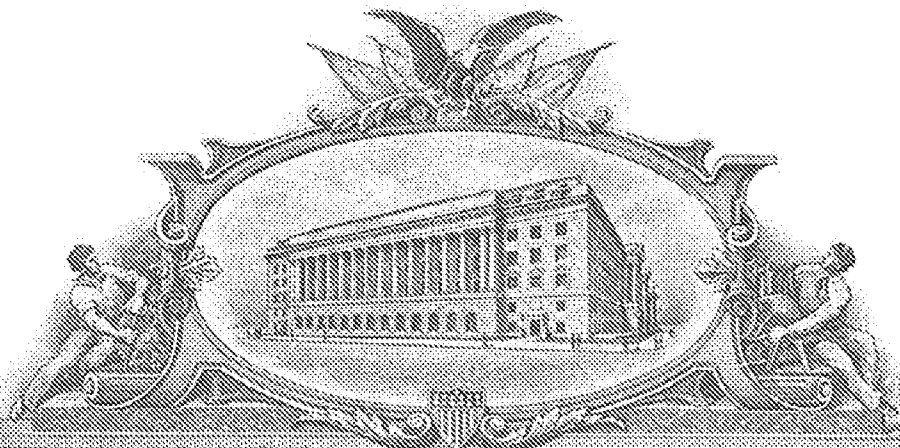


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FOUNDATION PIERS FOR AXIAL SOLAR ARRAYS AND RELATED SYSTEMS AND METHODS**BACKGROUND**

- [001] Solar energy is the world's largest source of untapped energy. At sea level, the usable energy density is approximately 250 watts per square meter. Using a two-dimensional model to approximate the earth, approximately $250 \text{ watts/square meter} \times \pi \times 6,371,000 \text{ meters}^2$ equals approximately 32,000 terra (trillion) watts of energy strikes the earth at any particular moment. Given that the sun will continue to supply this energy for billions of more years, the survival of human life will ultimately depend on harnessing this essentially unlimited, clean energy source.
- [002] As in any industry, achieving scale is critical to maximizing the competitiveness of solar relative to other energy sources. This economic reality militates in favor of large-scale (multi-megawatt to multi-gigawatt) solar power plants over residential solar, although there is room for both modalities in the market place. Large-scale solar power plants are predominantly configured as either fixed-tilt or single-axis tracker arrays. Fixed-tilt arrays are arranged as East-West oriented rows of panels tilted South at an angle dictated by the latitude of the array site. By contrast, single axis trackers are rows of solar panels arranged on a rotating North-South axis called a torque tube that sweeps through an East to West rotation through the course of the day, following the sun's progression through the sky. For purposes of this disclosure, both fixed-tilt and single axis trackers will be referred to collectively as axial solar arrays.
- [003] Many large-scale solar projects are funded with so-called power purchase agreements (PPAs), whereby a customer agrees to purchase the power generated by the array at a predetermined megawatt hour rate (e.g., \$25-35 per megawatt hour at today's prevailing rates). Knowing the lifetime of the array (e.g., 35-40 years), a bank or other investor will be comfortable financing such a project given the predictable stream of revenue the array will generate over its lifetime.
- [004] Excluding land acquisitions costs, overall project costs typically include site preparation (road building, leveling, grid and water connections etc.), foundation piers, tracker hardware or fixed-tilt hardware, photovoltaics, inverters and electrical (conduit, wiring,

trenching, etc.). Inherent in all of these are also labor costs. At today's prevailing rates, this totals about \$1 per watt of energy. So, building a 100-megawatt solar power plant today would cost approximately \$100,000,000 dollars.

- [005] Many of these system component costs have dropped over the past few years, in particular solar panels and solar mounting hardware, however, one area that has been mostly overlooked is the cost associated with foundation piers. These structures physically couple solar trackers or fixed-tilt solar arrays to the earth. Typically, after the site has been prepped, a grid of H-piles or other structures are driven into the ground at regular intervals and other components are subsequently attached to those piles. In a conventional, large-scale single-axis tracker array, these piers will typically represent 5-7 percent of the cost of installing an array. Despite this relatively small share of the total array cost, any savings in steel and labor associated with foundation piers will amount to a significant amount of money over a multi-gigawatt portfolio of solar power plant projects. This is particular true in the solar power plant business because many of these deals are locked in years before the installation costs are incurred. Therefore, the savings will be in addition to profits already factored in the calculations that supported the PPA. Reducing steel and associated labor costs used in foundation piers is the object of this application.

DESCRIPTION

- [006] Contrary to conventional single I or H pier foundations, with an A-frame style foundation, lateral wind forces tend to pull out the windward frame member and to compress or buckle the leeward frame member. Therefore, increasing resistance to pull out and compression in such arrays can allow installations to go less deep into the ground with their support members relative to I and H pier foundations, saving money in steel and other materials as well as time.
- [007] FIG. 1 shows components of a system for constructing a foundation pier for an axial solar array according to at least one exemplary embodiment of the invention. In this exemplary embodiment, the system comprises an elongated mandrel having an insertion tip end and a driving end with a driving head. In various embodiments, the

insertion tip end will have a substantially uniform geometry and outside diameter spanning the length of the mandrel up to the point where the larger driving head begins. The mandrel is elongated with a uniform cross section from the insertion tip to the driving head with a channel formed on at least one face running substantially the entire length as seen in the second image of FIG. 1.

[008] In the embodiment shown in this FIG, a recess is formed near the insertion tip. The recess is designed to receive an insert portion that alters the uniformity of the cross section of the mandrel after it has been inserted all the way through a foundation or support pier (labeled support beam in the Figure), closing a channel present in the pier. In particular, it fills in the channel formed in the mandrel.

