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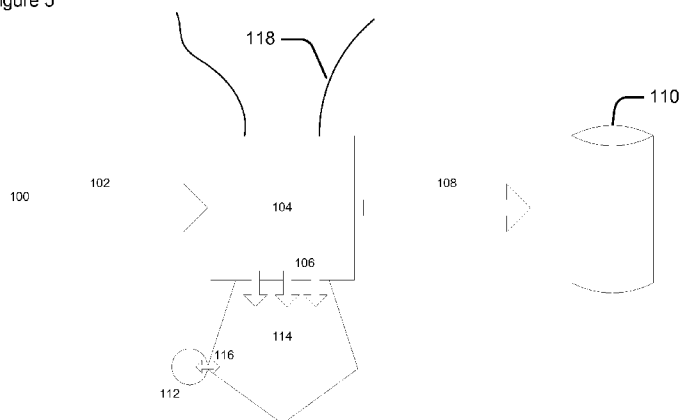
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Figure 5



(57) Abstract: This disclosure teaches systems and methods for distributed production of liquefied natural gas by utilizing refrigeration to reach the condensation of natural gas, removing of compression heat loads, sensible heat loads, and latent heat at ambient temperatures utilizes the Stirling cycle, both refrigeration and thermal heating processes, for enabling cryogenic refrigeration and the portable production of LNG. Generally, the natural gas may be supplied from existing or nearby pipelines and the LNG production system itself may be powered by electric motors or internal combustion engines. The refrigeration machine / LNG production system may be installed at, within or nearby to existing or new construction gas stations for refueling of all classes of motorized vehicles. Additional embodiments include the refrigeration machine installed into standard over-seas containers for LNG import or export, as well as any other portable platform for distributed LNG production.



SYSTEMS AND METHODS FOR DISTRIBUTED PRODUCTION OF LIQUIFIED NATURAL GAS

CROSS REFERENCE TO RELATED REFERENCES

[0001] This application claims the priority of U.S. Provisional # 61/662,341 filed on June 20, 2012 and entitled “SYSTEMS AND METHODS FOR DISTRIBUTED PRODUCTION OF LIQUIFIED NATURAL GAS”.

TECHNICAL FIELD

[0002] This disclosure relates in general to the field of liquefying gases and more particularly to systems and methods for distributed production of liquid natural gas.

BACKGROUND

[0003] Natural gas is amongst the cleanest burning of fossil fuels, and is a major source of energy. However, many of the end-sources of natural gas consumption may be located far from the gas fields from where it is produced. Transporting gas may be costly and impractical, especially over long distances. An efficient means of transporting natural gas, including situations where pipelines cannot be built, is in the form of liquefied natural gas (hereinafter, “LNG”).

[0004] In this, LNG differs from liquid petroleum gas (hereinafter, LPG) in that it is required to be refrigerated to a (-162°C) cryogenic temperature, which is the temperature low enough to achieve liquefaction of the gas, and allow efficient storage and/or transport of the material.

[0005] Natural gas is a colorless, highly flammable gaseous hydrocarbon consisting primarily of methane (80-99%) and ethane. It may also contain smaller quantities of propane and heavier hydrocarbons, as well as other minor substances including, but is not limited to: carbon dioxide, hydrogen, hydrogen sulfide, nitrogen, helium, and argon (please reference Table 1 below for a list of typical natural gas composition). In the Union Gas system, the typical sulphur content of natural gas is 5.5 mg/m³. This includes 4.9 mg/m³ of sulphur in the odorant (mercaptan) added to gas for safety reasons. The water vapor content of natural gas in the Union Gas system is less than 80mg/m³, and is typically 16 to 32 mg/m³. Natural gas commonly occurs in association with crude oil and is extracted from drilled wells. Although some natural gas may be used as it comes from the well without any refining, most require processing before use.

Table 1. Typical Natural Gas Composition.

Methane	95.2	87.0 - 96.0
Ethane	2.5	1.5-5.1
Propane	0.2	0.1-1.15
iso-Butane	0.03	0.01-0.03
normal-Butane	0.03	0.01-0.03
iso-Pentane	0.01	trace-0.14
normal-Pentane	0.01	trace-0.04
Hexanes plus	0.01	trace-0.06
Nitrogen	1.3	0.7-5.6
Carbon Dioxide	0.7	0.1-1.0
Oxygen	0.02	0.01-0.1
Hydrogen	trace	trace-0.02
Specific Gravity	0.58	0.57-0.62

[0006] Traditionally, natural gas is transported either in its natural gaseous state by pipeline or after liquefaction by cooling, by tankers. LNG is a clear, colorless, non-toxic liquid that may be more easily transported and stored than natural gas in its gaseous form because it occupies up to six hundred times less volume. Natural gas is converted to LNG by cooling it to below -262° Fahrenheit (-162° Celsius), at which point it becomes a liquid. This allows natural gas to be transported efficiently by sea, truck, or various other means. Once it reaches its destination, LNG is unloaded from ships at import terminals or from trucks at facilities where it is stored as a liquid until it is warmed back to natural gas. The natural gas may then be sent through pipelines for distribution to homes, businesses, industries, or used as a fuel for vehicles.

[0007] Existing LNG production facilities in use today employ a variety of LNG production technologies including, but is not limited to: expander, nitrogen refrigeration, single mixed refrigerant, cascade refrigeration, nitrogen refrigeration, and other multiple refrigerant schemes. The predominant technology has been the mixed refrigerant system, with over sixty percent of installations using this technology. Currently, modern LNG production facilities are employing expander, nitrogen refrigeration or single mixed refrigerant designs. The cascade and multiple loop systems have proven to be too complex and too costly to operate.

[0008] The expander process uses the feed gas pressure expanding to a lower pressure to drive the liquefaction process. In many instances, plants are located where the natural gas is sourced from a high pressure main line and is to be delivered to local distribution systems. In these cases, the liquefaction of a portion of the feed gas can be accomplished with little or

no compression or mechanical refrigeration. A typical facility would liquefy approximately fifteen to twenty percent of the feed gas with the balance going to the downstream system. These expander plants have been used frequently where the requisite pressure drops are available. If the tail gas could not be dumped to a low-pressure system, this type of process would not be considered. Recompression of the tail gas would result in a high cost and low efficiency process.

[0009] **FIGURE 2** displays an exemplary expander process system that uses feed gas pressure expanding to a lower pressure.

[0010] The nitrogen refrigeration process has been used on a limited basis for liquefaction, especially in smaller systems. The process is similar to the expander process in that it uses a vapor refrigeration stream with an additional large compressor for nitrogen circulation. Since the process relies on nitrogen vapor for condensing, the refrigeration flow is quite large and the system will be significantly larger than a mixed refrigerant system. The amount of power needed to run this system is much larger than other technologies.

[0011] **FIGURE 3** displays an exemplary nitrogen refrigeration process system for liquefaction.

[0012] The single mixed refrigerant process is a lower cost design for small-scale liquefaction systems. This technology, in contrast to the other technologies in the prior art, has only a single compression system for the refrigeration. The main exchanger is a simple plate-fin unit with a minimal number of connections, designed to offer a liquefaction system that is easy to operate. During a shutdown the refrigerant inventory is maintained in the system so that no venting or pressure relieving is needed.

[0013] **FIGURE 4** displays an exemplary single mixed refrigerant process for liquefaction systems.

[0014] **FIGURES 2** through **4** illustrate existing technologies that are used for liquefaction of natural gas. **FIGURE 2** displays an exemplary expander process system that uses feed gas pressure expanding to a lower pressure to drive the liquefaction process. **FIGURE 3** displays an exemplary nitrogen refrigeration process system for liquefaction. **FIGURE 4** displays an exemplary single mixed refrigerant process for liquefaction systems. Generally, these processes require about 260–370 kilowatts (kW) per MMcf/d of LNG capacity. The exact value will depend on the system design parameters, such as feed gas pressure, ambient conditions, and process specifications. Besides the refrigerant compressor, the main exchanger is the key piece of equipment in the liquefaction system. The main exchanger is an aluminum plate-fin core or cores in a carbon steel box. The box is filled with

perlite for insulation. All connections are external to the box, eliminating any leak potential inside the box. However, the portability of LNG makes it an ideal fuel to be supplied from a single point to multiple customers. In addition, users can access supply from a variety of sources. This necessitates even smaller scale LNG production than is available with today's technologies for enabling the end user access to LNG at discrete sources within the local markets.

[0015] Although various systems and methods for small scale production of liquefied natural gas are known to the art, all, or almost all of them suffer from one or more than one disadvantage and have shortcomings. Therefore a need has arisen for systems and methods for improving the production of liquefied natural gas via a distributed production process which corrects the problems identified above.

SUMMARY

[0016] The following disclosure presents concepts for distributed production of liquefied natural gas. The disclosed subject matter significantly improves upon prior art aimed at LNG production by utilizing the Stirling refrigeration process.

[0017] It is an aspect of the present disclosure to permit distributed production of liquefied natural gas within a compact and complete refrigeration system, which can be a portable micro scale refrigeration system.

[0018] One aspect of the disclosed subject matter is a cowling designed as an insulated pressure resistant closed space vessel, which is fitted to a Stirling Engine, and which allows for the refrigeration of natural gas down to its condensing temperature.

[0019] Another aspect of the disclosed subject matter is that refrigeration of the natural gas is achieved through the application of mechanical work to the Stirling Engine.

[0020] In one embodiment, the required mechanical work is provided via an electric motor.

[0021] Another aspect of the disclosed subject matter is a plurality of entry ports for accommodating a number of valves, control, and measuring devices.

[0022] Yet another aspect of the disclosed subject matter is a plurality of exit ports for extracting LNG, draining of condensed water, and the venting of carbon dioxide.

[0023] Another aspect of the disclosed subject matter is a plurality of instrument ports for carrying control signals to the process control hardware.

[0024] Yet another aspect of the disclosed subject matter is control software for efficient management of the liquefaction processes.

[0025] In some embodiments, the refrigeration system is arranged so that the system is capable of withstanding ambient temperatures on the outside shell and cryogenic temperatures on the inside shell, such that the construction is capable of operating while taking heavy mechanical and molecular stresses caused by operation temperatures. In yet another aspect of preferred embodiments, the system comprises a main storage tank capable of storing long term amounts of LNG and a transfer tank serving as a buffer for eliminating LNG overflow.

[0026] These and other aspects of the disclosed subject matter, as well as additional novel features, will be more apparent from the following detailed description of preferred embodiments of the invention, along with the accompanying drawings in which like numerals represent like components. The intent of this summary is not to be a comprehensive description of the claimed subject matter, but rather to provide a short overview of some of the subject matter's functionality. Other systems, methods, objects, features, aspects, and advantages here provided will become apparent to one with skill in the art upon examination of the following **FIGURES** and detailed description. It is intended that all such additional systems, methods, features and advantages that are included within this description, be within the scope of the accompanying claims and any claims filed later.

BRIEF DESCRIPTIONS OF THE DRAWINGS

[0027] The novel features believed characteristic of the presently disclosed subject matter will be set forth in any claims within the scope and any claims that are filed later. The presently disclosed subject matter itself, however, as well as a preferred mode of use, further objectives, and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

[0028] **FIGURE 1** is a pressure/volume graph of an idealized Stirling cycle (Prior Art).

[0029] **FIGURE 2** displays an exemplary expander process system that uses feed gas pressure expanding to a lower pressure (Prior Art).

[0030] **FIGURE 3** displays an exemplary nitrogen refrigeration process system for liquefaction (Prior Art).

[0031] **FIGURE 4** displays an exemplary single mixed refrigerant process for liquefaction systems (Prior Art).

[0032] **FIGURE 5** illustrates a logical flow diagram for the inflow of **102** natural gas from an **100** external supply to the **104** exemplary cowling, the **106** transfer of heat from the natural gas to the **114** Stirling Engine through a process of applying **116** work by an **112** (external) motor to the Stirling Engine, and the outflow of **108** LNG from the system to an **110** exemplary storage tank. **118** illustrates the exemplary input mechanism by which the system is able to respond to external or internal triggers.

[0033] **FIGURE 6** illustrates a logical flow diagram for the removal of frozen material from the cowling device, through **130** interrupting the inflow of natural gas, **134** interrupting the outflow of LNG, the **136** application of work in a manner/direction differing from normal operation of the system to produce heat, **132** the transfer of heat from the Stirling Engine to the Cowling, and the venting of material, typically water or CO₂ from the system by a secondary (or plurality of secondary) vent(s).

