized gas Methane (M=16 kg/kmol)

	High Pressure Gas Wells		
Enter Flowrate in Mcfd	**10,000**	**6,000**	**2,000**
Volumetric flow rate in cfs:	115.7	69.4	23.1
Enter Pressure in psig:	**7000**	**5000**	**3000**
Pressure ratio for expansion to 15 psig	0.0021	0.0030	0.0050
Enter Temperature in degrees Fahrenheit:	150	150	0
Temperature in degrees Kelvin	338.6	338.6	255.2
Equals Power Produced in Megawatts (MW)	**359**	**150**	**33**
Equals MW Hours Per Year	2,988,395	1,247,621	272,496
Equals Annual Revenues @ 5-cents/kWh	$149,419,771	$62,381,026	$13,624,814
Expected Temperature w/ isentropic expansion turbine	82.32	88.94	75.41
Expected Temperature in degrees Fahrenheit	-311.23	-299.30	-323.65
Ideal work (kJ/kg)	577.56	562.62	405.29
volumetric rate in m^3/s	3.28	1.97	0.66
mass flow rate in kg/s	888.21	380.66	100.99
mass flow rate in lb/s	1954.06	837.45	222.18
power produced in kW	512,994	214,169	40,930
power produced in hp	687,660	287,090	54,866
Enter turbine efficiency	0.7	0.7	0.8
power produced in kW, with above efficiency	359,096	149,918	32,744
power produced in hp, with above efficiency	481,362	200,963	43,893

Prepared by Professor Stathis Michaelides of Tulane University, New Orleans, LA [2]

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http://www.me.tulane.edu/Faculty/Michaelides/homepage/eemhome.htm
http://www.me.tulane.edu/Faculty/Michaelides/homepage/resume-eem.htm

Mcf is one thousand cubic feet. Natural gas is sold in units of Mcf. Mcfd represents the number of Mcf units per day. In the first line of the chart 10,000 Mcfd equals ten million cubic feet of gas per day (10,000 times 1,000 = 10,000,000). The second line converts this volume of gas into flow rate per second, which is 115.7 cubic feet per second (10,000,000 cubic feet of natural gas / 24 hours per day / 60 minutes per hour / 60 seconds per minute = 115.7 cubic feet per second flow rate).

Moving down Column One we see that the pressure is 7,000 pounds per square inch and that the ratio of expansion is from 7,000 psi down to almost atmospheric pressure (14.7psi) of 15 psi is used in the calculation. In real gas wells a residual pressure may be required in order to go into the natural gas transmission line that is often on the order of 1,000 psi. In this instance the net kinetic energy is 6,000 psi instead of 7,000 psi (7000 psi well pressure – 1,000 psi residual pressure in order to enter the transmission line = 6,000 psi pressure drop available for electrical power generation). Wells that do not have pressure ranges greater than 1,000 are not usually candidates for direct natural gas driven linear power generation, unless the transmission pressure is much lower or the gas will be used on site so that essentially all of the pressure may be used, such as for electric power generation to supply low pressure gas to a natural gas fired power plant.

One of the variables that must be taken into consideration is the efficiency of the turbine unit or linear power unit used to harness the kinetic energy of the natural gas well. The calculation uses a mechanical efficiency of seventy percent (70%) to eighty percent (80%). Below the efficiency we see the ideal power that is produced by the kinetic energy of the natural gas in kilowatts and in horsepower. For the gas well presented in column one, the ideal power generation potential from its kinetic energy level is 512 megawatts.

After taking the seventy percent rotary turbine or linear power equipment mechanical efficiency into consideration, we have an estimated actual electrical power generation potential of 359 megawatts produced by this natural gas well flowing ten million cubic feet of gas per day at 7,000 psi. A typical nuclear power plant would be expected to generate about 1,000 megawatts of electrical power. Three high-pressure, high flow rate natural gas wells of the magnitude of the well presented herein in Column One possess the kinetic energy potential to generate an amount of electrical power roughly equal to the power output of a nuclear power plant that would cost billions of dollars to build!

Natural gas wells in the Barnett Shale formation located between Dallas and Ft. have flow rates of upwards to twelve million cubic feet per day at pressures in the range of eighteen hundred pounds per square inch with a discharge pressure of three hundred pounds per inch needed in order to go into the transmission line. This provides a useful pressure drop of approximately one thousand five hundred pounds per square inch. Plugging these inputs into Professor Michaelides spreadsheet, we find that the potential kinetic energy level of such a Barnett Shale well is on the order of 91 megawatts of power. Only about eleven reasonably low-pressure, high rate of flow gas wells of the pressure range and flow rate of the Barnett Shale are needed to equal the power output of a nuclear power plant. There are tens of thousands of reasonably dry natural gas wells that meet these criteria.

IV. How Linear Power Equipment Works

Linear power equipment cycles back-and-forth like an old locomotive steam engine. This is accomplished by maintaining a pressure differential to the opposite sides of the piston. A driver unit that is a modified slide valve supplies high-pressure steam, gas, water, etc. working fluid into the cylinder on one side of the piston at the same time as it exhausts the working fluid from the cylinder to lower pressure on the opposite side of the piston. The piston moves in the direction of the lower pressure in response to force applied by the higher pressure. Once the piston has moved to the end of the cylinder, the slide valve reverses the high-pressure input and low-pressure exhaust to cause the piston to move in the opposite direction, and then reverses again in a continuous back-and-forth cycle that maintains a continuous pressure imbalance on the opposite sides of the piston.

Linear Alternator developed by Linear Power, Ltd.

The Linear Power Ltd. proprietary linear power unit used to harness the kinetic energy of natural gas wells comprises three pieces of reciprocating equipment: (1) a linear alternator that is driven back-and-forth by a pneumatic ram in order to generate 60 Hz AC electrical power; and, (2) a pneumatic ram prime mover, being a movable piston and rod within a cylinder that forms a housing, that is actuated by a driver mechanism that controls the flow of high-pressure natural gas into the cylinder of the ram and directs the exhaust flow from the cylinder; and, (3) a driver, being a modified slide valve, whose function is to maintain an alternating pressure differential on the opposite sides of the piston within the cylinder in order to produce a back-and-forth motion of the piston, rod attached to the piston, and the coil of the linear alternator in order to produce electricity.

The pneumatic ram and the linear alternator are placed inline, which creates a perfect vector angle in order to obtain maximum benefit from the energy input. Steam locomotives convert linear motion into rotary motion that cause poor vector angles to be formed along much of the circular path thereby losing much of the power produced and creating a poor mechanical efficiency. All of the force applied by the piston, which has a very high efficiency itself, is directly applied to the linear alternator with no angular losses, resulting in a very high mechanical efficiency for the linear power equipment used to harness kinetic energy resources.

A perfect vector angle is 90 degrees. A rod that pushes a piston straightforward forms a 90 degrees angle to the face of the piston. Linear Power equipment always has a perfect 90 degrees vector angle; and, therefore it has a very high mechanically efficiency.

The linear alternator comprises at least one positive field and at least one negative field. Movement back-and-forth generates alternating current by successively moving from the positive field to the negative field then back to the positive field in a continuous cycle. In order to produce sixty-Hertz alternating current power, the cycle rate must reach 3,600 cycles per minute (60 cycles per second times 60 seconds per minute = 3,600 cycles per minute). In the alternative, the number of positive and negative fields may be increased so that more than one pulse of electricity is produced by each stoke of the piston thereby reducing the number of strokes needed to generate 60 Hz AC power.