[009] As shown, a section of Unistrut or C-channel is used as the support beam, although it should be appreciated that other shapes may be used with the various embodiments of the invention, including an elongated C, Sigma or even a closed box cross-section. The support beam in this embodiment has a series of windows located at regularly spaced intervals over at least a portion of its length on one face, preferably closest to the end that is driven into the ground. Inside each window resides an anchor tab member that is pre-formed to point upward in the direction of the main axis of the beam before the beam is installed. The corresponding channel formed in the mandrel allows it to be inserted into the beam and to pass by the tabs without bending or altering their orientation. This is shown in greater detail in FIG. 2.

[010] The first image of FIG. 2 shows the mandrel tip being mated with the open end of a section of a support beam. In various embodiments, the beams are pre-cut into uniform lengths and the mandrel is slightly longer, allowing access to the recess after the mandrel has been inserted into the pier, prior to driving. In this embodiment, the tip is inserted so that the channel formed in the mandrel faces the anchor tabs and windows pre-formed in the beam.

[011] In various embodiments, width W of the insertion end of the mandrel is slightly smaller than the inside width of the support beam, allowing it enter the beam smoothly. The second image of FIG. 2 shows how the anchor tabs fit into the channel, allowing the

mandrel to be inserted lengthwise into the beam until the larger diameter driving head strikes the top of the beam without disturbing the anchor tabs. Once the mandrel has been fully inserted to the point where the beam hits against the larger diameter driving head of the mandrel (e.g., third image of FIG. 3), the insertion tip will be projecting out of the bottom end. In various embodiments, while holding the beam flush against the driving head, or at least high enough up to reveal the recess, the insert is slid into place, thereby preventing the beam from separating from the mandrel, at least under its own weight prior to insertion into the earth.

- [012] It should be appreciated that in various embodiments, an actuator or other device may be used in place of the insert to cause a pin, bar, protrusion or other structure to extend into the channel after the mandrel is fully inserted. This could be done with a hydraulic actuator or other device. In still further embodiments, a spring loaded pawl or other structure could be formed in the mandrel tip that can be easily compressed into the mandrel during insertion, but that once the bottom of the beam has been cleared, it will not compress in the other direction. These types of pawls are frequently used to allow one-way access to parking lots or other areas where it is desirable to control the direction of traffic by positioning so that they easily fold over when pushed from one side but stand firm when pushed from the other side, puncturing the tires of any vehicle driving over them. This would allow relatively easy insertion of the mandrel into the beam but prevent the beam from being removed without engaging the anchor tabs on the way out.
- [013] Once the mandrel and beam assembly is configured, it is ready to be driven into the ground. In various embodiments, this may be accomplished by applying a large downward force to the mandrel. In various embodiments, this force could be steady pressure. In other embodiments, it could be a series of impacts, vibration, or some combination of these forces. In some embodiments, one type of force may be used until the assembly will no longer go in, at which point a different force may be applied. For example, if during driving with steady pressure sub-surface rock is encountered that opposes and/or prevents further driving with the steady pressure force, a hammering

force may be employed in an attempt to break up and/or drive through the sub-surface rock. In various embodiments, this will cause the entire mandrel/beam assembly to enter into the ground until a desired depth has been reached. This is seen best in FIG. 4. It should be appreciated that the specific machine used to drive the mandrel has been intentionally omitted from this Figure. In various embodiments, a special-purpose machine may be used. In other embodiments, it may be done using a piece of multi-purpose equipment (e.g., excavator, skid steer loader, back hoe, tractor, pile driver, etc.) with or without a special-purpose attachment.

- [014] In various embodiments, once the desired depth has been achieved, an opposite pulling force may be applied to the head of the mandrel. This could be done with the same piece of equipment used to drive the mandrel/beam assembly into the ground or with another device specifically made for pulling. Also, it should be appreciated that although the mandrel/beam assembly are shown as being driven into the ground perpendicularly, in certain embodiments, it may be desirable to drive the mandrel/beam assembly into the ground at an angle with respect to normal (i.e., greater than or less than 90 degrees). In general, the upward pulling force required to remove the mandrel should be much less than the force required to insert the mandrel and beam assembly into the ground.
- [015] When the upward pulling force is applied to the mandrel it will attempt to move upward within the beam. In various embodiments this will cause the insert or other structure near the mandrel tip to engage each anchor tab portion as it passes by, rotating it outward through its corresponding window by approximately 90 degrees, thereby setting the anchor tabs into the surrounding earth. Once the mandrel has been completely removed, the foundation pier will look similar to the side sectional view shown in the third image of FIG. 4. The plurality of set anchor tabs should increase the resistance to pullout forces relatively to the beam before the anchor tabs are set, allowing the beam to have the same pullout resistance as a conventional beam but without needing to be driven as far into the ground, thereby saving money on time and steel.

- [016] In the exemplary embodiment shown in FIGs. 1-4, each time a new beam is driven, the insert must be removed before inserting the mandrel into another beam. In various embodiments, it may be desirable to have the entire tip be detachable so that if the tip is damaged by hitting a rock or other solid object, a replacement tip may be added without discarding the entire mandrel. Also, the relatively small size of the insert may make it likely to get lost or fall into cracks or holes in the earth.
- [017] To compensate for these issues, FIGS. 5A and 5B show two alternative embodiments, where the entire mandrel bit tip is detachable. In 5A, the tip portion has a pair of tabs that fit into corresponding recesses formed in the mandrel end. Once inserted, a screw, pin or other fastener is forced through the outside of the mandrel to engage openings in the tabs. If separate fasteners are used on each side of the mandrel, the openings in the tabs may be threaded. Alternatively, if a single fastener passes through the entire mandrel and the openings in the tabs, threads may only be used in the mandrel itself. In still further embodiments, a bolt may be passed through the mandrel and tabs and come out the other side where a nut is torqued down on the free end, or a cotter pin or other device is driven through it without requiring any threading of the mandrel openings or tab openings. In various embodiments, the openings in the outer face of the mandrel may be countersunk to minimize resistance to driving.
- [018] 5B shows yet another embodiment where the tip and mandrel may be selectively coupled quickly and without using any tools. In this embodiment, the tip has a projection with a unique geometry that is inserted into a reciprocal opening formed in one face of the mandrel. In various embodiments, the projection is inserted into an opening formed in the mandrel, near its end, with the tip portion oriented orthogonal to the axis of the mandrel. It is then slid down the opening with the wider portion of the T of the projection, trapped in a channel internal to the mandrel until it "bottoms out" as is rotated downward to be aligned with the axis of the mandrel (i.e., it points downward). In various embodiments, the bottom portion of the mandrel may be rounded over to allow the detachable tip to rotate downward. This tool-free connection