[0034] **FIGURE 7** depicts an exemplary distributed LNG production system employing the Stirling cycle refrigeration process. **Figure 7a, 7b, and 7c** depict the same exemplary distributed LNG system in extracted figures.

[0035] **FIGURE 8** illustrates a side view diagram of an exemplary cowling assembly.

[0036] **FIGURE 9** depicts a three-dimensional isometric view an exemplary cowling assembly.

[0037] **FIGURE 10** illustrates another side view diagram of the cowling as it relates to mounting to the Stirling refrigerator system.

[0038] **FIGURE 11** illustrates an exemplary embodiment of the first step of LNG production by opening a main natural gas grid valve.

[0039] **FIGURE 12** portrays an exemplary embodiment of the system operating under normal LNG production parameters.

[0040] **FIGURE 13** depicts exemplary processes after normal operations have been interrupted.

[0041] **FIGURE 14** illustrates exemplary processes for elimination of ice from the LNG production system.

[0042] **FIGURES 15a, 15b, and 15c** depict exemplary connections and welds as taught by the current disclosure.

[0043] **FIGURES 16a, 16b, and 16c** depict an exemplary cowling of the present disclosure and its associated structures.

[0044] **FIGURES 17a and 17b** depict side and front angle views into an exemplary cowling of the present disclosure.

[0045] **FIGURE 18** illustrates a logical flow diagram for the initial interface and the formation of operating software of the present disclosure's system.

[0046] **FIGURE 19** illustrates a logical flow diagram for the user interface and the formation of operating software of the present disclosure's system.

[0047] **FIGURE 20** illustrates a logical flow diagram for the technician interface and the formation of operating software of the present disclosure's system.

[0048] **FIGURE 21** illustrates a logical flow diagram for the programmer sequence and the formation of operating software of the present disclosure's system.

[0049] **FIGURE 22** illustrates a logical flow diagram for the standby interface and the formation of operating software of the present disclosure's system.

[0050] **FIGURE 23** illustrates a logical flow diagram for the startup sequence and the formation of operating software of the present disclosure's system.

[0051] **FIGURE 24** illustrates a logical flow diagram for the control loop auto run sequence and the formation of operating software of the present disclosure's system.

[0052] **FIGURE 25** illustrates a logical flow diagram for the shutdown sequence and the formation of operating software of the present disclosure's system.

[0053] **FIGURE 26** illustrates a logical flow diagram for the de-icing sequence and the formation of operating software of the present disclosure's system.

[0054] **FIGURE 27** illustrates a logical flow diagram for the emergency stop sequence and the formation of operating software of the present disclosure's system.

[0055] **FIGURE 28** illustrates a logical flow diagram for the H2 sub-process and the formation of operating software of the present disclosure's system.

[0056] **FIGURE 29** illustrates a logical flow diagram for the emergency stop sequence and the formation of operating software of the present disclosure's system.

[0057] **FIGURE 30** illustrates a logical flow diagram for the indicators directory and the formation of operating software of the present disclosure's system.

[0058] **FIGURE 31** illustrates a logical flow diagram for the controls directory and the formation of operating software of the present disclosure's system.

[0059] **Figure 32 a)** depicts one embodiment of the disclosure with the cowling shown fitted to the Stirling Engine.

[0060] **Figure 32 B)** depicts an exemplary cowling in its un-insulated form.

DETAILED DESCRIPTION OF THE SPECIFIC EMBODIMENTS

[0061] Although described with particular reference to liquefaction of natural gas, those with skill in the arts will recognize that the disclosed embodiments have relevance to a wide variety of areas in addition to those specific examples described below.

[0062] All references, including publications, patent applications, and patents, cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

[0063] **FIGURE 1** generally depicts a pressure/volume graph of an idealized Stirling cycle. It is a reversible thermodynamic cycle and is commonly known as the hot air engine. In actual practice, the pressure-versus-volume thermodynamic processes do not have such definite liquid to gas transitions. A more realistic representation of most real Stirling engines is the adiabatic Stirling cycle (not shown) which is more quasi-elliptical shaped when compared to the idealized cycle; however, this is shown as a simplified version.

[0064] The Stirling cycle consists of four main thermodynamic processes: 1. Isothermal Expansion; 2. Constant-Volume heat-removal; 3. Isothermal Compression; and 4. Constant-Volume heat-addition. These processes are not discrete, but rather the transitions overlap. As applied to an exemplary embodiment of the present disclosure, the thermodynamic processes occur in four different phases as follows: 1) during the isothermal expansion phase, the working gas undergoes near-isothermal expansion by means of an external heat source; 2) during the constant-volume heat-removal phase, iso-volumetric heat removal occurs by means of an internal heat exchanger or regenerator, where the heat is dumped to a matrix of regenerator fibers. This cools the gas and stores the removed heat to be used in the opposite phase of the Stirling cycle; 3) during the isothermal compression phase, the working gas is reduced in volume at the same time as it is cooled, removing almost all compression related heat; and 4) during the constant-volume heat-addition phase, iso-volumetric heat addition occurs where the already compressed gas flows back through the previously heated regenerator, removing stored heat from the regenerator matrix, and is thus preheated before flowing back to the externally heated expansion chamber.

[0065] The thermal Stirling cycle is fully reversible when the Stirling engine is heated through the isothermal expansion phase and is capable of producing mechanical work at efficiencies close to the well-known Carnot cycle. However, if the Stirling cycle engine is provided with mechanical work, it will produce refrigeration (e.g. heat removal) from the isothermal expansion phase due to the expansion of the working gas by means of

mechanically applied work. This mechanically applied work enables the isothermal expansion phase to take heat from the exterior even though the temperature is lower than the temperature within the isothermal compression phase. This repetitive mechanically induced expansion and compression of the working gas will create refrigeration or heat removal. By producing a Stirling engine with the correct volumetric displacement, an efficient regenerator matrix, adequate engine cooling, and engine speeds that enable correct timing for the cooling and heating cycles of the working gas, it is possible to obtain sufficiently low temperatures for liquefaction of natural gas.

[0066] In one embodiment of the disclosed subject matter, natural gas enters the system through an inlet valve, or a plurality of inlet valves. The natural gas is then exposed to a temperature difference induced through the application of mechanical work to the Stirling Engine. The resultant temperature difference results in the natural gas being refrigerated until liquefaction is achieved and LNG is produced. The resultant LNG is released from the system via an outlet valve, a liquid seal prevents gaseous natural gas to leave the cowling allowing thus only LNG to be displaced out of the cowling into the LNG external reservoir this process been limited or controlled by one or a plurality of outlet valves.

[0067] Ready access to LNG within local markets may be enabled by an exemplary distributed LNG production system employing the Stirling cycle refrigeration process, as depicted within **FIGURE 5**. This process of refrigeration to reach the condensation of natural gas, removing of compression heat loads, sensible heat loads, and latent heat at ambient temperatures utilizes the Stirling cycle, both refrigeration and thermal heating processes, for enabling cryogenic refrigeration and the portable production of LNG. Generally, the natural gas may be supplied from existing or nearby pipelines or directly from a gas well service valve regulated to operating inlet pressure and the LNG production system itself may be powered by electric motors or internal combustion engines. The refrigeration machine / LNG production system may be installed at, within or nearby to existing or new construction gas stations for refueling of all classes of motorized vehicles. Additional embodiments include the refrigeration machine installed into standard over-seas containers for LNG import or export, as well as any other portable platform for distributed LNG production.

[0068] Construction of a complete compact refrigeration system for distributed production of LNG requires the integration of various elements as set forth below, with interconnects generally depicted within **FIGURE 5**. A control panel, for both power and control, reaches with proper wiring to all instruments within the system, external monitoring devices, and signaling devices. A working gas cylinder for industrial presentation of highly

compressed hydrogen or helium is connected to a both a working gas shut off valve and pressure regulator, which are usually attached to a gas bottle. The system is further comprised of a working gas compressor, which may be a solid state hydride compressor for hydrogen or mechanical piston driven for helium, and a first check valve "A" to prevent working gas returning to the bottle system.

[0069] Continuing with this particular embodiment, the system is also comprised of a dry cooler system with 2Kw s motor fans each is a fan and coil which provides cooling for the Stirling engine coolant. Flow-meter "A" and thermocouples "A" and "B" provide process signals to the control panel. In one embodiment, the 'work' is provided via an electric motor, which may range from 38 Kw to 149 Kw depending on the production rate. The Stirling cycle engine or short block, which may be supplied by various providers, could be comprised of an exemplary engine size of 260CC per cylinder, with four cylinder blocks capable of running from 900 to 2200RPM operating pressures of 15.5MPa maximum temperature on the heads of 750°C, minimum temperature -200°C. The engine should be capable of running in both rotations clockwise and counter clockwise at any given speed.

[0070] The exemplary system further comprises a transfer tank, a cryogenic insulated day tank capable of holding LNG at quantities approximately equivalent to eight hours of production. This tank may be considered as a buffer tank for eliminating LNG over flow and the capturing of re-liquefaction vapors produced at a main storage tank. The transfer tank may be equipped with a transfer pump "A", a low level sensor "A", and a high level sensor "A", with all instruments sending signals to control panel. The main storage tank may be capable of storing LNG production at quantities approximately equivalent to seven days or more worth of production. This main storage tank is connected to the transfer tank by means of transfer pump "A" and flexible joint for allowing the use of load cells at the bottom of main storage tank. This use of flexible tubing and joints is important for enabling the weighing of amounts of LNG stored within both the main storage tank and the transfer tank. Also, the flexible tubing enables the system to handle various stresses due to contraction of material from low cryogenic temperatures. The main storage tank may also be equipped with a low level sensor "B", a high level sensor "B", a safety gas relief valve "B", and a re-liquefaction line for condensing any boil-off occurred due to increasing temperature in the main storage tank. This re-liquefaction line may be equipped with a manual valve "D", a flexible joint, a re-liquefaction solenoid valve, and a check valve "C". Further, the system includes a natural gas entry valve train including, but is not limited to: a check valve "B", a cowling pressure regulator, a cowling solenoid valve, a dryer cartridge, a filter cartridge,

manual valves “A”, “B” and “C”, a process pressure regulator, a process solenoid valve, and connections to the natural gas grid system.

[0071] Condensation of LNG by means of Stirling cycle refrigeration requires design and construction of a specific cowling, as depicted generally in **FIGURES 6 – 8**. **FIGURE 6** illustrates a side view diagram of an exemplary cowling assembly. **FIGURE 7** depicts a three-dimensional isometric view an exemplary cowling assembly. **FIGURE 8** illustrates another side view diagram of the cowling as it is relates to mounting to the Stirling refrigerator system. As defined for purposes of this disclosure, a cowling will be defined as an insulated pressure resistant closed space vessel that makes possible the refrigeration of natural gas down to its condensing temperature of -162.5°C at a process pressure with minimal heat loss to the atmosphere and to the engine’s hot face. The cowling carries sufficient numbers of entry ports for accommodating a number of valves, control, and measuring devices, a number of exit ports for extracting the natural gas in is liquid stage (LNG), draining of condensed water, venting of carbon dioxide, as well as a number of instrument ports that will carry control signals to the process control hardware.

[0072] Construction of the exemplary cowling is performed utilizing specific stainless steel alloys capable of handling heavy contraction mechanical and molecular stresses caused by operating temperatures and the repeated cooling and heating processes, from cryogenic temperatures as low as -185°C to ambient temperatures or higher. Other embodiments of the cowling are possible provided the material can handle these stresses while holding operating pressures and extreme emergency pressures stable. The cowling may be insulated by with various materials including, but is not limited to: polyurethane foam, expanded perlite, volcanic glass foam, elastomeric synthetic rubber, vacuum chambers and or various other composites. In the exemplary cowling, the external shell of the cowling and internal shell of the cowling are welded to a common mounting flange for allowing the free expansion and contraction of the pieces freely without causing additional mechanical stress, gas leak, or heat losses.