Shown above on the left are permanent magnets in a Housing and to the right a copper wire coil attached to non-magnetic stainless steel bars that drive the coil back-and-forth

Linear Power Ltd.'s permanent magnet linear alternator designed by its founder Robert D. Hunt uses ferrous metal free coils that move instead of the magnets to produce electrical power. The coils that are made of non-magnetic copper wire are not attached to a ferrous metal core, instead they move freely back-and-forth over stationary internal ferrous metal cores that act as the passageways for magnetic flux in order to entirely eliminate "cogging". Cogging is the attraction of ferrous metal to the permanent magnets used in permanent magnet electrical generators and alternators.

Virtually all generators and motors manufactured today connect a stationary coil of copper wire to a stationary ferrous metal core that acts as a passageway for the flow of magnetic flux, which causes the magnets that rotate to strongly attract to the ferrous metal used in the core. For this reason permanent magnet generators require a great deal of starting torque, even when no electrical load is applied. Until a load is applied, Linear Power Ltd.'s linear alternators and rotary generators move freely -- having absolutely no cogging. Further because the coil only weighs approximately twenty percent (20%) as much as the metal and heavy magnets, moving the light weight coils instead of the metal and magnets requires far less energy input.

The elimination of cogging that allows generators and alternators to freely reach high velocities before a load is applied is an important step in harnessing the power of low temperature resources, such as low temperature geothermal, low temperature solar power generation, ocean thermal energy conversion (OTEC) that uses low temperature water in the oceans of the world that possess stored solar thermal energy, waste heat from power plants and thousands of other low temperature energy sources because these low temperature resources produce very low starting torque.

Pairs of coils move in opposite directions to each other, like clapping your hands together and then moving them apart with each hand going in the opposite direction in order to cancel out vibration. The coils are vertically mounted and are connected together by a series of gears that form a mechanical fulcrum. The fulcrum eliminates the effect of gravity on the coils. In order for the upper coil to move downward, its weight lifts the lower coil, as the two coils are geared together by a rack and pinion gear.

Positive displacement pistons within a cylinder used as the prime movers in linear power systems are not pressure dependent. While the amount of power generated is determined by the amount of pressure available, linear power positive displacement pistons can operate from 20 psi to 20,000 psi with equal effectiveness of above ninety percent (90%) piston efficiency.

The positive displacement of pistons capture all of the force of the working fluid in the same manner as does the pistons used by a car engine. Unlike a car, however, power is not lost converting linear motion to rotary motion via rods that create poor vector angles and a massive crankshaft that takes a great deal of power to rotate. The linear motion of the piston is used to directly drive Linear Power Ltd.'s proprietary linear alternator in order to achieve a much higher mechanical efficiency.

Within a closed cylinder, pressurized fluids exert pressure equally in all directions. The piston connected to a rod however is the only moveable member within the cylinder; and, the piston and rod move backward in response to the pressure. The amount of force exerted by the rod of a piston may be determined by multiplying the area of the piston times the pressure. High-pressure gas wells produce very large amounts of force on the rod. For example; a well with a ten-inch diameter and having pressure of 7,000 psi as applied to a ten-inch diameter piston and cylinder would exert 549,500 pounds of force on the rod (calculated as $A = r^2 \pi$ or 5" radius^2 X 3.14 = 78.5 sq. in. displacement area of piston times 7,000 psi pressure = 549,500 lbs of force).

The area of the piston displacement (pressure differential on the opposing sides of a piston with high pressure on one side and lower pressure on the opposite side to cause powerful movement of the piston in the direction of the lower pressure) that is positively used by linear power systems in their process to harness the kinetic energy of gas wells is roughly equivalent to the detrimental end thrust experienced by rotary equipment as a force equal to the cross sectional area of the shaft times the pressure in pounds per square inch destructively pushes the turbine to the side of the shaft penetration of the pressurized housing of the turbine placing extreme pressure against the seals and bearings of the rotary turbine unit as it rotates at high speed. While various methods have been developed by rotary equipment manufacturers to deal with end thrust in regard to the use of high-pressure working fluids, end thrust still remains a serious concern for turbine builders.

The maximum velocities that rotational equipment can achieve are limited by detrimental centrifugal forces. Destructive centrifugal forces that overheat bearings, pulls brittle magnets apart, etc. increase as the turbine rotates faster. Most generators only rotate at 1,800 to 3,600 revolutions per minute. Recent innovations such as air bearings have allowed turbines to achieve much greater rotational velocities on the order of 160,000 revolutions per minute, which is considered by most scientists to be close to the upper limits possible for rotating generators and alternators. At this velocity, materials from which the turbines are constructed are near their structural limits.

However, while it is initially counter intuitive, it is possible that reciprocating linear power equipment that does not have centrifugal forces may attain much higher velocities than those possible of rotating equipment. Gases molecules enclosed in a pressure vessel can vibrate back-and-forth at velocities over 30,000 times per second and quartz vibrates at 32,000 times per second or 1,920,000 times per minute forever with no additional power input, no energy losses, and with no damage to the molecule. The natural resonance frequency of the cesium atom is 9,192,631,770 Hz (per second). How is that possible? It is explained as a perfect elastic state that is achieved by molecules on the molecular level. In analogy, the kinetic energy is converted to potential energy as they stretch an internal spring and then the spring accelerates the molecule backward in the opposite direction without any loss of energy, creating vibration at great velocities.

While we cannot achieve a perfect elastic state on our macroscopic level due to friction, mechanical constraints, etc. there are a number of ways to create an efficient “bounce”. A basketball filled with air when dropped, bounces back almost as high as the height from which it was dropped. The potential energy of height is converted to kinetic energy of motion via the acceleration of gravity as the ball drops. When the ball hits the hard surface of the floor, the air within it compresses as the kinetic energy of motion of the ball is transferred to the air in the impact and the air is thereby compressed. After the ball stops, the pressure of the compressed air applies a force sufficient to accelerate the ball in the opposite direction; and, the ball bounces back upward.

Springs work okay but have a lot of mechanical losses. The repulsion of two magnets of the same polarity works extremely well and probably has the highest efficiency available because the forces that power the repulsion are electromagnetic in nature, instead of being mechanical. Gravitational acceleration also is not mechanical and is very effective as is evidenced by the high efficiency of the pendulum, which sequentially converts kinetic energy of motion into potential energy of altitude, changes direction and converts the potential energy of altitude back into kinetic energy via the acceleration of gravity. However, gravity is a weak force in comparison to the repulsion of two magnets of the same polarity. Much more acceleration can be attained by their use due their greater force.

The pendulum losses a little energy due to fiction losses and resistance of the air every time it makes a swing until it finally comes to rest. A little energy is added to the pendulum of a clock by a spring in order to maintain the height of its swing. Likewise the linear power equipment must have additional power added to each stroke of the ram in order to maintain its velocity, even though most of its forward momentum is conserved by the bounce effect of the compression of the gas at the end of each stroke.

The Linear Power, Ltd. proprietary equipment uses the compression of gases to create its bounce effect like the basketball. The slide valve design seals off the chamber within the pneumatic ram and the air compresses. Because the momentary force of stopping the piston, rod and coil are so great, the pressure within the cylinder can become higher than the pressure of the incoming kinetic energy working fluid supply, which in many instances may be a dual-phase mixture of gases and liquids.