should allow for rapid connect and disconnect between driving each beam and also provide for relatively cost-efficient replacement of lost or damaged tips.

- [019] It should be appreciated that various other known mechanisms may be employed to allow the tip to be detached without requiring tools including spring loaded connectors, a threaded connection with the mandrel, electromagnet or other known means. The majority of the forces experienced by the tip during insertion and removal will be axial, allowing more options for this interconnection.
- [020] It should also be appreciated that although the various embodiments of the invention have been shown and described as being driven into the ground individually, in order to speed up installation time, it may be desirable to drive a pair of support beams in the ground at the same time and at angles to one another. In various embodiments, this may be accomplished by a machine with a pair of parallel driving mechanisms, each with their own mandrel, that can be used to simultaneously or substantially simultaneously drive two foundation piers into the ground.
- [021] FIG. 6 illustrates one exemplary embodiment of a machine for driving a pair of foundation piers at substantially the same time according to various embodiments of the invention. In various embodiments, the machine may include a pair of articulating hydraulic arms connected to a driver (e.g., hammer, pusher, vibrating hammer, etc.) that can be controlled to automatically drive a pair of adjacent foundation piers into the ground at independent angles. In various embodiments, each or both articulating arm may be operated by a human operator. In other embodiments, they may function according to a computerized numeric control (CNC) system that causes the machine to drive piers at a desired angle and with desired spacing between adjacent piers.
- [022] In various embodiments, each arm will have its own mandrel that is loaded with a corresponding beam or foundation pier by a human operator prior to driving. The machine itself may have a box, bed or other structure for transporting a plurality of piers to reduce the required reload time. Also, as shown, this machine is on a pair of chain belt tracks, but it should be appreciated that the machine may be on tires and may be towed behind or attached to another standard piece of equipment.

- [023] Also, it should be appreciated that the machine shown in FIG. 6 is exemplary only. In other embodiments, the driving mechanisms could be fixed at a desired angles relative to normal and desired spacing with each driving mechanism operable to rotate as a single objection to preserve the relative angles and spacing when installing on a sloped grade.
- [024] FIG. 7 is a flow chart detailing the steps of a method of driving foundation piers according to various embodiments of the invention. The method begins by inserting a mandrel into a support beam. As discussed herein, in various embodiments, the beam may have a cross-sectional shape that is dimensioned to receive and capture the mandrel so that once fully inserted, the mandrel and beam assembly may move in the axial direction as a single object. Also, in various embodiments, the beam may have one or more anchor tab features pre-formed in it that are in an un-set position before receiving the mandrel and that remain in that position during driving.
- [025] After the mandrel has been fully inserted in the beam (e.g., when the top of the beam hits the larger diameter driving head), the insertion tip is adjusted to support the beam under its own weight and also to engage the insert or projection that will set each anchor tab when the mandrel is removed. In various embodiments, this may consist of installing an insert into a corresponding recess formed in the tip to alter the cross-section of the mandrel tip. In other embodiments, this may involve actuating a hydraulically controlled projection to extend closing a portion of a channel formed in the mandrel near the tip. In still other embodiments, this may comprise attaching a tip to the end of the mandrel, with or without the assistance of tools. In embodiments where a pawl or other similar device is used, this step may be performed automatically once the pawl emerges from the open end of the beam.
- [026] Next, the mandrel and beam assembly is driven into the earth. As discussed herein, this may comprise applying a steady downward force along the desired vector of insertion. In other embodiments this may comprise applying a hammering force, vibration or some combination of these. In other embodiments, the mandrel and beam assembly may be driven with a default driving method (e.g., steady downward force) until driving

is impeded, such as, for example when a rock or other hard object is encountered. In various embodiments, this may cause the driving mechanism to switch to another mode, such as, for example, hammering in an attempt to break through the rock impeding the assembly's progress.

- [027] Next, once the assembly has been driven to the desired depth, the mandrel will be backed out. In various embodiments, this involves applying a pulling force to the mandrel to back it out of the support beam, leaving the beam behind. In various embodiments, it may be desirable to stabilize the beam so that the axial pulling force does not also back out the beam. In various embodiments, backing out the mandrel will cause an insert, projection, pawl or other feature to engage one or more anchor tabs formed in the beam so that they are forced by contact from an unset position to a set position where they project outward, substantially perpendicular to the beam's main axis into the surrounding earth.
- [028] It should be appreciated that this process may occur in parallel, that is by a single machine, that is driving a pair of support beams into the ground at substantially the same time. Also, the process may be repeated, such as, for example, at the next desired support location in that row, or in another row of an axial solar array site.