[0073] The exemplary cowling utilizes a double-wall insulated cowling with fully welded mounting flanges capable of withstanding ambient temperatures on the outside shell and cryogenic temperatures on the inside shell to allow for different contraction rates in the materials involved. Further, connections to the inside shell capable of allowing independent thermal expansion and contraction of both shells while offering a low thermal heat transfer rate to the outside is desired. The cowling must further be able to operate safely at all

working pressures. Due to these criteria, construction materials for this embodiment involve multiple, different stainless steel alloys.

[0074] In one embodiment, the cowling is further equipped with entry ports for incoming natural gas at ambient temperature and process operating pressures of 60PSI, which also accommodates vent valves for carbon dioxide, pressure transducer, and safety gas relief valve “A”. Additionally, the cowling may also carry exit ports for extraction of LNG, a water drain solenoid valve, a LNG discharge solenoid valve, and an in-line with flow-meter “B”. The cowling may further be fitted with instrument port to carry at least four cryogenic-capable thermocouples, one pressure transducer, a solid state camera, and room for additional non-commissioned future instruments.

[0075] **FIGURE 9** illustrates an exemplary embodiment of the first step of LNG production by opening a main natural gas grid valve. Natural gas is allowed to flow through a gas entry valve train and the process solenoid valve opens. A cowling solenoid opens [for] allowing a cowling pressure regulator to drop the gas pressure down to operating parameters. The natural gas is contained by discharge solenoid valve and check valve “C” and a pressure transducer sends signal to a control panel signaling a next step in the liquefaction process.

[0076] **FIGURE 10** portrays an exemplary embodiment of the system operating under normal LNG production parameters. The refrigeration process begins when the system is charged with natural gas and all safety supervision devices show a safe system for operation. As power is applied to ramp up the electric motor to 1800RPM, for the next 25 seconds the Stirling engine must elevate the oil pressure to normal value of 45PSI and the engine coolant flow-meter must show correct operating parameters for flow and temperatures. Working gas pressures shall also be within proper ranges of operation for this stage of the ramp up. After all start up protocols are satisfied, the program sends the electric motor signals to run steady for a designated X number of minutes, with safety supervision operations occurring up to 200 times per second. After ramp up procedures are finished, the control panel signals the program to run steady in “normal run”, until a designated approximation temperature is reached. This designated temperature may range between -125 and -155°C, which are the temperatures at which the process reaches final refrigeration stages. At these temperatures is where natural gas condensation begins to occur. Next, the software program signals the engine into automatic condensation temperature mode, allowing the software to calculate the optimal combinations for motor RPM, electric current, coolant temperatures, natural gas pressure, and working gas pressure to reach the process set up of -163°C for LNG production. Once the process is in automatic mode, the speed of electric

motor will continuously change to produce LNG with the most efficient uses of power. The process running in automatic mode will keep producing LNG uninterrupted unless any of the following exemplary trigger actions occurs: main storage tank becomes full, manual commands to stop operations, any system failures, safety, or power, engine alarm for low coolant, low oil pressure, or low working gas pressures. Working gas may added to the engine as required for keeping optimal pressure at cold temperatures.

[0077] Additional embodiments of the cowlings allow the system to respond to external triggers in accordance with general practice of flammable material, transfer of dangerous good, standard safety practices for electrical equipment, severe natural gas pressure variations, aggravated contamination of natural gas, sudden vessel overheat, safety features for portable equipment etc.

[0078] **FIGURE 11** depicts exemplary processes after normal operations have been interrupted by a high pressure signal from the main storage tank. If not attended to, safety gas relief valve “B” would open, venting natural gas to the atmosphere. This unwanted gas relief, as it wastes input materials, may be prevented by interrupting normal natural gas feed to the cowlings and allowing by differential pressures, re-liquefaction pressure being set up higher than grid pressure feed, with that higher pressure from the main storage tank entering the cowlings. At this moment, the main storage tank pressure is sufficiently high for operating until the refrigerator system removes heat from the otherwise vented gas. By condensing this otherwise vented gas back into LNG and reducing main storage tank pressure to close to atmospheric values or any other safe operating pressure, LNG is drained back into transfer tank until safe pressures are achieved. Further, if the main storage tank is not full yet, normal operation begins again and allows grid natural gas to feed the refrigerator until main tank reaches its high level sensor mark.

[0079] **FIGURE 12** illustrates exemplary processes for elimination of ice from the LNG production system. During normal operations, it is expected that small quantities of water vapor and carbon dioxide carried by the feed gas will produce ice on the surface of the cold refrigeration heads. The ice will cause no harm to the liquefaction process until energy efficiency begins to drop. This is due to the ice and dry ice acting as insulation and preventing proper heat transfer between natural gas and the refrigeration heads. At this point, the system will run the following deicing procedure: natural gas feed gas will be interrupted at the cowlings solenoid valve, re-liquefaction gas will be interrupted at the re-liquefaction solenoid valve, and LNG drainage will be cut off at the discharge solenoid valve. This has the effect of isolating the cowlings from the overall process. When this isolation occurs, the

refrigerator will gradually reduce engine speeds to 0 RPM. After all safety systems confirm motor speeds at 0 RPM, it will be signaled to reverse rotation at 150RPM and gradually increase the speed for reversing the refrigeration process and pumping heat into the cooling heads until carbon dioxide becomes gas again and gets vented off the cowling through the carbon dioxide venting solenoid valve. A negligible amount of natural gas will invariably be vented with it, but at amounts that will not impact overall efficiency of the system. The refrigerator will keep rotating slowly in reverse mode until a head temperature of 60°C is achieved for allowing all water ice to be thawed and drained out the system through the water drain solenoid valve. After running in reverse rotation and when heads are at the temperature of 60°C, both draining valves will be shut off and the system reverses the engine again. The motor will reduce speed to 0RPM, and when the software verifies that motor speed is at 0 RPM, it will signal to the motor to restart in forward cooling direction. After ramping up to 1800 RPM, the motor speed will be kept constant at that RPM until all thermocouples inside the cowling show a temperature close to -163°. This reaches the set up temperature necessary for normal operations and will be the permitting temperature for sequencing the opening of the feed gas valve, re-liquefaction valve, and LNG discharge solenoid valve to regain normal operating status. This thawing procedure is expected to occur every 72 hours, but may occur more or less frequently, relative to the feed gas quality.

[0080] **FIGURES 13a, 13b, and 13c** depict exemplary connections and welds as taught by the current disclosure. **FIGURES 14a, 14b, and 14c** depict an exemplary cowling of the present disclosure and its associated structures. **FIGURES 15a and 15b** depict side and front angle views into an exemplary cowling of the present disclosure.

[0081] **FIGURES 16 through 29** illustrate logical flow diagrams for the formation of operating software of the present disclosure's system. **FIGURE 17** illustrates a logical flow diagram for the user interface. **FIGURE 18** illustrates a logical flow diagram for the technician interface. **FIGURE 19** illustrates a logical flow diagram for the programmer sequence. **FIGURE 20** illustrates a logical flow diagram for the standby interface. **FIGURE 21** illustrates a logical flow diagram for the startup sequence. **FIGURE 22** illustrates a logical flow diagram for the control loop auto run sequence. **FIGURE 23** illustrates a logical flow diagram for the shutdown sequence. **FIGURE 24** illustrates a logical flow diagram for the de-icing sequence. **FIGURE 25** illustrates a logical flow diagram for the emergency stop sequence. **FIGURE 26** illustrates a logical flow diagram for the H2 sub-process. **FIGURE 27** illustrates a logical flow diagram for the emergency stop sequence. **FIGURE 28** illustrates

a logical flow diagram for the indicators directory. **FIGURE 29** illustrates a logical flow diagram for the controls directory.

[0082] The foregoing description of the preferred embodiments is provided to enable any person skilled in the art to make or use the claimed subject matter. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without the use of the innovative faculty. Thus, the claimed subject matter is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

[0083] The detailed description set forth above in connection with the appended drawings is intended as a description of exemplary embodiments in which the presently disclosed apparatus and system can be practiced. The term “exemplary” used throughout this description means “serving as an example, instance, or illustration,” and should not necessarily be construed as preferred or advantageous over other embodiments.

[0084] Further, although exemplary devices and schematics implement the elements of the disclosed subject matter have been provided, one skilled in the art, using this disclosure, could develop additional hardware and/or software to practice the disclosed subject matter and each is intended to be included herein.

[0085] In addition to the above described embodiments, those skilled in the art will appreciate that this disclosure has application in a variety of arts and situations and this disclosure is intended to include the same.

Reference Number List

100 Control Panel	170 Flexible Joint
101 H ₂ or He	204 800 GD/DAY
102 Working Gas	200 LT/day
104 H ₂ Compressor Thermocouples	206 Main Storage Tank
106 Process Thermocouples	208 Pump B
108 Stirling cycle pressure transducers	210 Reliquefaction Solenoid Valve
110 Tachometer	212 SS Tubing
112 Power Supply	170 Flexible Joint
114 Stirling cycle thermocouples	216 Manual Valve D
116 Electric Motor	218 Low Level Sensor B
118 Dry Cooler	220 High Level Sensor B
120 Ambient Temperature	222 Gas Relief Valve B (pressure safety)
122 Water Ethylene-Glycol (automotive cooler)	224 Manual Valve C (bypass valve)
124 Flowmeter A	226 NG / 60 PSI
126 Thermocouple A	228 Process Solenoid Valve
128 Thermocouple b	230 Process Pressure Regulator
130 Mounting Flange	232 Manual Valve B
132 Stirling Cycle Engine	234 18 PSI
134 Process Pressure Transducer	236 Filter
136 Manual Valve E	238 Dryer
138 Solenoid Valves	240 Manual Valve A
140 Check Valve A	242 Cowling Solenoid Valve
142 Gas Compressor (Solid State)	244 Cowling Pressure Regulator
144 Cowling Output Flange	246 Stirling Cycle Engine Working Gas
146 Coolant Thermocouple	248 Natural Gas at Ambient Temperature
148 Coolant flowmeter	250 Liquid Natural Gas
150 Solenoid Valves	252 Natural Gas to Reliquify (Boile of Gas)
152 Flowmeter	254 Cool Coolant Flow
154 To Control Panel	256 Hot Coolant Flow
156 Cowling Input Flange	258 Control Line
158 Gas Relief Valve (pressure safety)	260 Power Line
160 Pressure Transducer	
162 N.G Port	
164 CO ₂ vent valve	
166 15 PSI	
168 Check Valve B	
170 Flexible Joint	
172 Check Valve C	
174 Outer Shell	
176 Inner Shell	
178 Thermal Insulation	
180 Thermocouple Port	
182 Gas Distributor	
184 Cowling	
186 L.N.G Port	
188 Water Drain Solenoid Valve	
190 Discharge Solenoid Valve	
192 Flowmeter B	
194 Low Level Sensor A	
196 High Level Sensor A	
198 Transfer Tank	
200 Pump A	

CLAIMS

What is claimed is:

1. A method for converting natural gas to liquid natural gas, the method comprising the following steps:

receiving natural gas into a cowling through one or more input valves, said cowling adapted to receive a stirling engine and having at least one heat transfer surface, said at least one heat transfer surface in direct contact with a cool head of said stirling engine such that heat is transferred from said natural gas to said heat transfer surface and then to said cool head of said stirling engine, thereby converting said natural gas into said liquid natural gas; and

outputting said liquid natural gas from said cowling through one or more output valves.

2. The method of Claim 1, wherein said LNG is outputted from said cowling through at least one of said output valves to at least one storage tank, at least one of said storage tanks comprising at least one level sensor, said at least one level sensor detecting the level of LNG contained in said at least one of said storage tanks; and

adjusting a rate or volume of LNG outputted through said cowling in response to said at least one level sensor.

3. The method of Claim 1, having at least two level sensors, said at least two level sensors comprising a high level sensor and a low level sensor.

4. The method of Claim 1, said method running in automatic mode thereby producing LNG uninterrupted unless a trigger actions occurs.

5. The method of Claim 4, wherein said trigger action is one or more of:

main storage tank becomes full;

manual commands to stop operations;

any system failures;

safety or power issues; and

engine alarm for low coolant, low oil pressure, or low working gas pressures.

6. The method of Claim 1, having at least two output valves, said two output valves comprising at least one LNG output valve and at least one bleed valve, wherein if a build up of frozen materials impedes said heat transfer, said method additionally comprises the following steps:

closing all of said one or more input valves thereby stopping said natural gas from entering said cowling;

closing all of said at least one LNG output valves;
opening said at least one bleed valve;
reversing said stirling engine such that heat is transferred from said cool head of said stirling engine to said heat transfer surface thereby melting said frozen material, said melted material exiting said cowling via said bleed valve.