A check valve prevents the reverse flow of working fluid back into the supply line. When the pressure is sufficient, the piston, rod and coil are stopped; and, then immediately accelerated back in the opposite direction by the compressed, extremely high pressure working fluid at which time the pressure drops as the piston moves forward providing a greater area allowing additional pressurized working fluid to enter the cylinder of the ram to apply a force against the piston to accelerate it back to the original speed as it moves down the cylinder in the opposite direction. This process can occur in a millisecond with no damage to the equipment because it is a smooth process of acceleration, deceleration, and then acceleration again in a cycle.

The velocities at which Linear Power, Ltd.'s equipment may ultimately be capable of attaining may be many times greater than the velocity ever achieved by rotating equipment due to the detrimental effect of centrifugal forces on turbines. Remember that the power generated due to kinetic energy is the square of the velocity. Therefore, linear power equipment has the potential to generate many times greater electrical power than will ever be possible to be produced by rotating equipment.

The herein described proprietary geothermal technology is extremely flexible in its ability to be used in virtually all geothermal methods of operation: (1) the unit can be driven by dry steam without the need of condensers and vaporizers as in the Geysers field or by high-pressure high flow rate natural gas; and, (2) it can be powered by a binary cycle using hot water with the use of condensers and vaporizers; and, (3) hot water that is flashed to steam to drive the unit. Further, our unit can reject heat to the air, evaporative cooling water, or shallow cool geothermal water as used by heat pumps, or via a proprietary refrigeration bottoming cycle.

Unique features of the Linear Power Ltd. design include: (1) pressurized re-injection of unwanted non-condensable gases into the earth via multiplication of force at equalized pressure system that eliminates the need for chemical abatement in dry steam and flash units; and, (2) pumping of water as a heat source and for other uses such as fish farming or pumping of water for pressurized re-injection of the water produced by the cycle back into the reservoir of a geothermal formation or for oil and gas well water injection into the ground; and, (3) the ability to use any pressure source either in liquid form, gas form, or as multiphase fluids, such as the combination of oil, gas, water, and non-condensable gases all mixed together as found in the oil field.

V. Linear Power System Designs Under Development by Linear Power Ltd

Three initial configurations of the linear power technology are discussed herein that are under development by Linear Power Ltd; (Linear A.) the use of the kinetic energy of pressurized gas, steam, pressurized water, etc to power a linear alternator via a driver and pneumatic ram that create a back-and-forth cycle to generate electrical power; and (Linear B.) the use of direct heat exchange of liquid phase low-boiling-point-liquid that is injected deep within the well bore of a natural gas well or oil well having a high water cut or geothermal water well in order to accelerate and gas-lift high mass liquids in order to increase their kinetic energy level substantially and to pump a large volume of accelerated liquid from the well to drive the linear alternator via a driver and pneumatic ram that creates a back-and-forth cycle to generate electrical power; and, (Linear C.) the use of a heat energy powered organic Rankine cycle (ORC) in order to generate high pressure gases to power a linear alternator via a driver and pneumatic

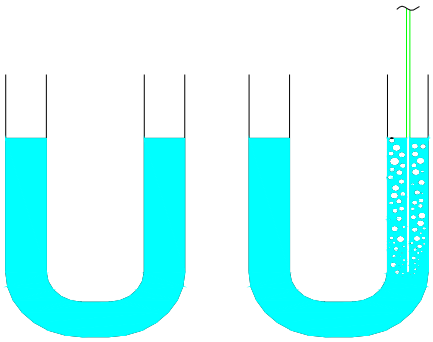
ram that create a back-and-forth cycle to generate electrical power, which can be accomplished at very high rates of speed.

Linear A that involves hooking up the linear driver, pneumatic ram, and linear alternator to a high pressure, high flow rate gas well that produces primarily dry gas is by far the simplest configuration shown herein. This configuration is essentially the “low-hanging-fruit” in regards to harnessing the kinetic energy of natural gas wells because the process is so simple and the equipment costs are substantially lowered. Although the resource decreases in pressure fairly quickly, very large sums of money can be made during this period of time. And, the equipment at some point can then be moved to a new well if the pressure drops below economic levels of power output.

The Linear B configuration of linear power generation is somewhat more complex and requires the installation of a condenser as an additional component for operation but perhaps ultimately will become the most widely used arrangement of linear power in use by oil and gas well operators of “stripper wells”, because this method provides the greatest number of benefits to the operator. Strippers are wells that are mainly flooded with water that produce a small percentage of their flow rate as oil and gas called the “cut”. This is the largest category of oil and gas wells in existence.

The Linear B configuration accomplishes gas-lift pumping of the well, provides a means to generate electrical power from low-pressure oil and gas wells at the same time that it gas-lift pumps a large volume of water, with traces of oil and gas from the well. Instead of the need for electricity being brought to the well site, power is generated by the well using its own thermal energy. Using the Linear B. technology, the flow rate from the well may be increased to the limits of the piping, geology of the reservoir, and the ability to dispose of the additional water produced. Preferably, an injection well would be located nearby to dispose of the water back into the reservoir using power generated by the linear power unit. Oil and gas operators using this technology most likely will produce more valuable oil and gas products due to the increased flow, eliminate existing pumping costs, and generate valuable electricity all at the same time with a relatively simple technology.

Gas lift works by tapping into the natural hydrostatic pressure generated by water at depth within the well bore and within the earth. One cubic foot of water weights 62.427 pounds, which applies hydrostatic pressure that is equal to .433 pounds of pressure per square inch for each foot of height of water (62.427 / 144 square inches per foot = .433 psi). A column of water five thousand feet high exerts 2,165 pounds of pressure per square inch at its base. Water is 821 times heavier than air. A five thousand feet high column of air only exerts 2.64 psi at its base. In fact, the entire atmosphere above us only exerts 14.7 pounds of pressure per square inch at sea level.



U-Tube Gas-Lift Technology

Imagine a tube in the shape of a "U" filled with water that is five thousand feet tall. The weight of the water exerts 2,165 pounds of pressure per square inch at the base of each column of the U-tube (5,000 times .433 = 2,165). Both sides of the U-tube are filled with high mass water and both sides exert equal pressure. If air is bubbled into a column on one side of the U-tube and occupies fifty percent (50%) of the area, the weight at the base of that column is lowered to 1,082.5. The hydrostatic pressure of the water is lowered at the base of the column to one-half. The mass differential pressure imbalance causes water to flow from the heavier column filled entirely with water, which exerts greater pressure of 2,165 psi, to the lighter column partially filled with air that exerts lesser pressure of 1,082.5 psi. The flow rate increases as the percentage of air in the lighter column increases and as the mass differential becomes greater.

A natural gas or oil well acts in much the same manner as the U-tube because the height of the water table generally extends upward to near the surface that causes the earth to act like an underground sea in most locations. When sufficient depth is available as is provided by deep oil and gas wells with a high water cut, the pressure differential can be into the thousands of pounds per square inch of gas-lift water pumping pressure. High mass water accelerated by these thousands of pounds of force can obtain very high velocities, resulting in an enormous kinetic energy potential that can be harnessed by linear power equipment.

An extremely powerful high-pressure high flow rate surge of water can be pumped from the well using gas-lift technology. The flow rate and pressure produced by the technology is determined by the temperature of the water in the well, the vapor pressure of the working fluid, the diameter of the well, and the depth of injection of the liquid phase working fluid into the well that creates the pressure differential as discussed above because the hydrostatic pressure increases with depth. The greater the hydrostatic pressure differential that is generated; the greater the flow rate of water that is produced from the well. The larger the diameter of the well bore; the greater the amount of area that is available for water and gas flow and lesser the amount of piping friction that is produced by the flow. The hotter the water; the greater the amount of thermal energy that is available to boil the liquid phase low-boiling-point-liquid working fluid into vapor and the higher the vapor pressure and the greater the volume of the vapor. The greater the pressure; the greater the force applied to the water; and, thereby, the greater the acceleration of the water to greater velocity; and, the greater the velocity attained by the water; the greater the kinetic energy level possessed by the water in order to generate electrical power.