CLAIM SET 1:

1. A system for installing foundation piers for an axial solar array comprising:
 - an elongated foundation pier member having a plurality of windows and plurality of anchor tabs, one formed in each window;
 - a mandrel having a first insertion end with a first outside diameter, and a second driving end having a second, relatively larger outside diameter, wherein the first insertion end of the mandrel fits into a channel formed within the elongated foundation pier without altering an orientation of the plurality of anchor tabs up to the point where the second relatively larger outside diameter driving end strikes an open end of the foundation pier;
 - a projection near a tip of the first insertion end, the projection expanding a cross sectional profile of at least a portion of the first insertion end, wherein removal of the mandrel from the foundation pier causes the project to contact each anchor tab, pressing it through the window, thereby setting each anchor tab in the surrounding earth; and
 - a driving mechanism, the driving mechanism operable to drive the mandrel and pier into the earth at a predetermined angle relative to normal, and to withdraw the mandrel from the pier after a desired driving depth has been achieved.
2. The system of claim 1, wherein the elongated foundation pier member is made of steel and has an open C-shaped cross section.
3. The system of claim 1, wherein the elongated foundation pier member is made of steel and has a closed rectangular cross section.
4. The system according to claim 1, wherein the projection is an insert that is placed in a corresponding recess formed in the mandrel after the mandrel is inserted into the foundation pier.
5. The system according to claim 1, wherein the projection is actuated from a first recessed position to a second extended position after the mandrel is inserted into the foundation pier.
6. The system according to claim 1, wherein the projection is a pawl that springs away from the plurality of anchor tabs when the mandrel is inserted into the foundation pier and that remains rigid when the mandrel is removed from the foundation pier, thereby engaging each of the plurality of anchor tabs, causing them to push outward into the surrounding earth.
7. The system according to claim 1, wherein the projection is a detachable tip that is attached to the mandrel after the mandrel is fully inserted into the foundation pier.
8. The system according to claim 1, wherein the driving mechanism applies a substantially continuous axial force to the mandrel.
9. The system according to claim 1, wherein the driving mechanism applies a hammering force to the mandrel.
10. The system according to claim 1, wherein the driving mechanisms applies a vibratory force to the mandrel.

11. The system according to claim 1, wherein the driving mechanism applies a first force to the mandrel until insertion is impeded and then applies a second force to the mandrel to overcome the impedance.

CLAIM SET 2:

12. A method of constructing foundation piers to support an axial photovoltaic array comprising:
 - inserting a first insertion end of a mandrel into a pre-cut section of steel foundation pier up to a point where an outside diameter of the mandrel is greater than an inside diameter of the steel foundation pier;
 - actuating a projection near a free end of the insertion end of the mandrel protruding from the foundation pier;
 - driving the mandrel and foundation pier into the ground at a desired angle and to a desired depth with a driving mechanism; and
 - after achieving the desired depth, removing the mandrel from the foundation pier by applying an axial pulling force to the mandrel, wherein as the mandrel is removed, the projection contacts a plurality of anchor tabs formed in the foundation pier, causing them to bend outward into the surrounding earth via windows framing each tab.
13. The method of claim 12, wherein removing the mandrel further comprising placing a retaining mechanism on the section of foundation pier to prevent it from being pulled out of the earth by the axial pulling force applied to the mandrel.
14. The method according to claim 12, wherein actuating the projection comprises an insert that is placed in a corresponding recess formed in the mandrel after the mandrel is inserted into the foundation pier.
15. The method according to claim 12, wherein actuating the projection comprises actuating the projection from a first recessed position to a second extended position after the mandrel is inserted into the foundation pier.
16. The method according to claim 12, wherein actuating the projection comprises attaching a pawl to the mandrel before inserting it into the foundation pier, wherein the pawl that springs away from the plurality of anchor tabs when the mandrel is inserted into the foundation pier and that remains rigid when the mandrel is removed from the foundation pier, thereby engaging each of the plurality of anchor tabs, causing them to push outward into the surrounding earth.
17. The method according to claim 12, wherein actuating the projection comprises attaching a detachable tip to the mandrel after the mandrel is fully inserted into the foundation pier, the detachable tip altering a portion of the mandrel cross-section.
18. The method according to claim 12, wherein the driving the mandrel and foundation pier comprises applying a substantially continuous axial force to the mandrel.
19. The method according to claim 12, wherein driving the mandrel and foundation pier comprises applying a hammering force to the mandrel.
20. The method according to claim 12, wherein driving the mandrel and foundation pier comprises applying a vibratory force to the mandrel.
21. The method according to claim 12, wherein driving the mandrel and foundation pier comprises applying a first force to the mandrel until insertion is impeded and then

applying a second force to the mandrel to overcome the impedance, wherein the second force differs from the first force by more than just a magnitude of the force.

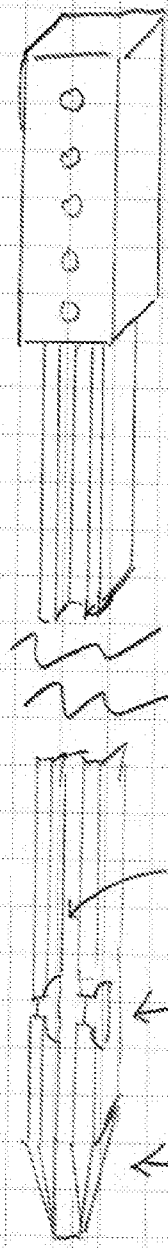
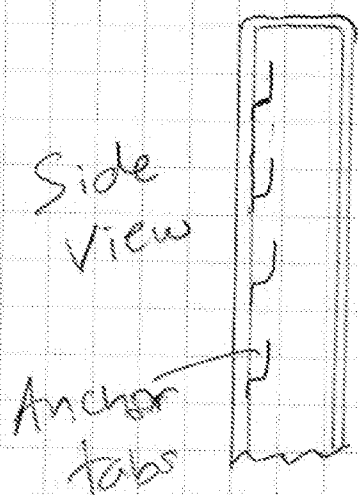
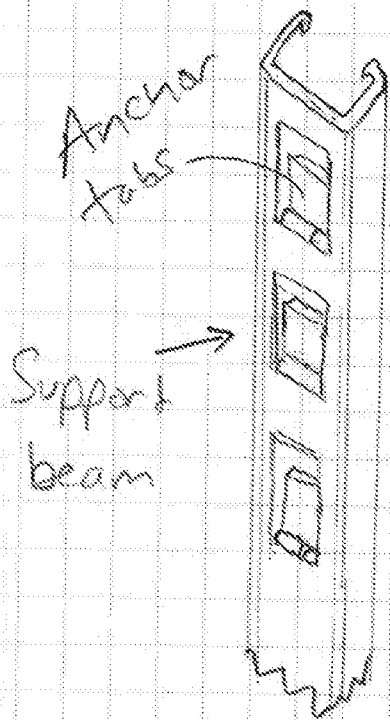
CLAIM SET 3:

22. A machine for installing foundation piers for an axial solar array comprising:
 - a chassis;
 - a drive mechanism attached to the chassis;
 - at least one mandrel comprising an elongated member having a first insertion end and a second driving end, the insertion end having a first outside diameter and the second driving end having a second, relatively larger outside diameter, the driving end coupled to the drive mechanism;
 - an actuatable projection near the first insertion end, wherein after driving a foundation pier into the ground with the mandrel, the actuatable projection adjusts a cross-sectional profile of the mandrel, causing at least one anchor tab formed in the foundation pier to push outward into the surrounding earth when the mandrel is pulled out.
23. The machine according to claim 22, further comprising a control mechanism operable to control a driving angle of the drive mechanism.
24. The machine according to claim 22, wherein the drive mechanism applies a substantially continuous driving force to the mandrel.
25. The machine according to claim 22, wherein the drive mechanism applies vibration to the mandrel.
26. The machine according to claim 22, wherein the drive mechanism applies a hammering force to the mandrel.
27. The machine according to claim 22, wherein the drive mechanism applies a first force to the mandrel until driving is impeded, and then applies a second force to the mandrel to overcome the impedance, the second force differing from the first force by more than just its magnitude.
28. The machine according to claim 22, further comprising a pair of parallel drive mechanisms and a pair of mandrels wherein each drive mechanism and mandrel are operable to independently drive a foundation pier into the ground at substantially the same time.
29. The machine according to claim 22, wherein the actuatable projection comprises an insert that is placed into a corresponding recess near a top of the mandrel after the mandrel is inserted into a foundation pier.
30. The machine according to claim 22, wherein the actuatable projection comprises a projection that may be actuated from a first recessed position to a second extended position after the mandrel is inserted into the foundation pier.
31. The machine according to claim 22, wherein the projection comprises a pawl that springs freely in one direction and remains ridged in an opposing direction.
32. The machine according to claim 22, wherein the pawl springs freely when the mandrel is inserted into the foundation pier by contact with at least one tab formed in the foundation pier remains ridged when the mandrel is removed from the foundation pier,

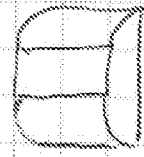
thereby engaging the at least one anchor tabs, forcing it to push outward into the surrounding earth.

33. The machine according to claim 22, wherein the actuatable projection is a detachable tip that is attached to the insertion end of the mandrel after the mandrel is fully inserted into the foundation pier.
34. The machine according to claim 33, wherein at least a portion of the detachable tip has a larger cross section than the insertion end of the mandrel, the portion with the larger cross section causing at least one anchor tab formed in the foundation pier to push outward into the surrounding earth when the mandrel is pulled out of the foundation pier.
35. The machine according to claim 22, further comprising an gripping portion, selectively engagable to grip the foundation pier when the mandrel is removed to prevent it from moving.

FIG. 1



Driving head



Insert

Mandrel

channel

Tip opening

Tip of mandrel

FIG. 2

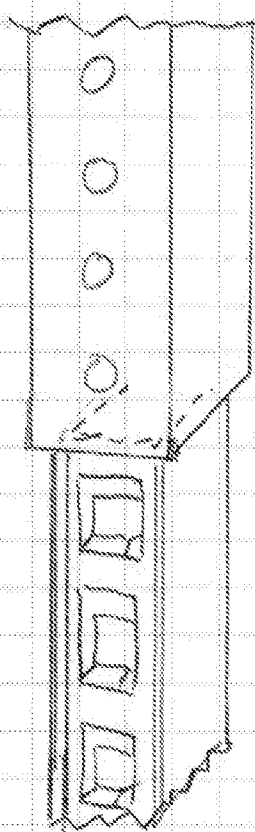
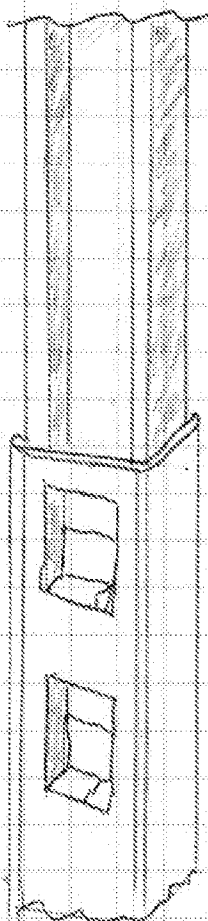
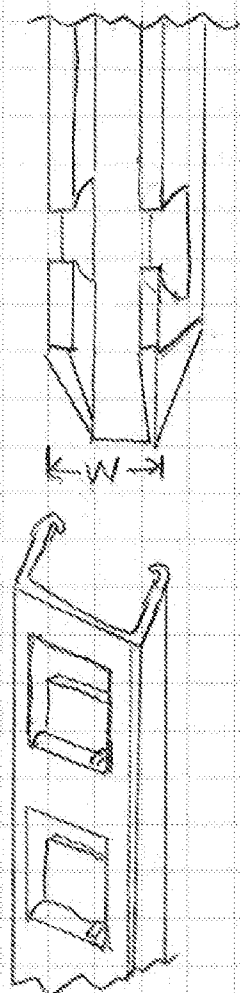