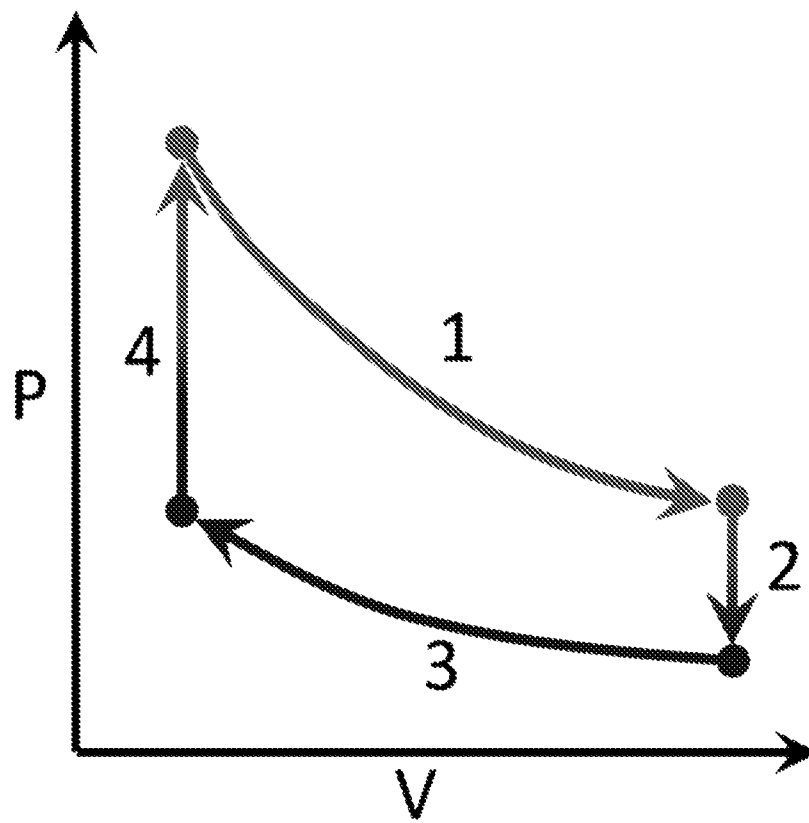


FIG. 1 (prior art)

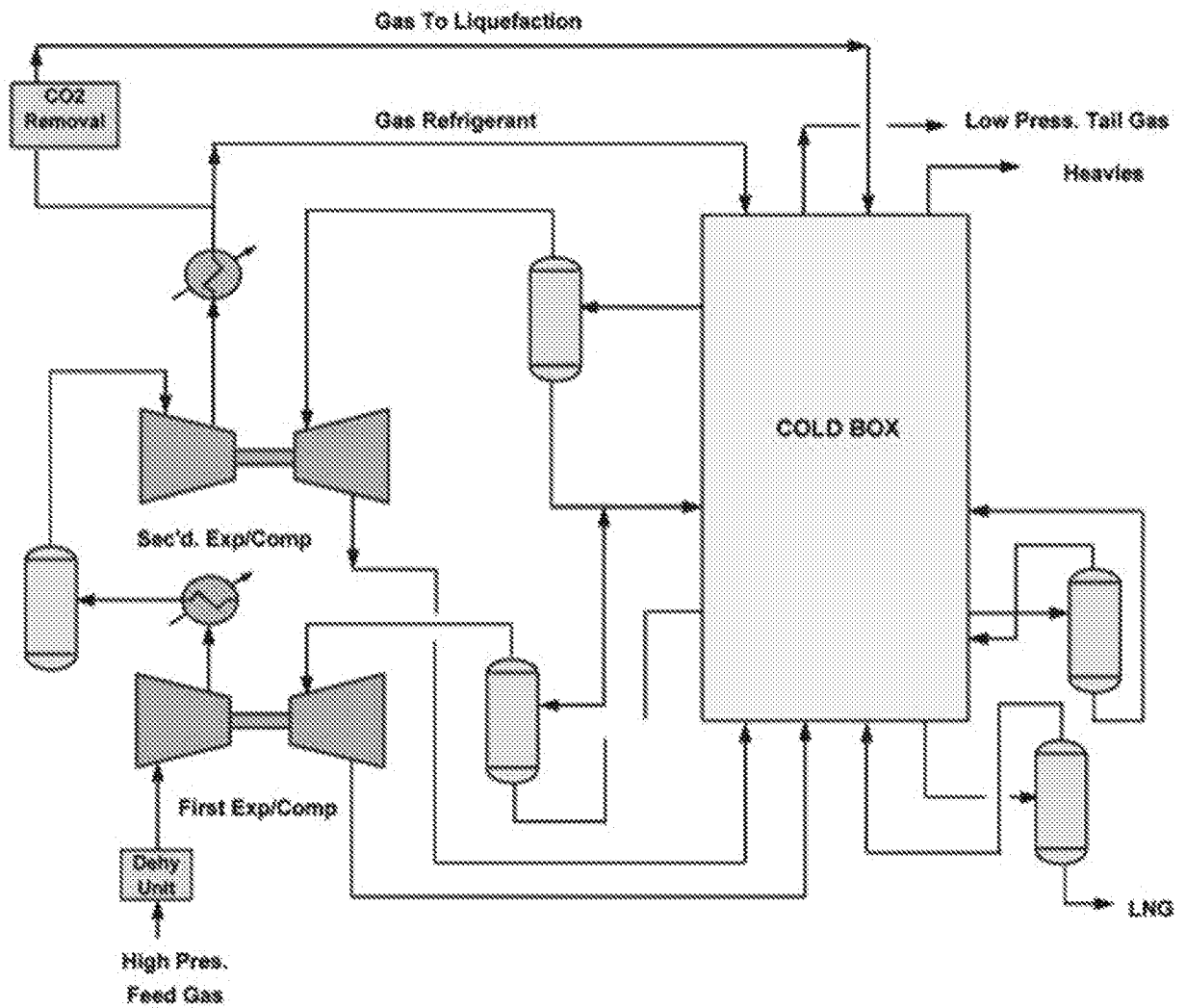


Figure 2 (Prior Art)

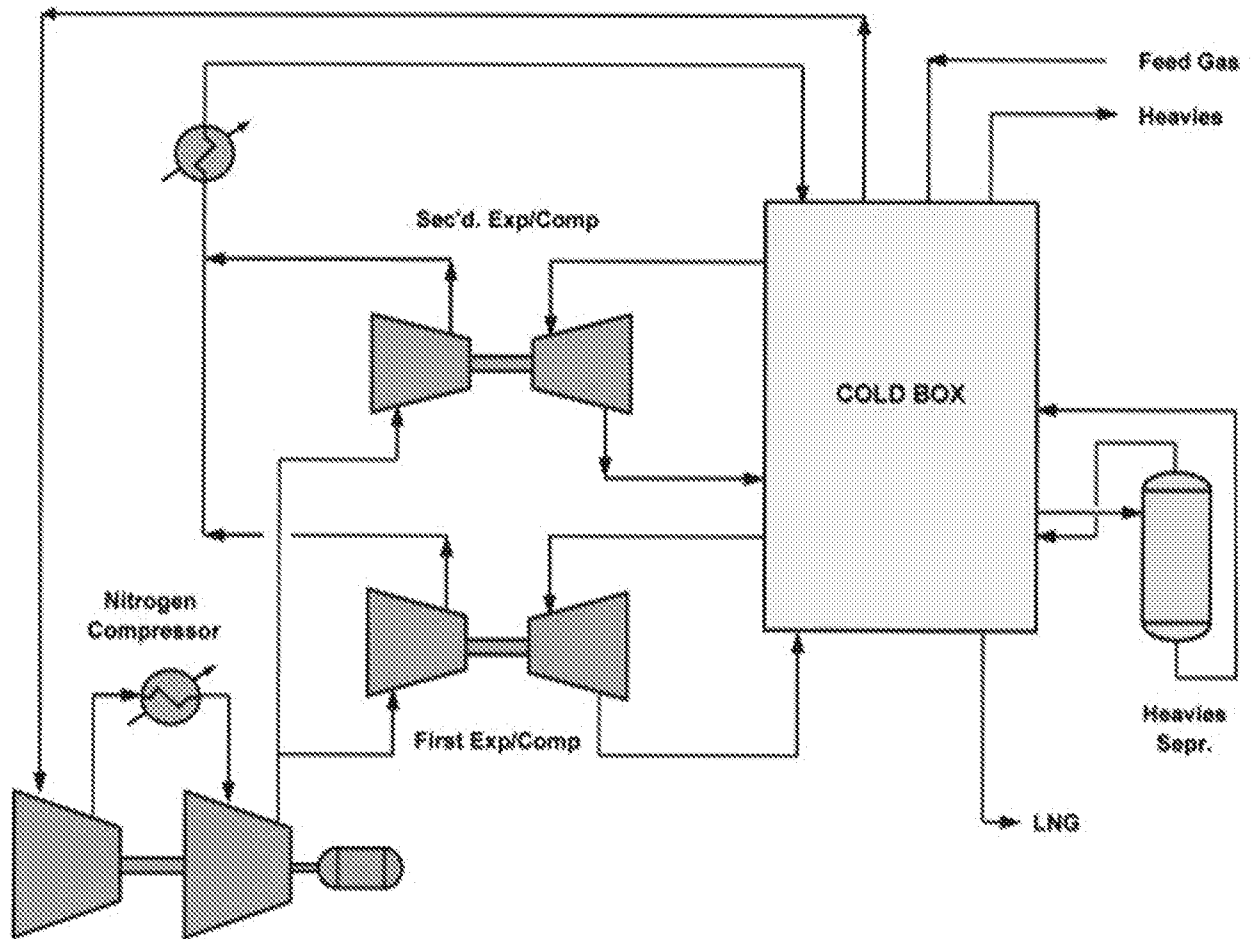


Figure 3 (Prior Art)

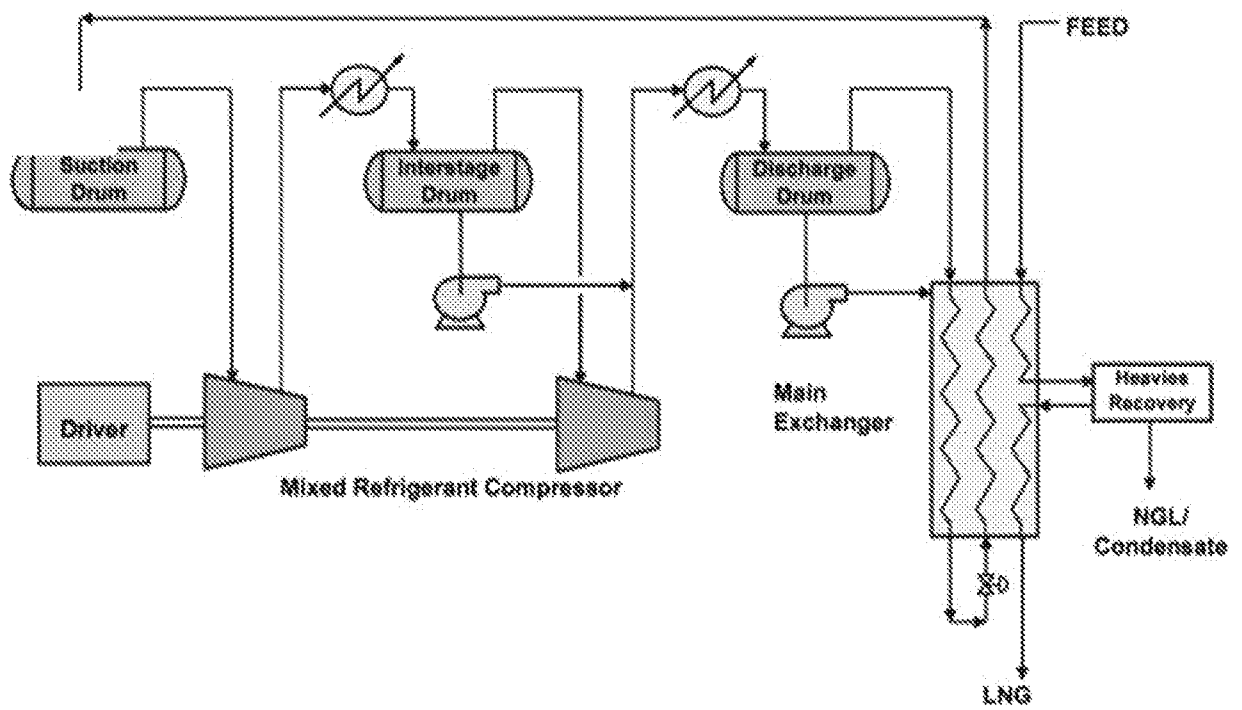


Figure 4 (Prior Art)