Propane and carbon dioxide are two high vapor pressure working fluids that work well as gas-lift pumping working fluids because they may readily be condensed back to the liquid phase, have high vapor pressures, and their rate of expansion is high in response to increased temperature so that their volume increases significantly as they are heated. Also, they are also easily separated from water.

In the process of Linear B. low mass vapor is used to accelerate high mass liquids to high velocity, resulting in a much larger power output due to the increased kinetic energy level of the water and resulting in a large quantity of hot liquid being pumped from the geothermal well. This high velocity, high mass water exerts a very substantial "waterhammer effect" that is created by suddenly starting or stopping a flow of water. The great force of the hammer effect beneficially provides a great deal of kinetic energy to power a prime mover, but the equipment used must be very robust and be specifically designed to handle the force of the impact of this powerful dual-phase working fluid that is applied to the prime mover.

In operation of the gas-lift power cycle, liquid phase low-boiling-point-liquid is injected deep into the well bore by a stringer tube and thermal energy provided by the hot liquid heat source boils the low-boiling-point-liquid into high-pressure vapor. In most cases the water temperature is only lowered a few degrees due to the large flow rate of hot water that is gas-lifted from the well. Therefore, this hot liquid may be used to provide thermal energy for an organic Rankine cycle (ORC) power cycle. This provides the potential for Linear Power, Ltd.'s proprietary gas-lift power cycle to be used in conjunction with the United Technologies Corporation's (UTC) or Ormat's proprietary ORC units in order to supply hot water for their ORC cycles.

Linear C. is an innovative power cycle created by Robert Hunt for Linear Power, Ltd. that is much like a conventional ORC except that the liquid pump is eliminated and the liquid phase working fluid is returned to the vaporizer at equalized pressure. Linear Power, Ltd.'s new process originated from experience in operation of a earlier cycle much like the Deluge, Inc. process that sequentially heats and then cools the working fluid to cause it to expand and contract as heat is added then removed to create a back-and-forth movement of a piston within a cylinder.

Thermal Hydraulic Engine Built in 2005

The advantage of this Sterling Cycle process of sequentially heating and cooling the working fluid to produce power is that liquid phase working fluid does not have to be pumped

back to a vaporizer as is required by the ORC process. Further, the Sterling process allows the use of high vapor pressure working fluids, such as carbon dioxide, because the energy required to pump the liquid phase back to the vaporizer in order to use an ORC process takes more energy than the cycle produces, due to the extreme-pressure maintained within the vaporizer with use of the these high pressure working fluids, the low entropy levels of these high-pressure working fluids to power bladed turbines, and the low expansion rates from the liquid phase to the gaseous phase of these high pressure working fluids, as compared to the expansion rate of the liquid phase to the vapor phase of typical working fluids used by ORC cycles that are many times greater.

The Hydraulic Thermal Engine pictured above was tested on March 25, 2005 and was in continuous operation producing of 3.5 kW power until it was lost to Hurricane Katrina in August 29, 2005. We believe that the unit holds the world record for commercial low-temperature power generation because the hot water heat source was only 90 degrees F. with heat rejection to 65 deg. F. temperature water, having only 25 deg. F. Delta temperature. The heat was rejected to fishpond water to provide water heating to insure their winter survival.

However, it was felt that the cycle time of once every twelve seconds to sequentially heat and cool the working fluid was much too slow, too much useful energy was wasted in the process, and it was believed that the process could be dramatically improved upon, which led to the development of an ORC process that returns the liquid phase working fluid back to the boiler using a multiplication of force process at equalized pressure in order to eliminate the liquid pump from the ORC cycle. In Linear Power Ltd.'s new ORC process, high pressure vapor from the vaporizer is available as soon as the control slide valve is opened to power movement of the positive displacement piston while at the same time on the opposite side of the piston the working fluid is exhausted to low pressure to the condenser when the control slide valve is opened. Continuous pressure differentials are sequentially and rapidly maintained on the opposite sides of the piston. Using the new process, cycle times of 3,600 times per minute may be obtained by a single pneumatic ram in order to directly generate 60 Hz AC power output without the need for expensive power conditioning equipment.

Deluge addressed the slow cycle time of their units by creating a series of pistons and cylinders working out of phase like the pistons of a combustion engine that are connected to a flywheel in order to create rotation. Linear Power, Ltd. believes that too much power is lost due to the poor vector angles attained while converting linear motion into rotary motion and by having to rotate a heavy flywheel in order to drive an electrical generator or alternator; and, thereby began development of its proprietary line of linear alternators that directly use a perfect vector angle in order to produce more power and to conserve energy.

Liquid phase water along with the non-condensable gases are re-injected into the earth, which provide two major improvements over conventional geothermal: (1) all of the water is returned to recharge the reservoir that will dramatically extend the life of the water resource; and, (2) chemical abatement plants are not needed as toxic non-condensable gases are sequestered as they are returned to the reservoir where they originated; and, the pumping force can also be used to pump water to an oil and gas water injection water well.

Below is a State Point Analysis of a Linear C., which is a Modified Rankine Power Cycle using Positive Displacement Multiplication of Force at Equalized Pressure Instead of using a

Liquid Pump, further Multiplication of Force may be used to Compress Vapor back into a Heater for a Modified Brayton Power Cycle

The object of the below described technology is to eliminate the liquid pump of a Rankine power cycle by substituting the use of multiplication of force, wherein pumping of the liquid phase working fluid from the condenser at lower pressure to the vaporizer at higher pressure is performed by high pressure vapor from the vaporizer that powers a positive displacement intensifier at equalized pressure. The positive displacement intensifier produces multiplication of force by exchanging a greater volume at lower pressure for a smaller volume at higher pressure. The excess net power output generated by the multiplication of force that is not needed to pump liquid back to the vaporizer is thereby available to drive a linear alternator back-and-forth to generate useful electrical power.

For example, a piston within a 20 inch (50.8 cm) long cylinder having a piston displacement surface area of 100 square inches (645 sq. cm) filled with a fluid with a pressure of 50 psi (345 kPa) will have a volume of 2,000 cubic inches (.0328 cubic meters) and will exert a force on the piston rod of 5,000 pounds (22.2 kN) of force (calculated as 100 sq. in. [645 sq. cm] piston displacement times 50 psi [345 kPa] = 5,000 lbs force [22.2 kN]). If the rod's force is applied to a cylinder 20 inches (50.8 cm) long having a piston displacement surface area of 5 square inches (32.3 sq. cm) and having a volume of 100 cubic inches (.00164 m3), then the 5,000 pounds of force (22.2 kN) applied by the rod of the larger piston to the smaller piston will generate a force of 1,000 lbs per square inch (4.45 kN) over the 5 sq. in. (32.3 sq. cm) (calculated as 5,000 lbs [22.2 kN] force / 5 sq. inches [32.3 sq. cm] small piston displacement = 1,000 psi [6,890 kPa] fluid pressure small cylinder) of the piston surface area of the smaller piston as compared to 50 psi (345 kPa) for the larger piston – 20 times more force or a multiplication of force ratio of 20 to 1. The ratio of the volume of working fluid used to produce the increase in force was also 20 to 1 (2,000 cubic inches [32.8 liters] of working fluid as compared to 100 cubic inches [1.64 liters]).