FIG. 3

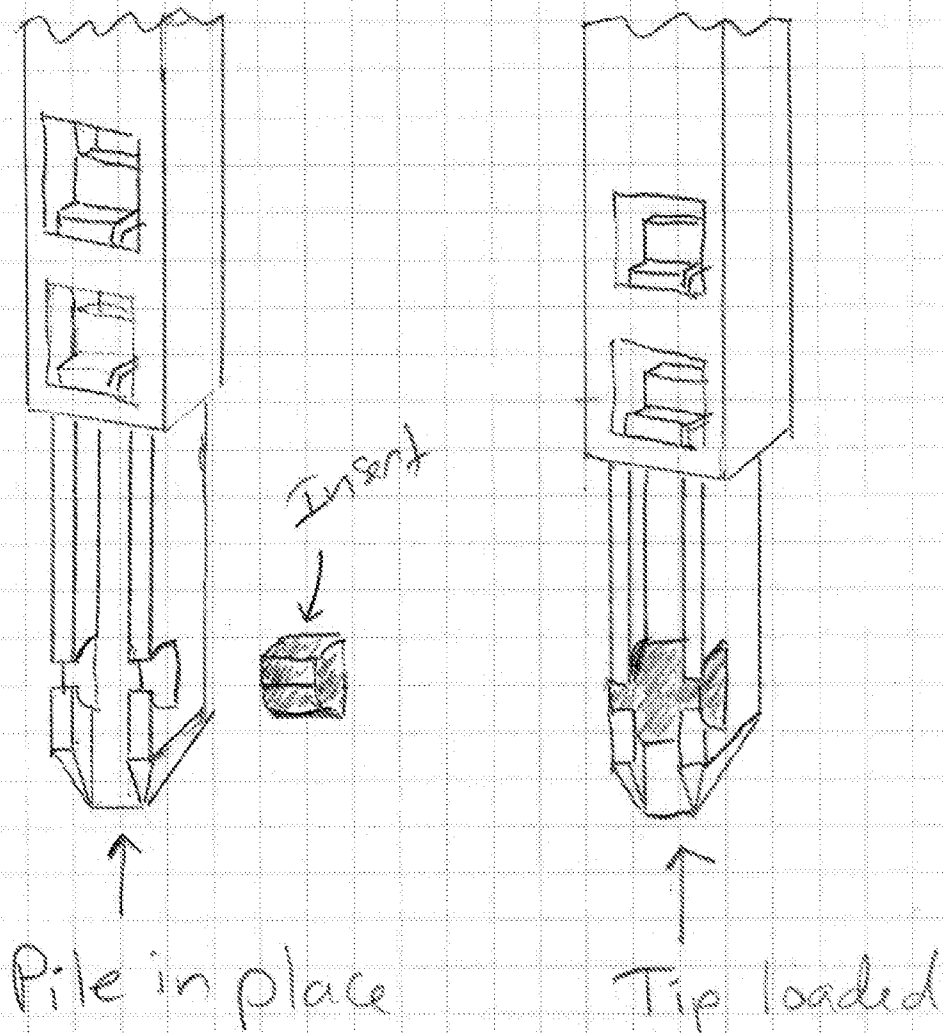
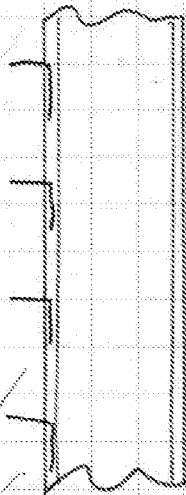
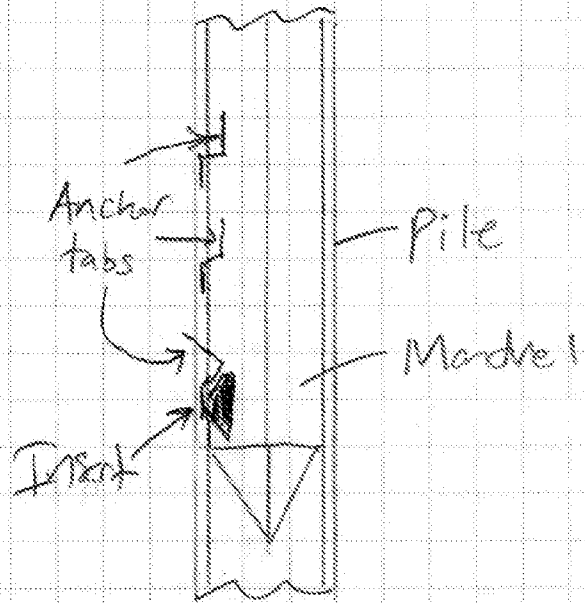
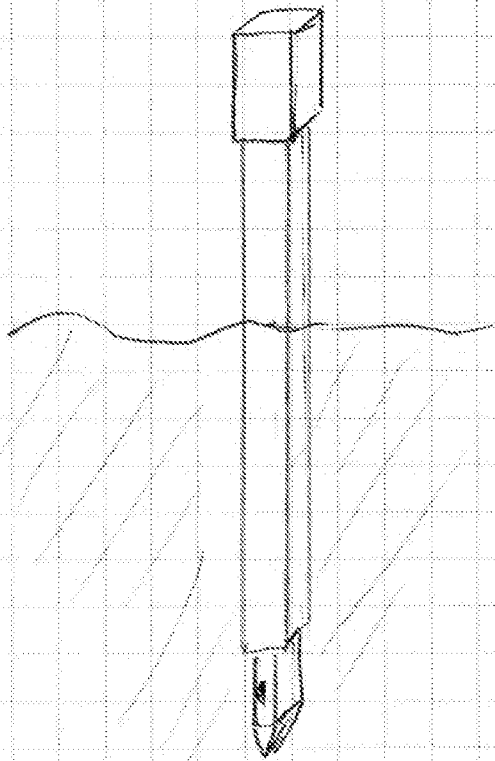