Figure 5

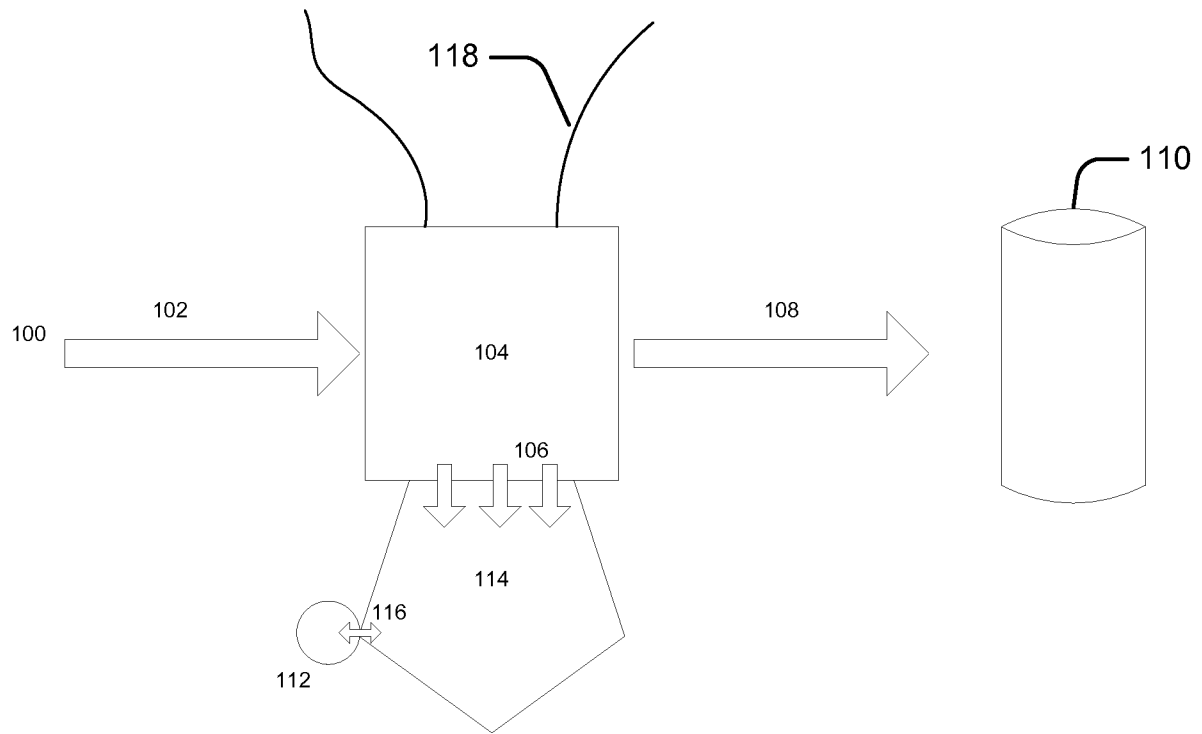


Figure 6

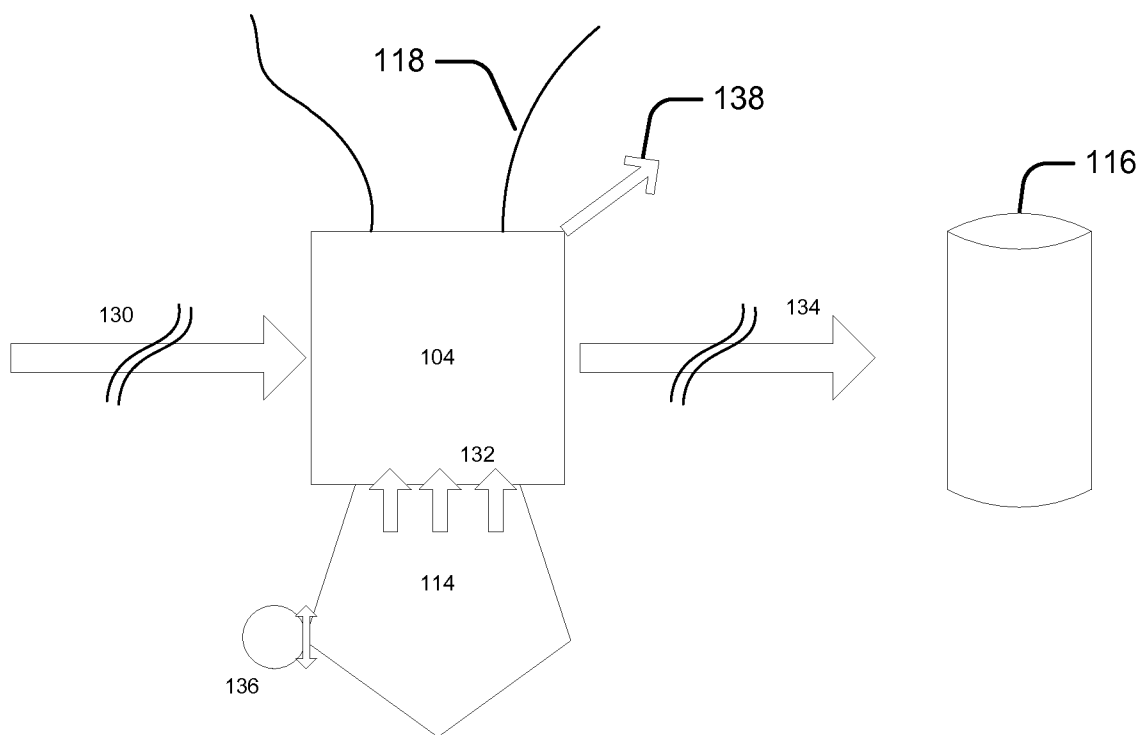


Figure 7

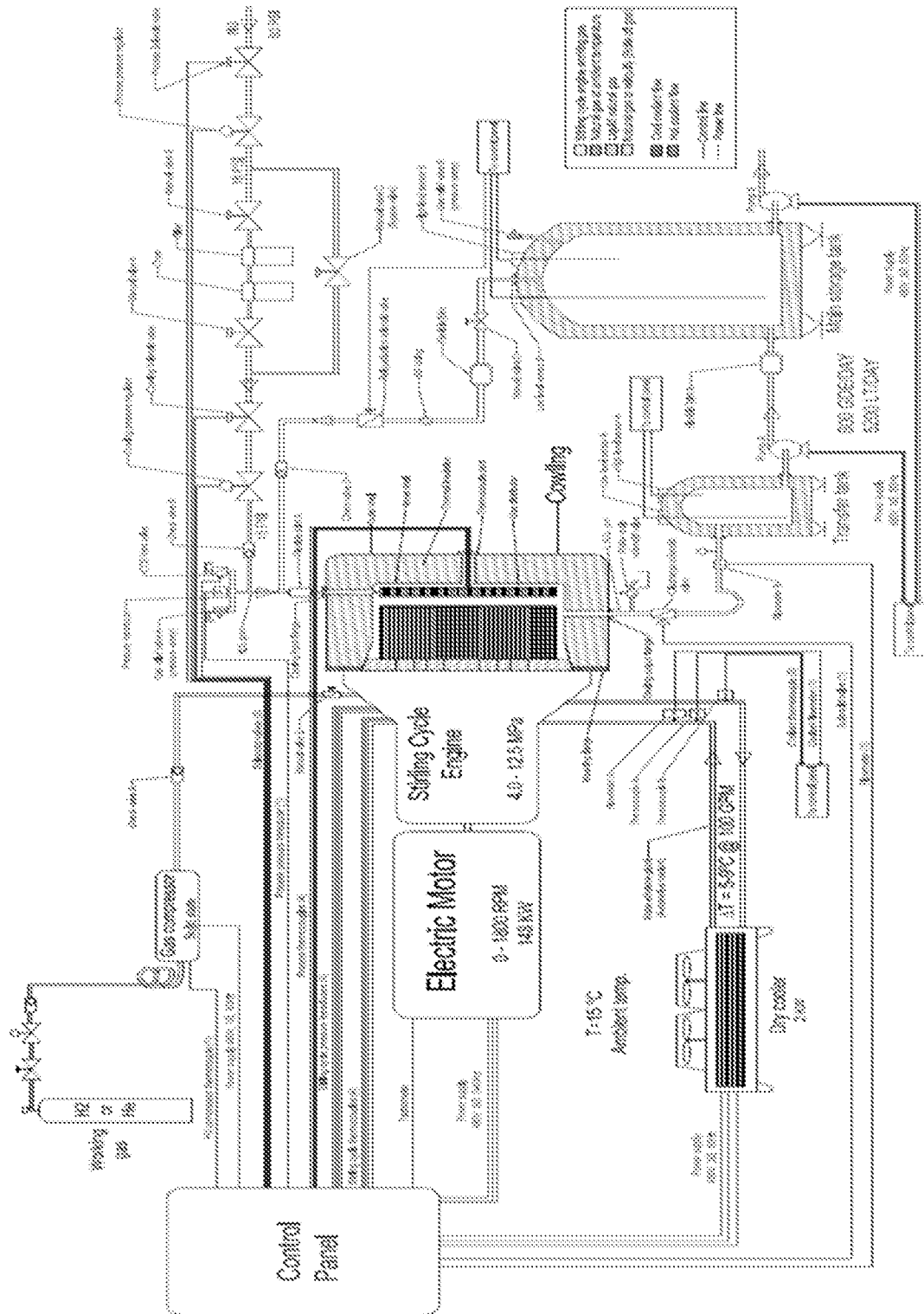


Figure 7 A)

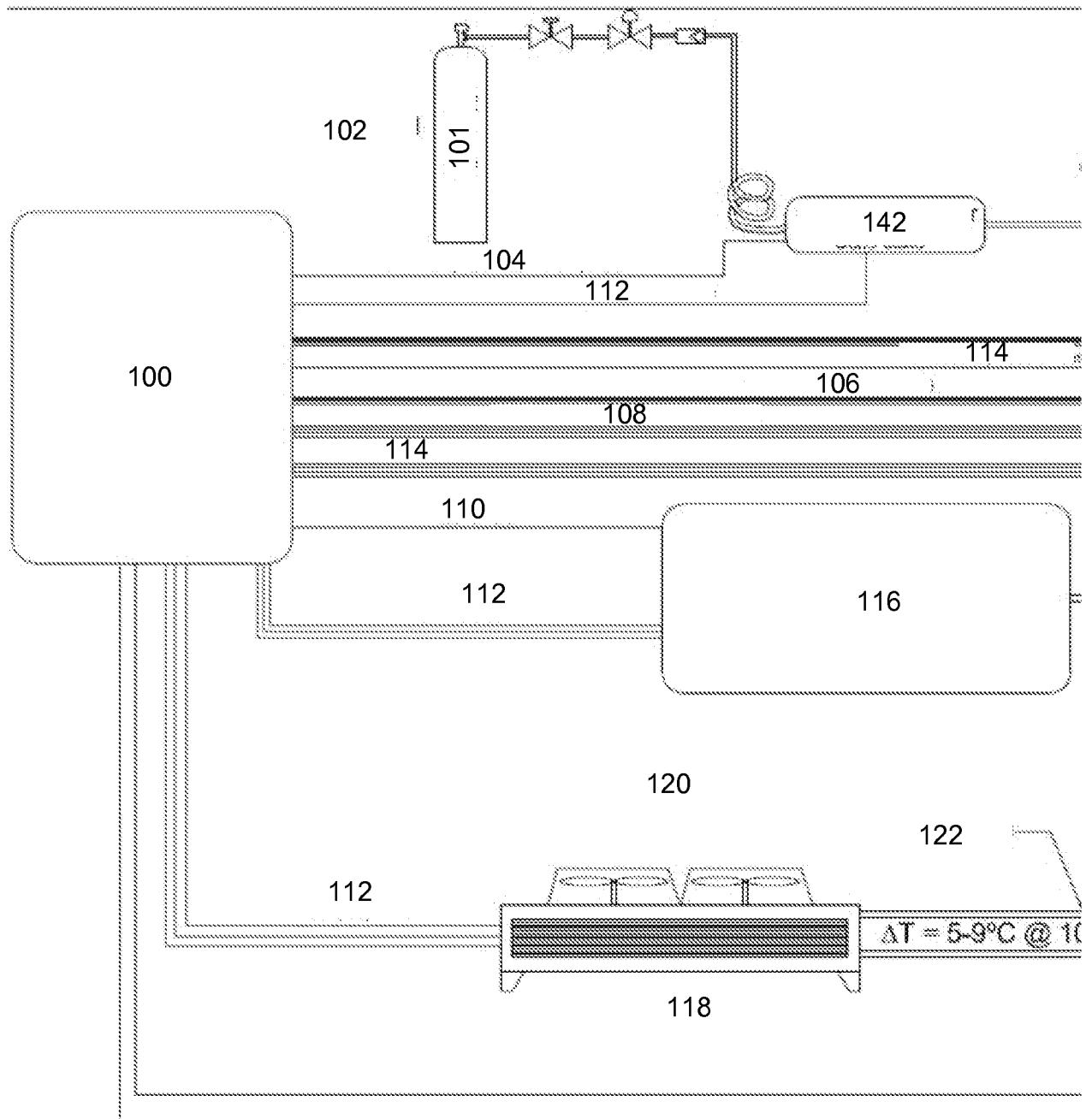


Figure 7 b)