A single cylinder can be used as an intensifier with the difference in volume being the area displaced by the rod on the rod side of the cylinder as compared to the volume of the cylinder having the rod. A pressurized fluid exerts equal force in all directions. The entire surface area of the side of a piston without a rod exerts force in the forward direction. On the side of the piston with the rod, no backward force is produced in the area of the piston displaced by the rod because the rod extends out of the cylinder and the fluid only applies force within the cylinder. No fluid force is applied against the end of the rod outside the cylinder. Only the surface area of the piston surrounding the rod applies force in the backward direction. Therefore, the pressure on the rod side of the cylinder is intensified by the force applied by the greater piston surface area on the side of the piston without the rod.

In the process analyzed herein, only a multiplication of force of 2 to 1 (or less) or a working fluid intensification volume of two to one is needed due to equalized pressure provided by the system design that will be shown herein later. Assuming the working fluid has a volume expansion ratio from the liquid phase at the condenser to the gas phase at the vaporizer of 15 to 1, then all of the additional volume of vapor being an intensification ratio of 13 is available to power the prime mover, such as a turbine driving an electrical generator or positive displacement piston powering a linear alternator, as power output (calculated as a working fluid volume expansion ratio of 15 within the vaporizer less a volume ratio of 2 volumes of vapor to 1 volume

of liquid needed to pump the liquid into the vaporizer equals a vapor ratio of 13 that remains as a net volume expansion ratio of the working fluid remaining for power output in this example).

The higher the volume expansion ratio of cold low pressure liquid from the condenser, which is expanded via heat input at the vaporizer into a greater volume of higher pressure vapor; the greater the net power output for this cycle, using positive displacement multiplication of power at equalized pressure that is able to be performed as a result of the ratio of fluid expansion within the vaporizer. This methodology also applies to a modified Brayton cycle wherein the expansion of gas within in a heater is sufficient to compress cooled, higher density vapor from a cooler back into the heater via multiplication of force at equalized pressure, having additional expansion remaining to produce power output.

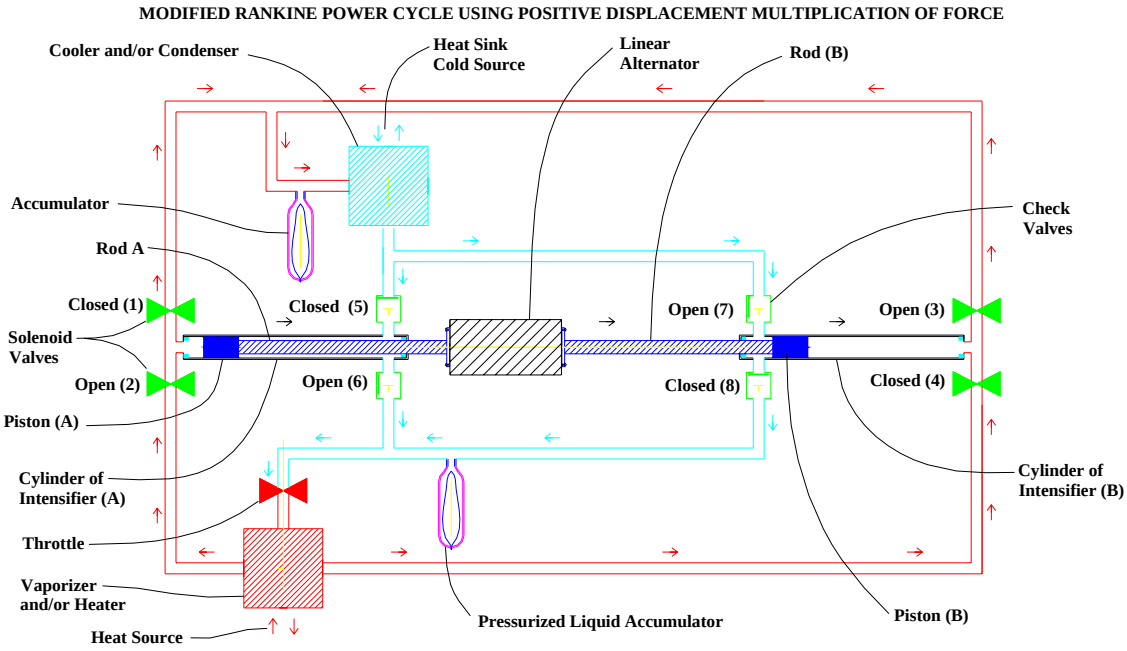
Only two state points need be analyzed because the operation of the power cycle forms a continuous back-and-forth reversal of these two states.

The working fluid used in this analysis is Honeywell brand refrigerant Genetron R245fa that has been specifically formulated for Rankine power cycles (See http://www.honeywell.com/sites/sm/chemicals/genetron/organicrank.htm and the Applications Development Guide at http://www.honeywell.com/sites/docs/doc19194b8-fb3ebd023d-3e3e4447ab3472a0c2a5e5fdc1e6517d.pdf to see the R245fa Thermodynamic Tables).

Both English and (SI) units are given in the analysis. Four different temperature ranges are analyzed: (1) 40 deg. F. (4.44 deg. C.) low temperature with 80 deg. F. (26.7 deg. C.) high temperature; and (2) 65 deg. F. (18.3 deg. C.) low temperature with 90 deg. F. (32.2 deg. C.) high temperature; and, (3) 110 deg. F. (43.3 deg. C.) low temperature with 165 deg. F. (73.9 deg. C.) high temperature; and, (4) 110 deg. F. (43.3 deg. C.) low temperature with 300 deg. F. (149 deg. C.) high temperature.

The above temperature ranges were selected because: (1) 40 deg. F. (4.44 deg. C.) low temperature with 80 deg. F. (26.7 deg. C.) high temperature is the temperature range of Ocean Thermal Energy Conversion (OTEC) technology; and, (2) a predecessor system was constructed and tested at the 65 deg. F. (18.3 deg. C.) low temperature with 90 deg. F. (32.2 deg. C.) high temperature; and, (3) the 110 deg. F. (43.3 deg. C.) low temperature with 165 deg. F. (73.9 deg. C.) high temperature is approximately the temperature range used by United Technologies Corporation (UTC) that is a refrigeration cycle run in reverse developed by their Carrier Air Conditioner division using an air conditioner compressor as the turbine that may be considered a competitor to the herein disclosed power cycle as its lowest high temperature capability; and, (4) 110 deg. F. (43.3 deg. C.) low temperature with 300 deg. F. (149 deg. C.) high temperature is the highest high temperature for which thermodynamic data is available for 245fa. The low temperature of 110 deg. F. (43.3 deg. C.) allows heat rejection to air and is thereby the temperature commonly used by many refrigeration and/or power cycles.

Drawing of State Point One



State Point One:

(1) Condenser @ 40 deg. F.:
Pressure – 9.5 psi
Liquid Density – 86.95 lb/ft3
Vapor Volume – 4.08070 ft3/lb

Vaporizer @ 80 deg. F.:
Pressure – 23 psi
Liquid Density – 83.29 lb/ft3
Vapor Volume – 1.7670 ft3/lb

Delta Pressure – 13.5 psi
Delta Temperature – 40 deg. F.