FIG. 4



Installed
pile after
mandrel
removed

FIG. 5A

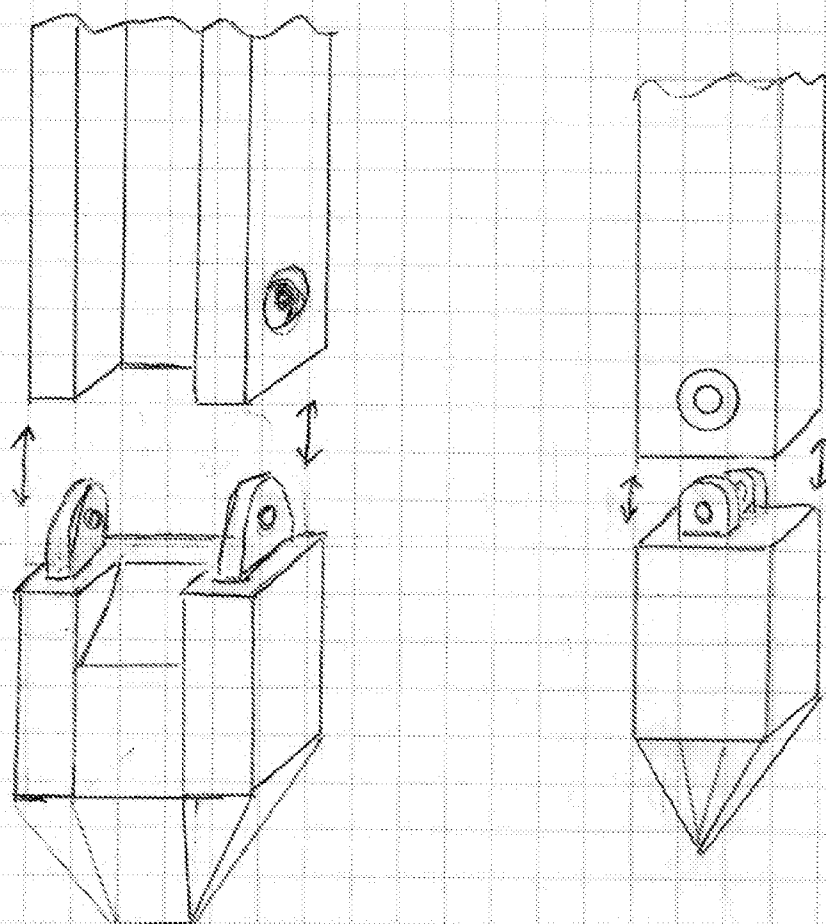


FIG. 5B

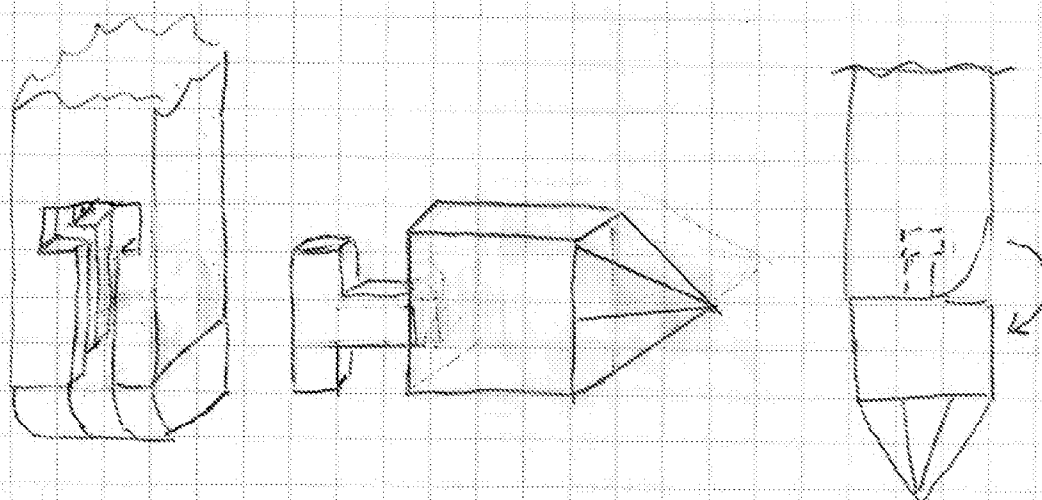


FIG. 6

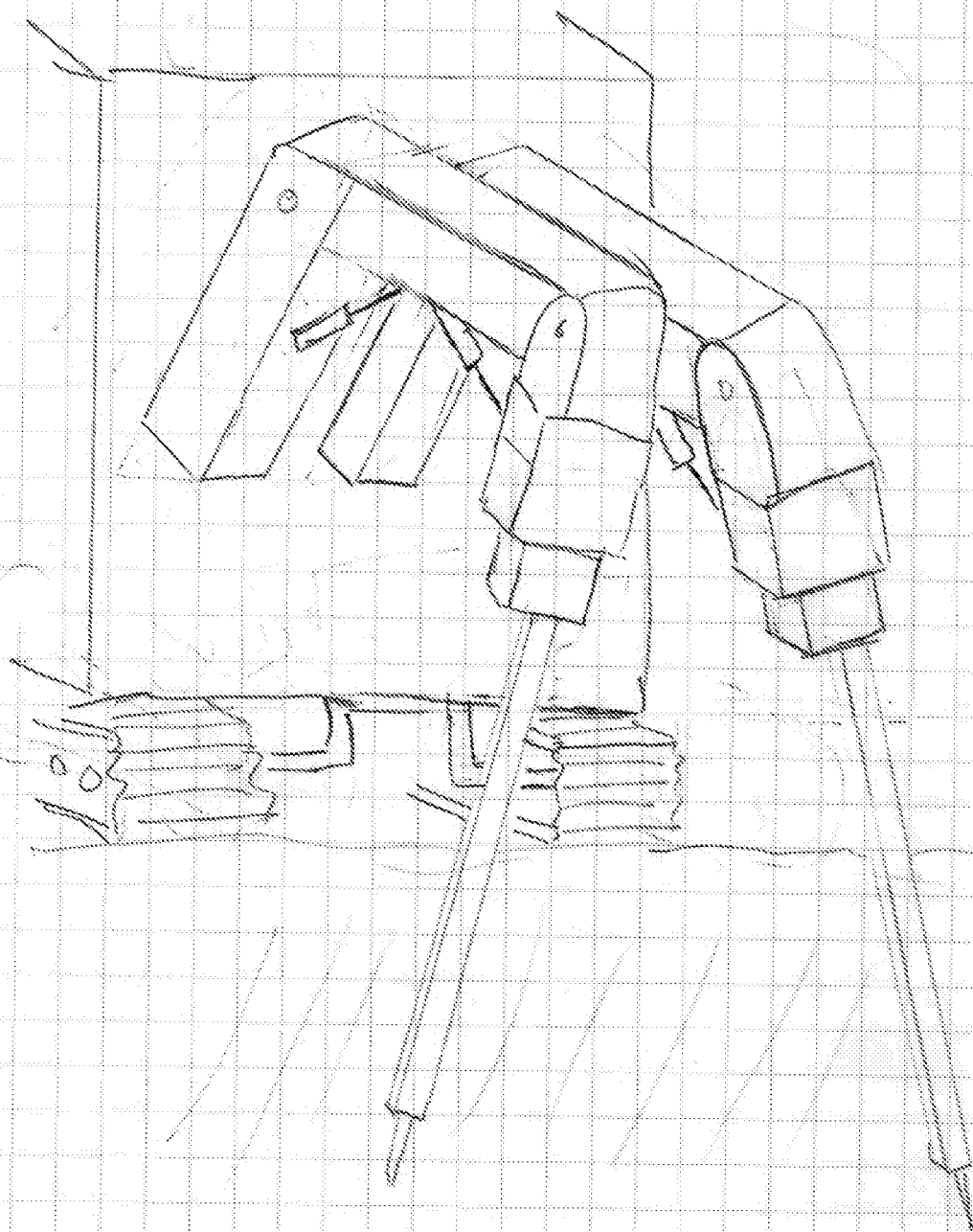
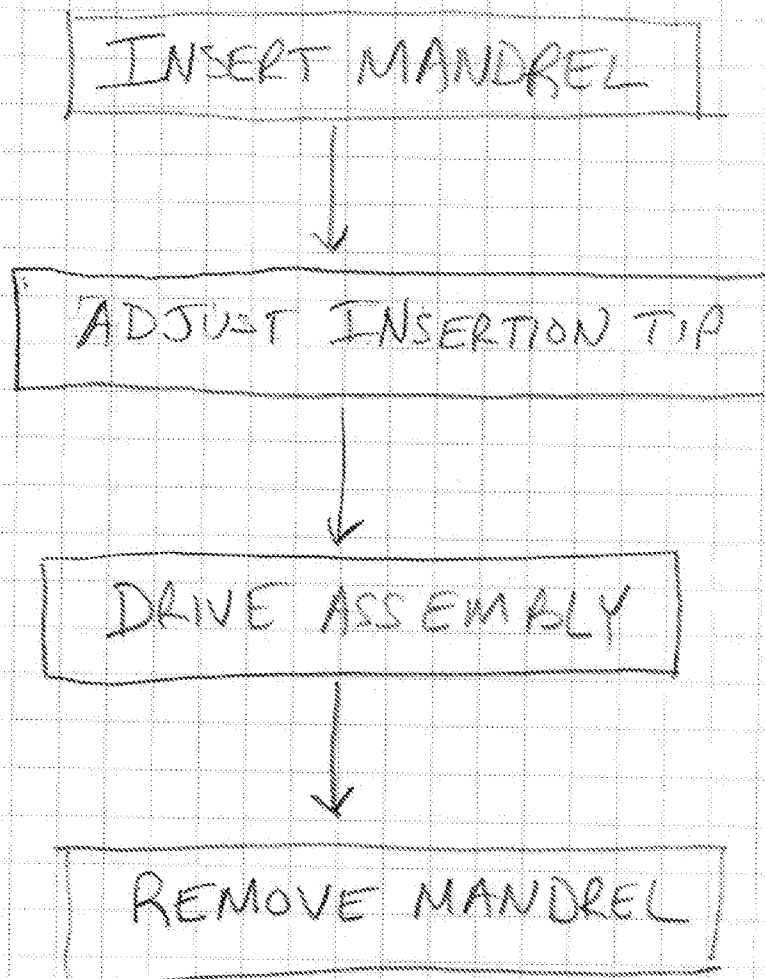


FIG. 7



Electronic Acknowledgement Receipt

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Application Number:	62702879
International Application Number:	
Confirmation Number:	3201
Title of Invention:	Foundation piers for axial solar arrays and related systems and methods
First Named Inventor/Applicant Name:	Charles Almy
Correspondence Address:	Ojjo, Inc. - 245 Kentucky St. Suite C-4 Petaluma CA 94952 US 415-786-4685 pmancini@ojjo.com
Filer:	Phillip Mancini
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Attorney Docket Number:	PPA4
Receipt Date:	24-JUL-2018
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Application Type:	Provisional

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2	Drawings-only black and white line drawings	PPA4_FIGS0003.pdf	662956	no	7
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