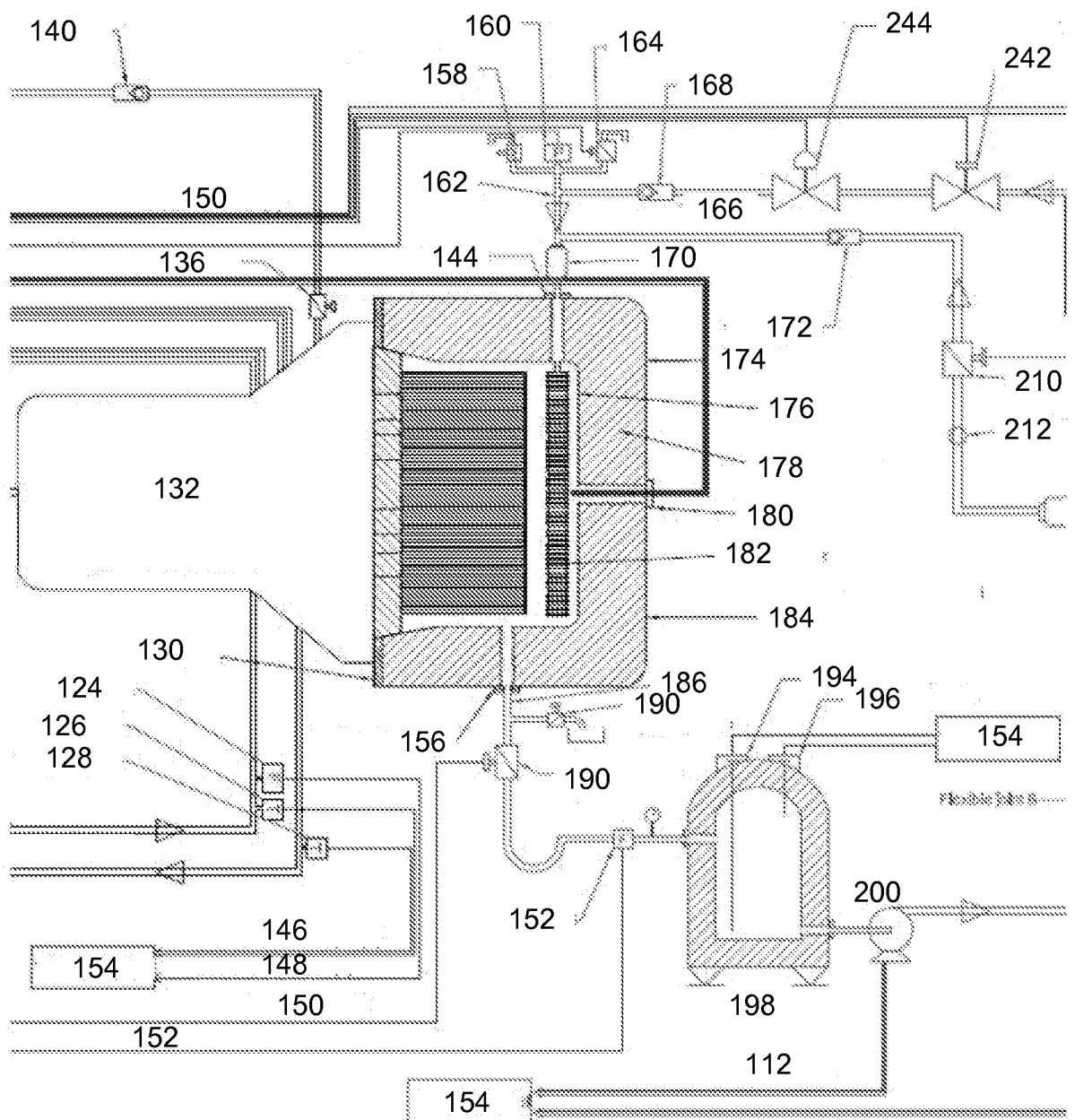


Figure 7 c)

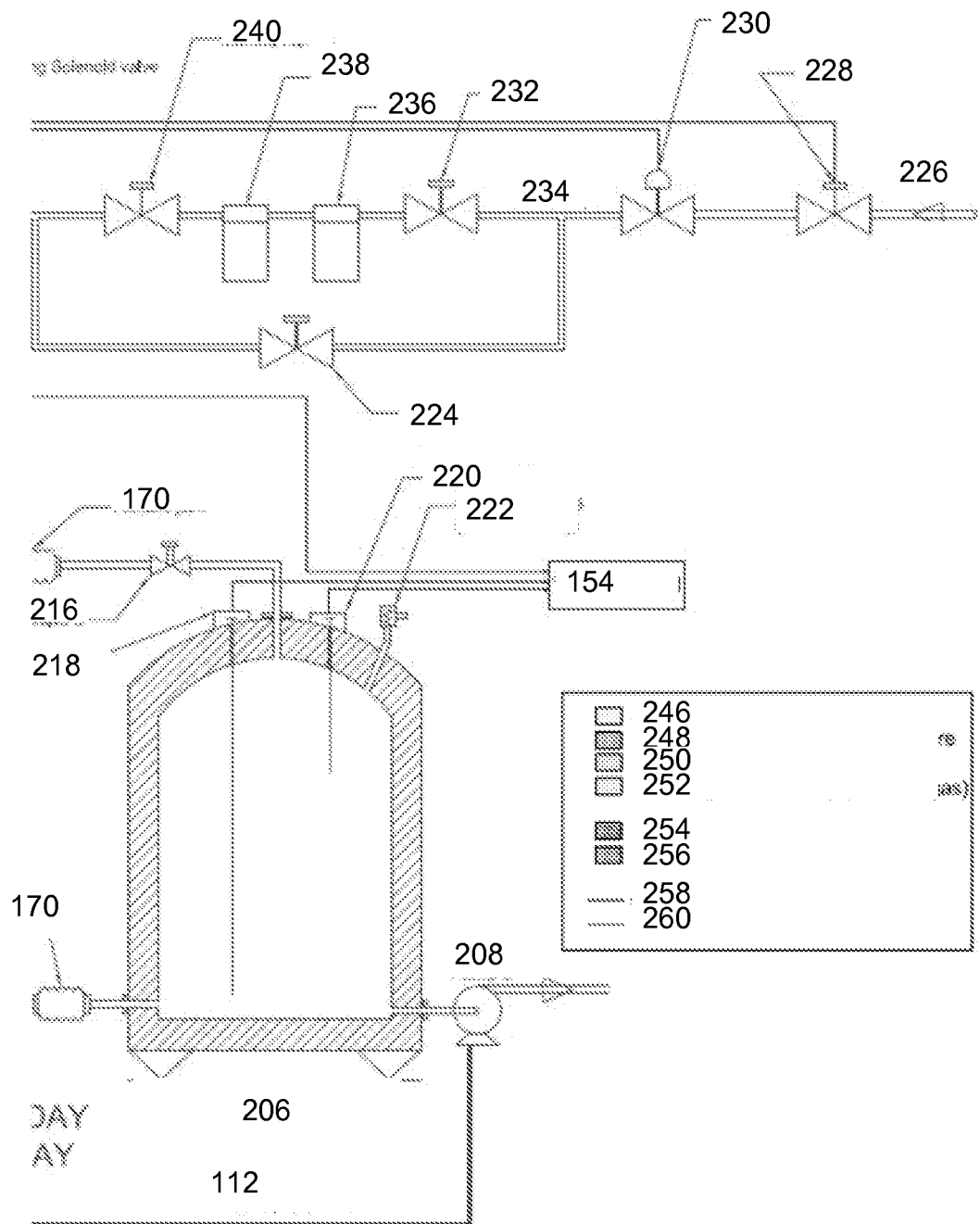
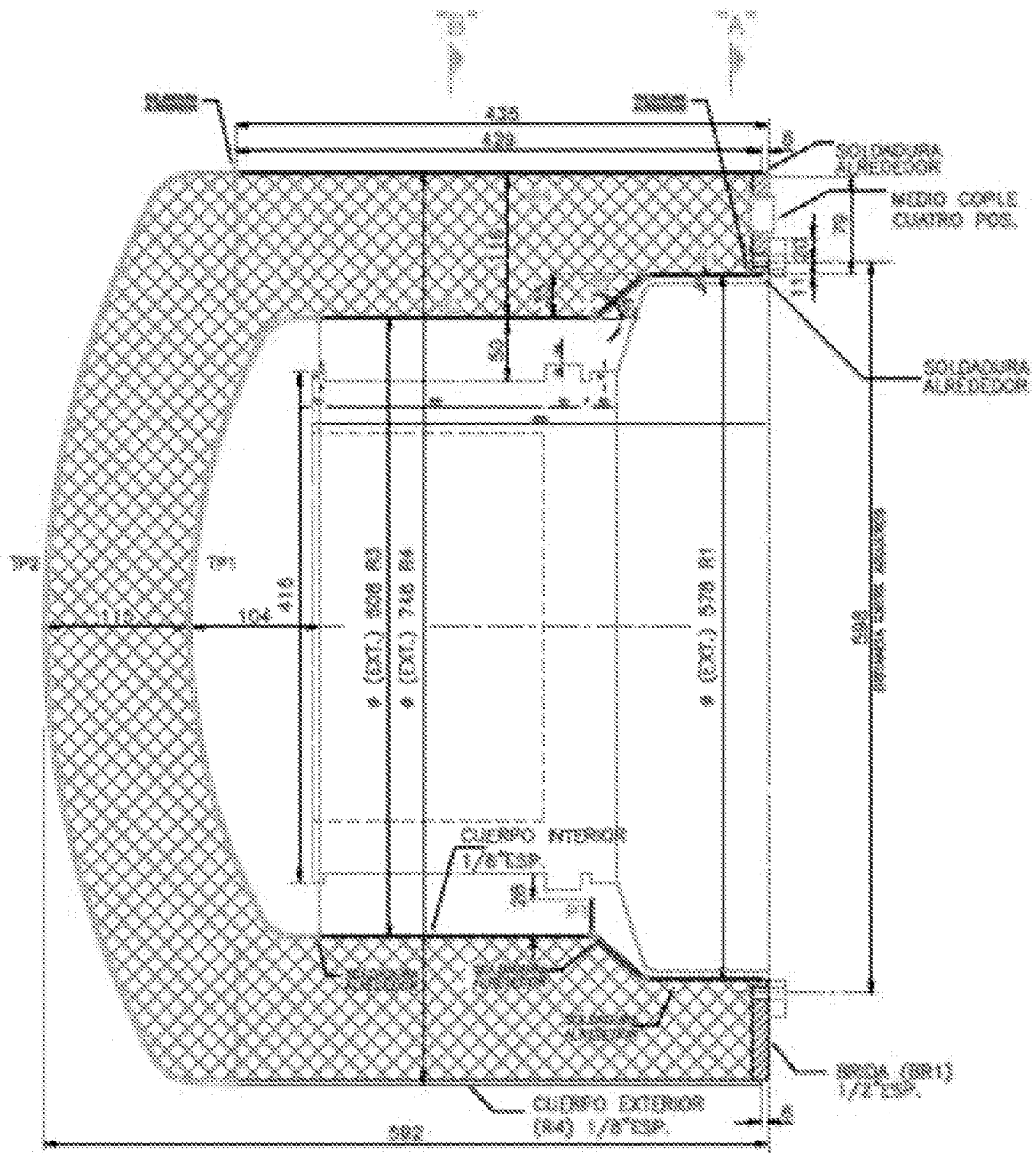