Intensification ratio – 153.64 to 1 (Expansion Ratio of Liquid Volume to Vapor Volume – 1 ft3 Liquid to 153.64 ft3 Vapor)

Intensified Force:
Gross Force – 3,533.72 lbs
Net Force – 1,424.36 (calculated as 3,533.72 lbs gross force; less 46 lbs liquid pumping force; less 2,082.36 lbs opposing force from condenser pressure; plus 19 lbs liquid force from condenser = 1,424.36 lbs of net power output force as described below)

The expansion ratio of liquid in the Condenser at 40 deg. F. having a density of 86.95 lb/ft3 into vapor within the Vaporizer at 80 deg. F. having a volume of 1.7670 ft3/lb is 153.64 to 1 (86.95 lbs X 1.7670 ft3 per pound = 153.64 ft3). One cubic foot of liquid from the Condenser at 9.5 psi

will vaporize into 153.64 cubic feet of vapor at 23 psi within the Vaporizer.

In the Drawing for State Point One, Intensifier A is connected to Intensifier B via connecting their rods together. Solenoid Valve #2 is open supplying vapor at 23 psi from the Vaporizer to Cylinder A of intensifier A. Assuming the surface area of the Piston A of Intensifier A on the side of Piston A without the rod is 153.64 times greater than the surface area of the opposite side of Piston A having Rod A because rod takes up nearly all the space on the rod side. The Rod B side of Intensifier A is filled with liquid phase working fluid from the Condenser. The length of Cylinder A is equal on both sides and the volume of vapor is 153.64 times greater (153.64 cubic feet) than the volume of the liquid (1 cubic foot) on the rod side as well. The liquid phase working fluid would have a pressure increase of 153.64 times being 3,533.72 psi (23 psi X 123.95 intensification ratio = 3,533.72 psi). Thereby, greater vapor volume is converted into an intensified substantially greater liquid pressure.

Check valve #6 is forced opened by the greater pressure exerted by the liquid (3,533.72) than the pressure exerted by the Vaporizer that only has a pressure of 23 psi. Obviously, 3,533.72 psi of pumping force is not needed to pump the liquid into the vaporizer through the Throttle that controls the rate of liquid flow into the Vaporizer. Assuming that only a liquid pressure of 46 psi (an intensification ratio of only 2 to 1 or 2 times 23 = 46) is needed to pump the one cubic foot of liquid back to the Vaporizer, then the remaining 3,487.72 pounds of force may be applied to the rod of intensifier A that is connected to Rod B of Intensifier B.

Rod A of Intensifier A is connected to the Rod B of Intensifier B and the net force of 3,487.72 pounds (3,533.72 – 46 = 3487.72) produced by intensifier A is thereby translated by Rod B to Piston B of Intensifier B. Cylinder B of Intensifier B on the side of the Piston B with no rod is filled with 23 psi vapor from the previous cycle. Solenoid valve #3 is open to the Condenser having a pressure of 9.5 psi that results in a flow of vapor from Cylinder B to the condenser that is expanded via the Prime Mover such as a turbine from 23 psi to 9.5 psi. As the vapor in Intensifier B flows into the Condenser and reduces in pressure, the force translated by Rod A to Rod B causes movement of both Piston A and Piston B in a direction to the right in the Drawing.

Rod A has a force of 3,487.72 pounds that is opposed by the pressure of 9.5 of the Condenser over 153.64 square inches of Piston B displacement that equals an opposing force exerted on Rod B of 2,028.14 lbs of force (153.64 intensification ratio times 9.5 Condenser Pressure = 2,028.14 lbs of force). Therefore there is a positive push of 2,028.14 pounds of force by Rod A in the direction to the right. This 2,028.14 pounds of force may is used to power a Linear Alternator connected in between Rod A and Rod B as shown or alternately (not shown) may be used to compress the vapor from Intensifier B through Solenoid Valve #3, through a Prime Mover, such as a rotary turbine connected to a generator or alternator in order to generate useful electrical power, and then into the Condenser to be cooled to 40 deg. F. and condensed back at 9.5 psi to the liquid phase.

In practice, connecting a linear alternator in between Rod A and Rod B that reciprocates back-and-forth to generate electrical power creates a much simpler and less expensive system and is the preferred embodiment of the technology. Additionally, the pressure drop of 13.5 psi (23 Vaporizer pressure less 9.5 Condenser pressure resulting in a pressure drop of only 13.5 psi) is so low that it would be difficult to operate a turbine with any degree of efficiency; therefore, a

positive displacement piston powering a linear alternator is most likely the most efficient option available for this temperature range as the desired amount of force required to be exerted on Rods A & B to power the linear alternator back-and-forth can be readily controlled by the displacement of the Piston A & B.

As Piston B moves to the right in the Drawing, liquid from the bottom of the Condenser fills the intensified side of Cylinder B that has Rod B thereby reducing its area by a ratio of 153.64 times less. The incoming one cubic foot of liquid from the Condenser is under 9.5 psi of pressure, but the surface area of the Piston B on the intensified side is nearly all taken up by Rod B and the positive force to help move to the right is only an additional 19 pounds of force (2 to 1 ratio) and is thereby negligible to the operation of the cycle, but partially offsets the 46 pounds of force needed to pump the liquid into the Vaporizer as previously described.

Note that the cycle provides equalized pressure. The pressure on both sides of Piston A within Cylinder A is 23 psi as both sides of Piston A are fluidly connected to the Vaporizer. Therefore only minimal additional pressure is needed to pump liquid from the intensified side of Cylinder A into the Vaporizer through open Check Valve #6. Likewise, both sides of Piston B within Cylinder B are fluidly connected to the Condenser having a pressure of 9.5 psi.

(2) Condenser @ 65 deg. F. (18.3 deg. C.):
Pressure – 16.8 psi (
Liquid Density – 84.69 lb/ft3 (
Vapor Volume -- 1.9471 ft3/lb (

Vaporizer @ 90 deg. F. (32.2 deg. C.):
Pressure – 28.1 psi (
Liquid Density – 82.34 lb/ft3 (
Vapor Volume -- 1.4636 ft3/lb

Delta Pressure – 13.5 psi

Delta Temperature – 40 deg. F.

Intensification ratio – 123.95 to 1 (Expansion Ratio of Liquid Volume to Vapor Volume – 1 ft3 Liquid to 123.95 ft3 Vapor)

Intensified Force:
Gross Force -- 3,483 lbs
Net Force – 1,310.84 (3,483 lbs gross force; less 56.2 lbs liquid pumping force; less 2,082.36 lbs opposing force from condenser pressure; plus 33.6 liquid force from condenser = 1,310.84 lbs of net power output force)

(3) Condenser @ 110 deg. F. (43.3 deg. C.):
Pressure – 40.7 psi
Liquid Density – 80.37 lb/ft3
Vapor Volume – 1.0254 ft3/lb (

Vaporizer @ 165 deg. F. (73.9 deg. C.):

Pressure – 98 psi
Liquid Density – 74.39 lb/ft3 (
Vapor Volume – 0.4309 ft3/lb

Delta Pressure – 57.3 psi

Delta Temperature – 55 deg. F.

Intensification ratio – 34.63 to 1 (Expansion Ratio of Liquid Volume to Vapor Volume – 1 ft3 Liquid to 34.63 ft3 Vapor)

Intensified Force:
Gross Force – 3,393.74 lbs
Net Force – 1,869.7 (3,393.74 lbs gross force; less 196 lbs liquid pumping force; less 1409.44 lbs opposing force from condenser pressure; plus 81.4 liquid force from condenser = 1,869.7 lbs of net power output force)

(4) Condenser @ 110 deg. F. (43.3 deg. C.):
Pressure – 40.7 psi
Liquid Density – 80.37 lb/ft3
Vapor Volume – 1.0254 ft3/lb (

Vaporizer @ 300 deg. F. (149 deg. C.):
Pressure – 480.5 psi
Liquid Density – 47.56 lb/ft3 (
Vapor Volume – 0.0568 ft3/lb

Delta Pressure – 440.43 psi

Delta Temperature – 190 deg. F.

Intensification ratio – 4.56 to 1 (Expansion Ratio of Liquid Volume to Vapor Volume – 1 ft3 Liquid to 4.56 ft3 Vapor)

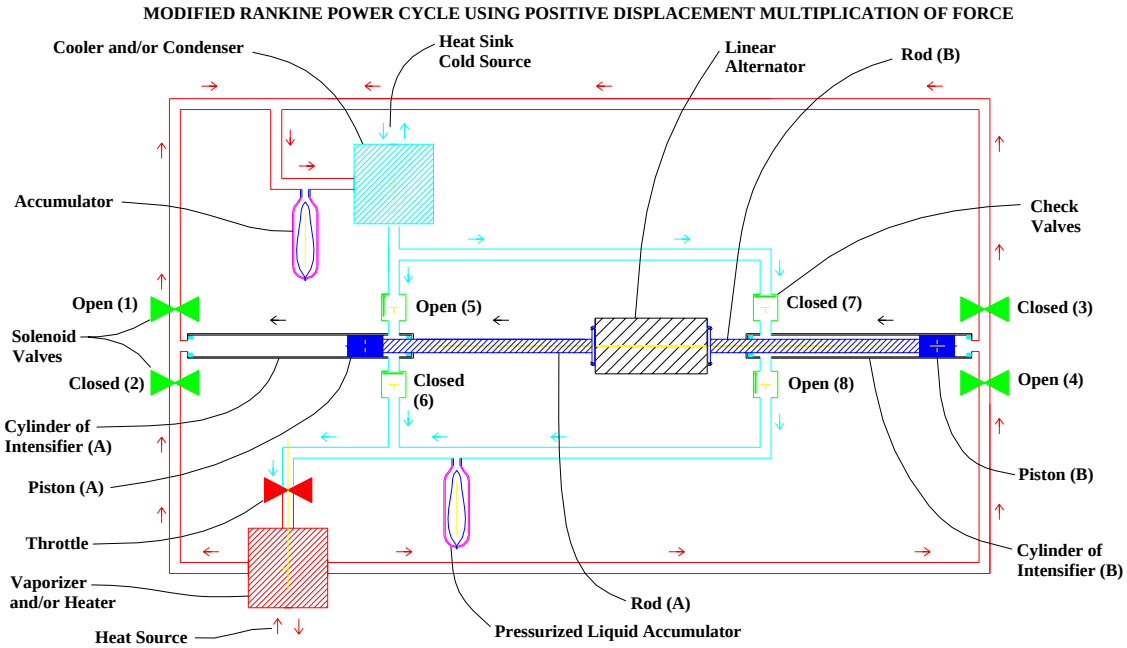
Intensified Force:
Gross Force – 2,008.36 lbs
Net Force – 943.17 (2,008.36 lbs gross force; less 961 lbs liquid pumping force; less 185.59 lbs opposing force from condenser pressure; plus 81.4 liquid force from condenser = 943.17 lbs of net power output force)

Note that the power output for this temperature range could be somewhat higher if less pressure is used to pump the liquid back to the vaporizer that has a pressure of 440.43 psi. For example, if 561 lbs of force is used to pump the liquid back to the vaporizer instead of 961 lbs of force than an additional 400 lbs of force will be added to the net force of 943.17 lbs that would increase the net force to 1,343.17 lbs of force.

State Point Two:

State Point Two is identical to State Point One only in the movement is in the opposite direction to the left instead of to the right as in State Point One. Higher-pressure vapor from the Vaporizer flows into Intensifier B through open Solenoid Valve #4. The force translated by Rod B to Rod A causes movement of both Piston A and Piston B in a direction to the left in the Drawing of State Point Two as the vapor in Intensifier A flows through open Solenoid Valve #1 into the Condenser and reduces in pressure. The intensified liquid on the Rod B side of Intensifier B is forced through open Check Valve #8 and flows through the Throttle to the Vaporizer to be vaporized into additional vapor in a cycle. Liquid from the Condenser is drawn into the intensified side of Cylinder A as Piston A moves to the left forming a Vacuum within the intensified side of Cylinder A having Rod A that reduces the area within the intensified side of Intensifier A.

Drawing of State Point Two



The determining factor to the overall power output of the cycle using multiplication of force is the expansion rate of the working fluid from lower pressure liquid phase at the condenser into higher pressure expanded vapor within the vaporizer via heat input and the Delta pressure differential. As can be seen above, the highest output of net power out put being 18.69.7 lbs of force to drive the linear alternator back-and-forth was produced by the middle temperature range of 110 deg. F. (43.3 deg. C.) low temperature with 165 deg. F. This provides a good case for low temperature power generation as compared with the highest temperature range of 110 deg. F. (43.3 deg. C.) low temperature with 300 deg. F. (149 deg. C.) high temperature that only produced a net power output of 943.17 lbs of force being less than half the power output of the lowest temperature range.

An additional big advantage of the use of multiplication of force at equalized pressure over the use of a liquid pump is its ability to process dual phase fluids due to positive displacement pumping.

The herein described cycle of multiplication of force at equalized pressure can readily be used as a modified Brayton cycle that remains solely in the gaseous phase with intensification of force used to compress vapor back into a heater, so long as the volume of the expanded higher pressure vapor when heated approaches or exceeds 2 to 1 as compared to the volume of the cooled vapor that is reduced in volume and pressure. Thermal energy is more efficiently used by the Brayton cycle because the latent heat of condensation and the latent heat of vaporization are not required. A much greater quantity of heat input is needed to perform vaporization than the quantity of heat needed for expansion of a working fluid by the use of sensible heat; and, then a much greater quantity of cooling is needed for heat rejection for condensation than is needed for contracting a fluid by sensible heat rejection cooling.

VII. Linear Power, Ltd. Test Unit Under Development

The unit being constructed in the photos below will replace the destroyed Hydraulic Thermal Engine formerly used to provide power and warm water for the fish farming, but will be much more powerful. It is more fully described as Linear C. above

The Linear Power Unit Pictured under Construction is described herein above as Linear B.

The linear power cycle will use propane as the working fluid. The temperature of the heat source geothermal water is 120 deg. F. and the cold-water heat rejection source is 90 deg. F. The calculated power output is 41 kW for a 300 gallon-- per minute flow rate.

VIII. Conclusion

The Linear Power Ltd. technology disclosed herein has the potential to solve one of the more persistent problems in geothermal power generation and harnessing the kinetic potential of high-pressure high flow rate natural gas wells– pressure change. For example if the Geysers geothermal field is going to remain a leading producer in the geothermal world, operators of the field need to find a new more advanced geothermal technology that can more efficiently utilize the substantially lowered and still falling steam pressures in addition to bringing more water to the reservoir. Obviously, it would also be more advantageous if this new technology could also produce electrical power at a lower cost. The Linear Power Ltd. technology provides a solution to the Geysers problems because the technology is not pressure dependant and returns the water to the reservoir.