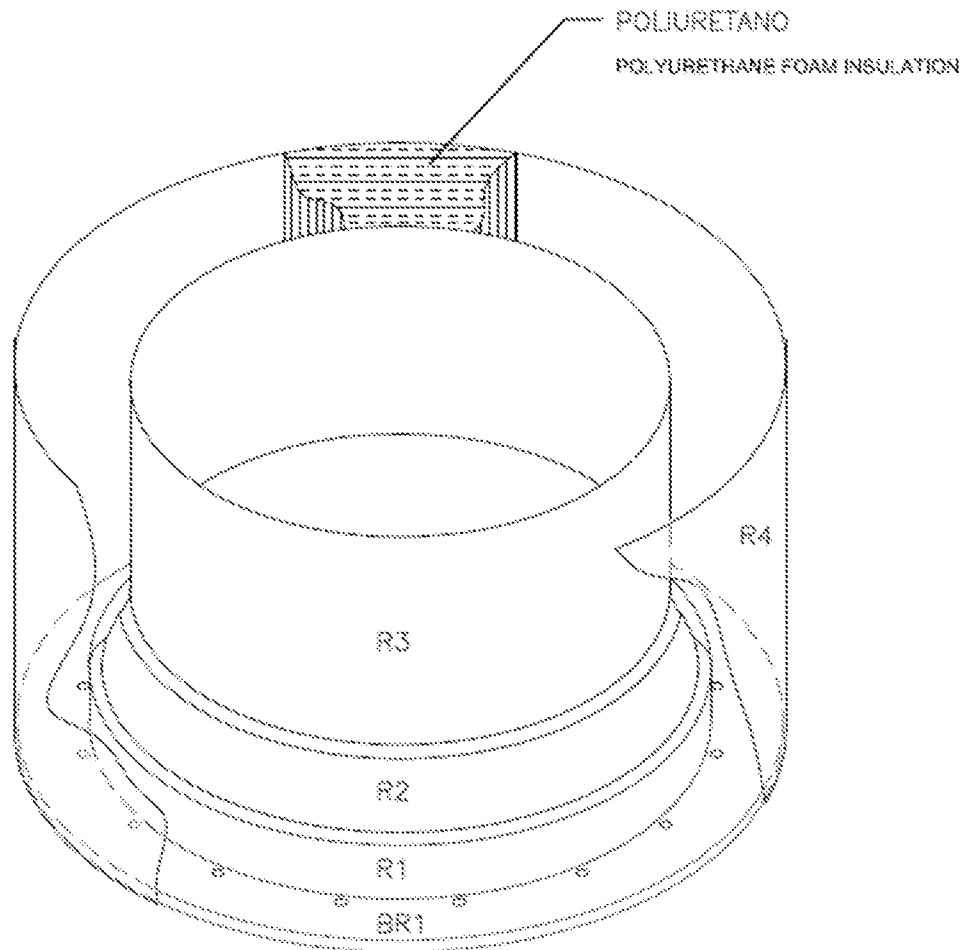
Figure 8



CAMPANA ENSAMBLE
MOTOR

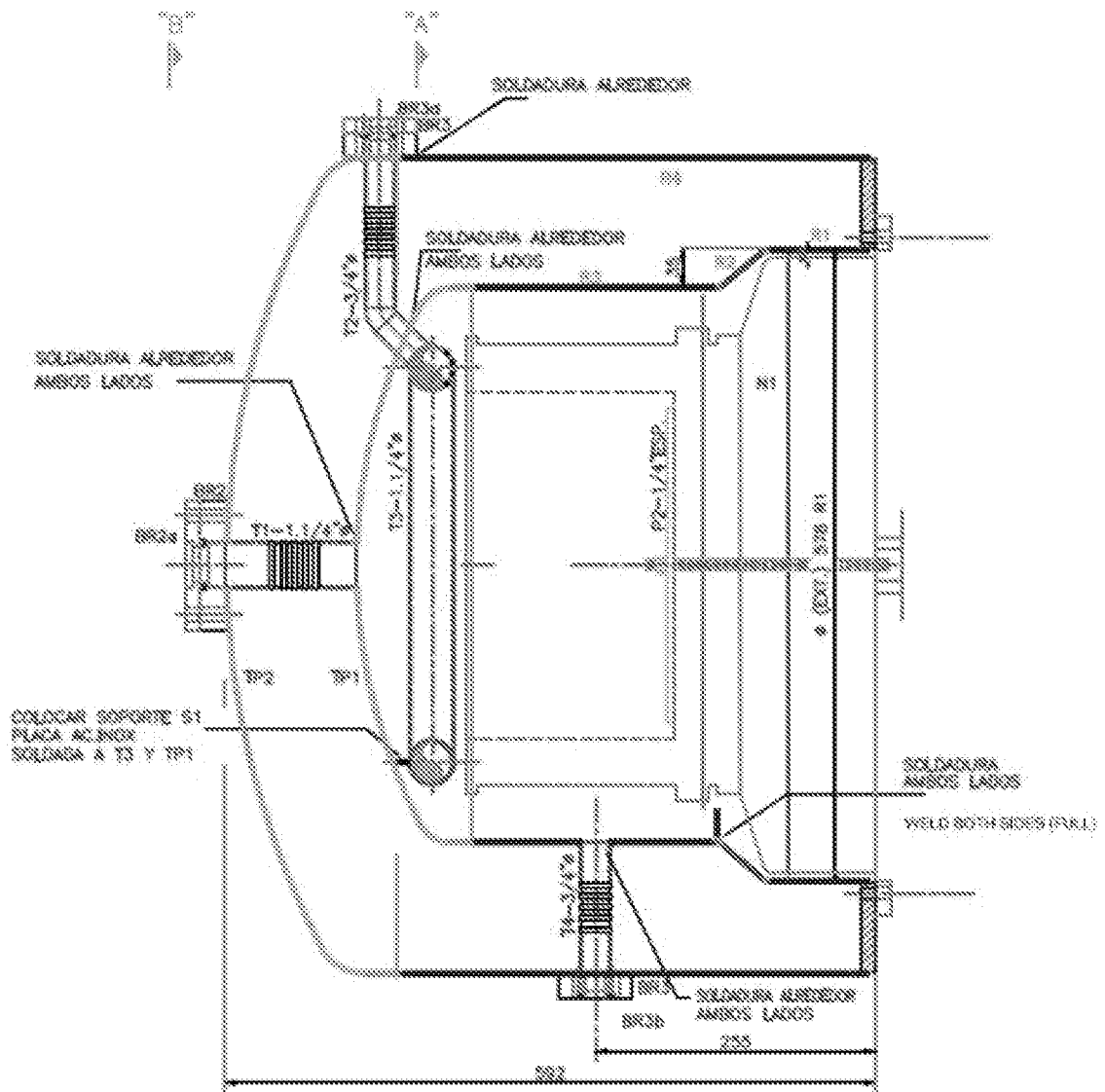
COWLING ASSEMBLY
STIRLING ENGINE

Figure 9



ISOMETRICO (ENSAMBLE)
 ENSAMBLE
 COWLING 3D ASSEMBLY

Figure 10



CAMPANA (VISTA LATERAL)