The Linear Power, Ltd. technology employs an advanced linear alternator that entirely eliminates “cogging” and substantially reduces “loading”, which is a very significant improvement over prior art permanent magnet generators and alternators that greatly enhances the ability to harness low temperature renewable energy resources.

Further, there is a tremendous opportunity to use Linear Power Ltd.’s proprietary technology that has much lower costs than conventional geothermal technology to exploit the large-scale need for electrical power by agriculture and aquaculture landowners and business owners who have low temperature geothermal resources lying below their property at shallow depths. (they are literally standing on potential income). Obviously, drilling to greater depths increases the costs, however, existing deep wells in Texas, Oklahoma, Louisiana, Mississippi, Arkansas, and the rest of the world may be used to power low and high temperature geothermal electrical power generation with extremely attractive economics.

Development of a mature gas and oil well power generation program will act to insure investors in drilling programs that they can get a payback over time from the heat energy of the earth even if they are not successful in striking petroleum reserves – there in essence will be no more dry holes. Every well drilled will be able to generate a revenue stream.

ROBERT D. HUNT

Theoretical Physicist / Inventor

Robert D. Hunt began his design and engineering career in 1969 as a New Nuclear designer for Newport News Shipbuilding, then a division of Tenneco Oil Company, where he designed nuclear reactor components for the U.S.S. Nimitz Aircraft Carrier.

Mr. Hunt became a private inventor during the mid-1980s while involved in the field of aquaculture. His firm the Redfish Hatchery was the first commercial company to successfully spawn redfish. For the aquaculture community, he invented and patented a cryogenic liquid oxygen system that pumps water via gas-lift using pure oxygen gas that simultaneously supersaturates oxygen into the water to support high-density fish culture. This was Mr. Hunt's first patent in 1986; and, his oxygen-lift system has become the standard of the aquaculture industry today. He has since dedicated his time to the development of his proprietary alternative, clean-energy generating technologies focused on low temperature power generation.

Mr. Hunt is the inventor of the GravityPlane that can fly without the use of fuels by creating an Atmospheric batch power cycle to control buoyancy using the thermal energy in the air near the earth as the energy source and rejecting heat to cold air at substantial height in order to accomplish fuel-less flight (See www.fuellessflight.com). In association with the GravityPlane he created a revolutionary new design vertical axis wind turbine that harnesses the wind's energy by the use of both drag and lift the employs Delta drag – the unit opens to create high drag to harness the kinetic energy of the wind then closes to go into the wind with minimal drag, while also creating lift.

Mr. Hunt is the inventor of the thermoelectric generator; and, his device has successfully generated power from the heat energy in the air with thermoelectric modules, using the stored solar thermal energy contained in the atmosphere as the energy source with heat rejection to cryogens at temperature ranges in the hundreds of degrees below freezing. In the process of vaporizing cryogens, electrical power is generated from stored solar thermal energy contained in air surrounding us.

Mr. Hunt has also invented a refrigeration cycle that uses the natural refrigerants air and water as the working fluids in the same manner as the earth does that is capable of producing either heat or cooling. The cycle works like an evaporative cooling unit that evaporates water to provide cooling, but is operated as a closed cycle -- with air being a pressure equaling gas to cause evaporation of the water at lower temperature. Because there are no harmful refrigerants used, one university has stated that Mr. Hunt's refrigeration may be the only form of refrigeration that is allowed at some future date.

Mr. Hunt began work on devices to harness the kinetic energy of natural gas wells in 1998; and, he has gained extensive experience in the design, construction, and use of both rotary and linear high-pressure equipment in the field. He is the inventor of the drum jet turbine and is the founder of Linear Power Ltd. that manufactures an innovative new line of linear power equipment designed to harness the kinetic energy of natural gas wells and geothermal resources.

Mr. Hunt is considered one of the leading authorities in low temperature power generation; and, he serves as an ocean thermal energy conversion (OTEC) intellectual property consultant to the Abell Foundation, Baltimore, MD, which has the goal of

producing power from the stored solar thermal energy within the world's oceans -- principally for island nations.

Mr. Hunt is the author of a number of published technical papers; and, he has made numerous conference presentations in the fields of Aquaculture, Aviation, and in Geothermal Power Generation.

News articles have been published regarding Mr. Hunt's inventions in almost every country in the world – most notably the GravityPlane that was recently featured in two of Japan's largest magazines during the same month. Mr. Hunt is a member of the American Institute of Aeronautics and Astronautics (AIAA), a member of the National Business Aviation Association, a member of the National Hydrogen Association, and he served as the first Chairman for the State of Mississippi for the Gulf of Mexico Program as an advisor to the EPA. Mr. Hunt received his degrees from colleges in the Mississippi State.

Prof. Efstathios E. (Stathis) Michaelides

A graduate of Oxford (B.A. Engineering Science and Economics, 1977) and Brown Universities (M.S. Engineering Science, 1979, Ph. D. Engineering Science, 1980), Professor Stathis Michaelides is currently the Leo S.Weil Professor of Mechanical Engineering. As of December 2002 Dr. Michaelides is the director of the South-Central Center of the National Institute for Global Environmental Change.

From 1992 to 2003 Professor Michaelides served as the Associate Dean for Graduate Studies and Research in the School of Engineering at Tulane University. During his tenure as Associate Dean, the number of graduate students of the School of Engineering increased by more than fifty percent and the outside research support more than tripled. From 1996 to 2003 he secured more than three million dollars in Graduate Fellowships support for the School of Engineering. He also served in the past as Head of the Mechanical Engineering Department at Tulane (1990 to 1992) and, on the faculty of the Mechanical Engineering of the University of Delaware (1980 to 1990). Professor Michaelides has also had temporary visiting appointments with: the Centre Nacionale de la Recherche Scientifique, Paris, France (Spring 1987, Summer 1989 and Summer 1995); the Universidad Complutensis, Madrid, Spain (Fall 1989); the Escuela Tecnica Superior de los Ingenieros Industriales Madrid, Spain (Fall 1989); the Université Claude Bernard, Lyon, France (Summer, 1997); the Aristotelion University of Thessaloniki, Greece (Fall 1997); and the Ecole Superior de Physique et Chimie Industrieles, Paris, France (Summer 2002).

Professor Michaelide's research interests are in the areas of Multiphase Flows, Environmental Flows, Energy Conversion and Conservation. He has published more than ninety journal articles, has edited twelve research volumes and made more than one hundred and twenty scientific presentations in Conferences. For his educational and scholarly work in 2002 he received the ASME Freeman Scholar Award, which is awarded biennially for achievements in the area of Fluids Engineering. He was also awarded an honorary M.A. degree from Oxford University (1983); the Casberg and Schillizzi Scholarships at St. Johns College, Oxford; the ASME/Phi,Beta,Tau excellence in teaching award (1991 and 2001); the Lee H. Johnson award for teaching excellence (1995); and a Senior Fulbright Fellowship (1997).

Professor Michaelides is currently serving in the executive committee of the ASME-Fluids Engineering Division. Prior to this he has chaired (1996-1998) the Multiphase Flow Technical Committee. He also served as the President of the ASEE Gulf-South Region (1992-93). In 1998 he was elected to the Governing Board for the International Conference on Multiphase Flows for a six-year term (1998-2004) as one of four delegates from America and in 2001 he chaired the 4th International Conference on Multiphase Flows, which took place in New Orleans from May 27 to June 1, 2001. He was the vice-chair of the 5th International Conference on Multiphase Flows that took place in Yokohama, Japan on May 2004.