MOTOR ARREGLO DE TUBERIAS

COWLING SIDE VIEW

MOUNTING TO STIRLING REFRIGERATOR

Figure 11

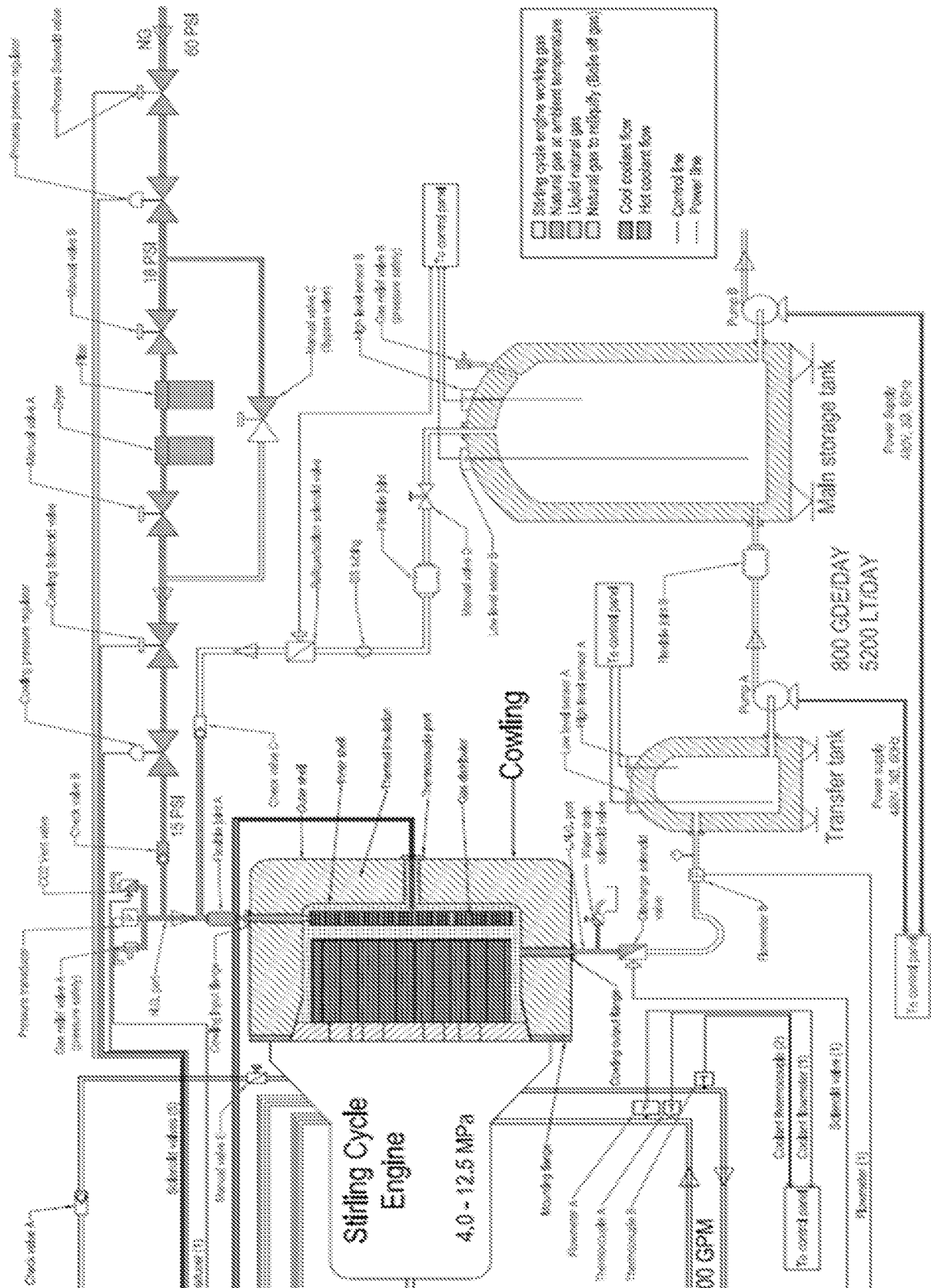


Figure 12

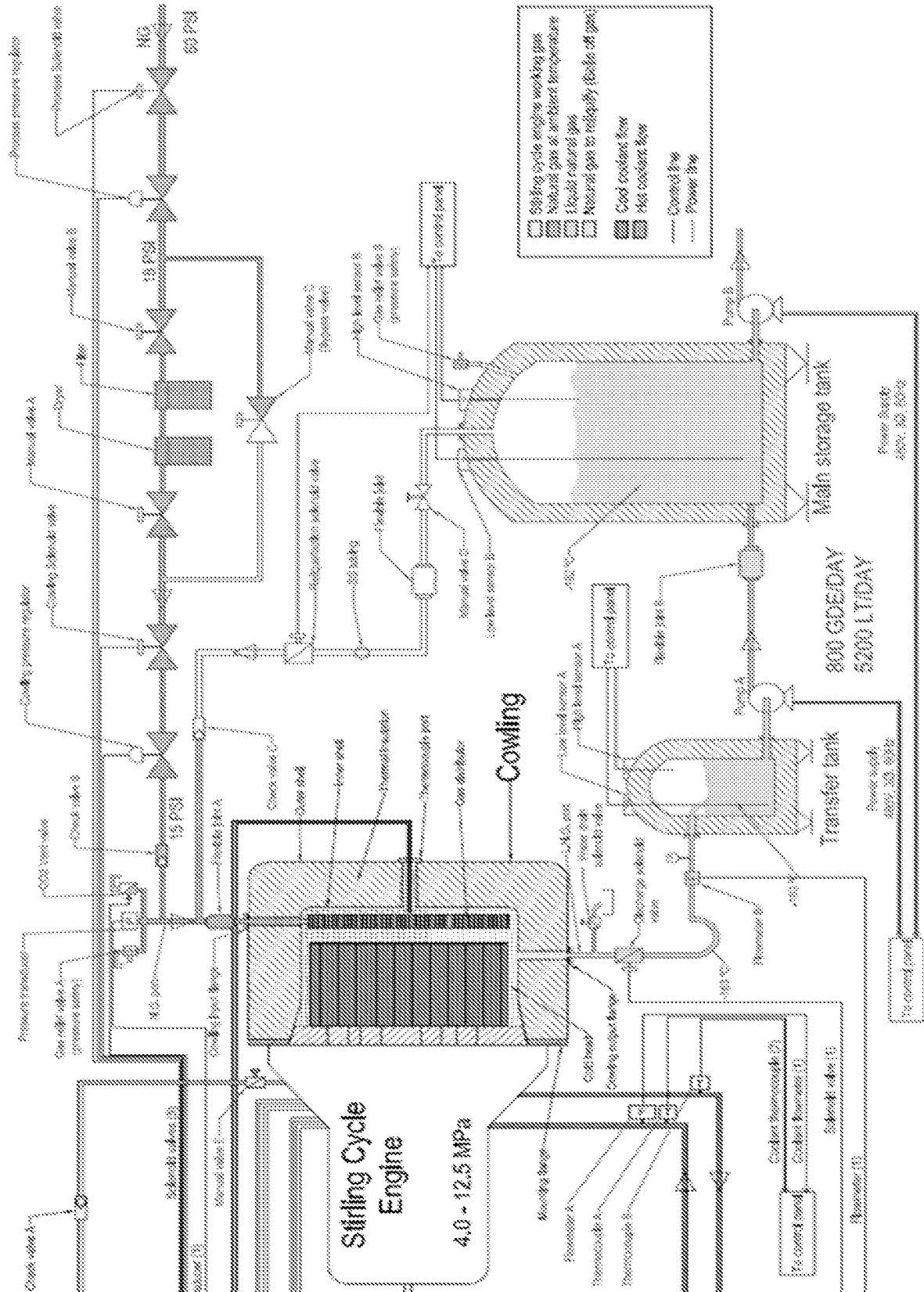


Figure 13

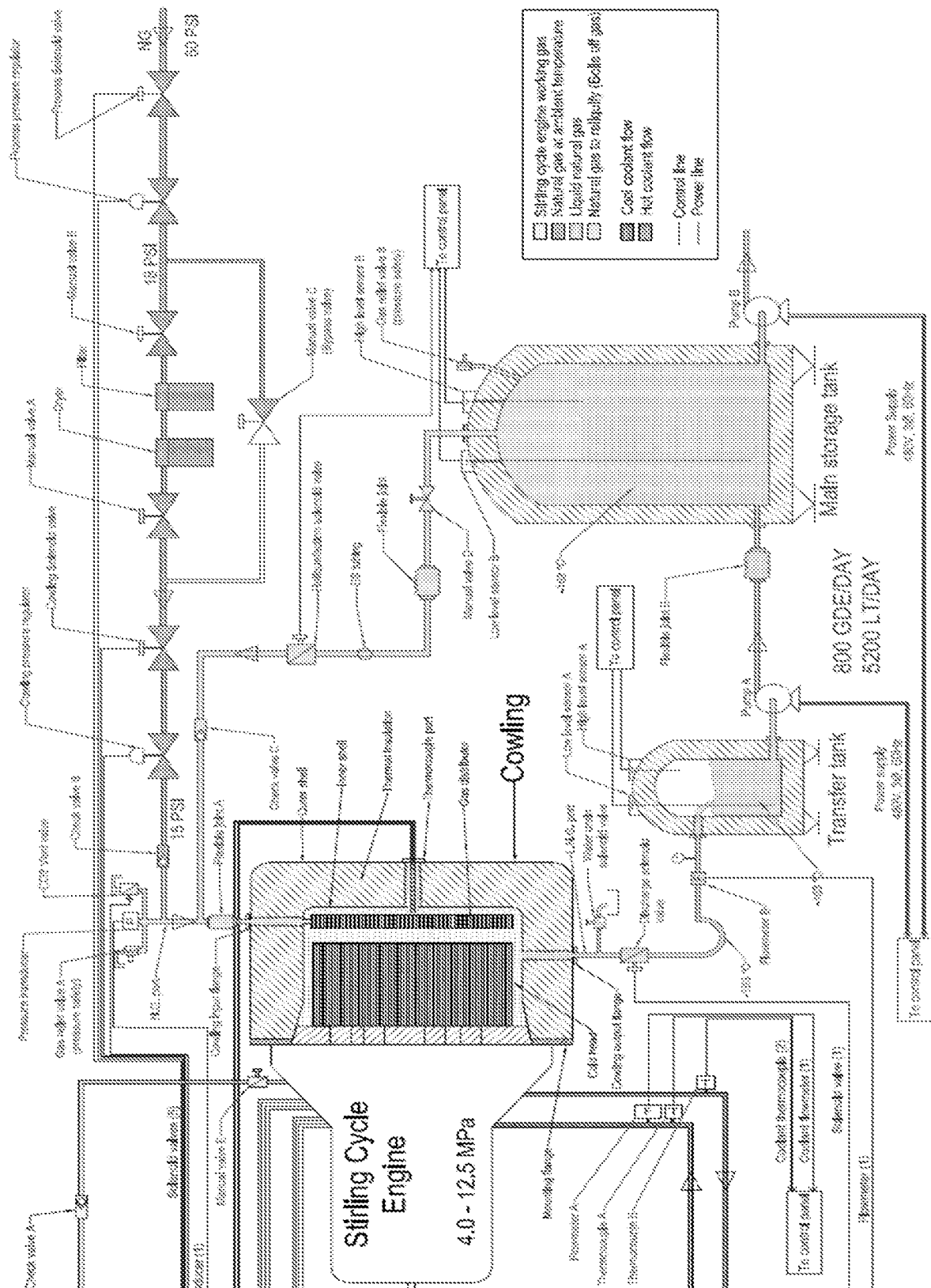


Figure 14

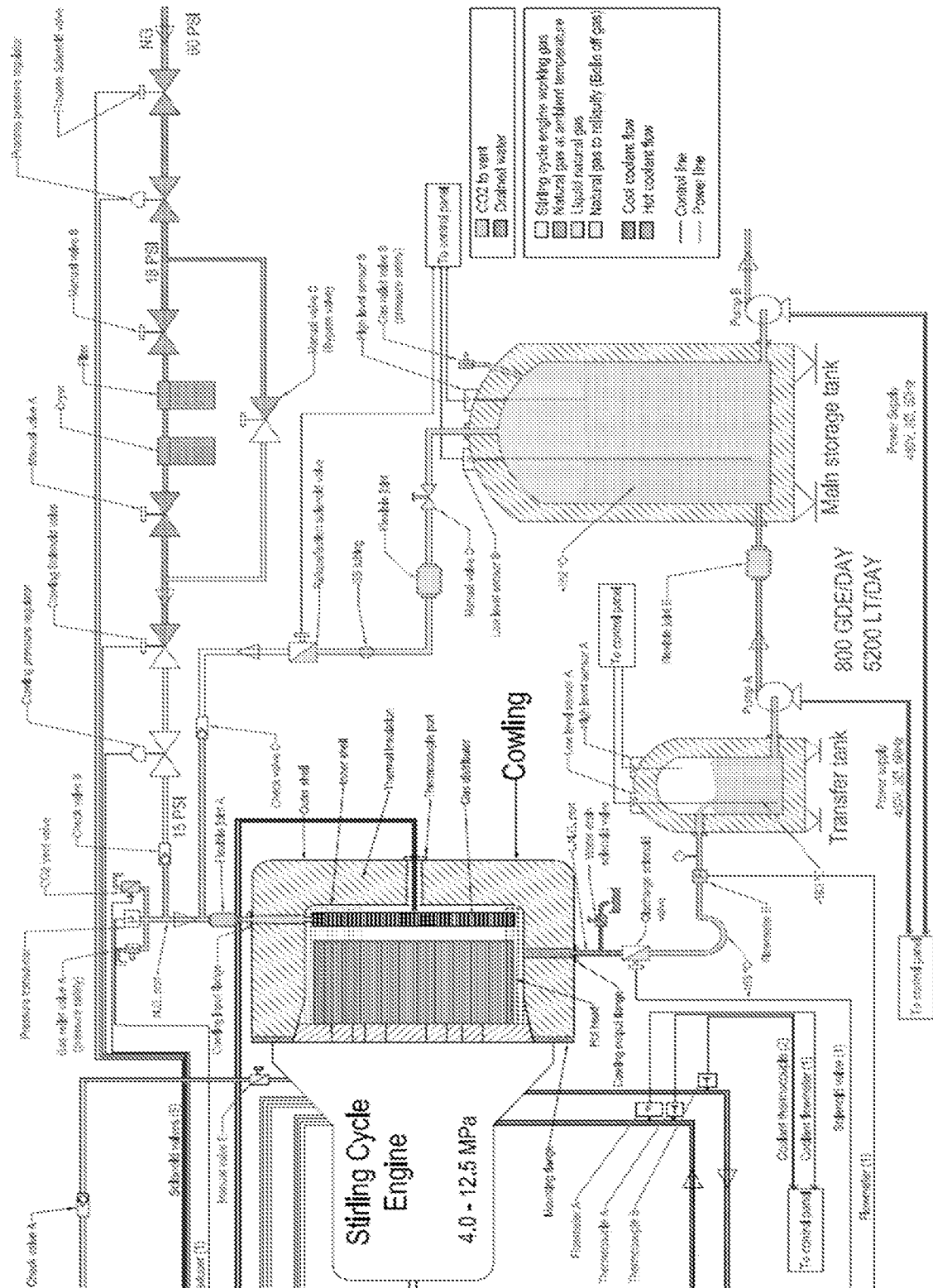


Figure 15 b)

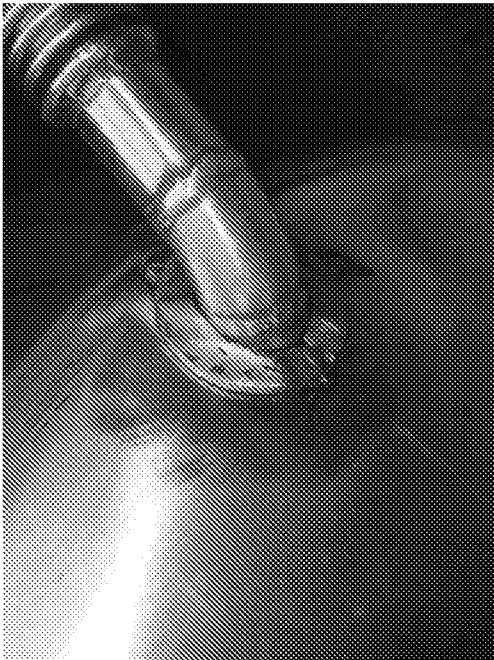


Figure 15 c)

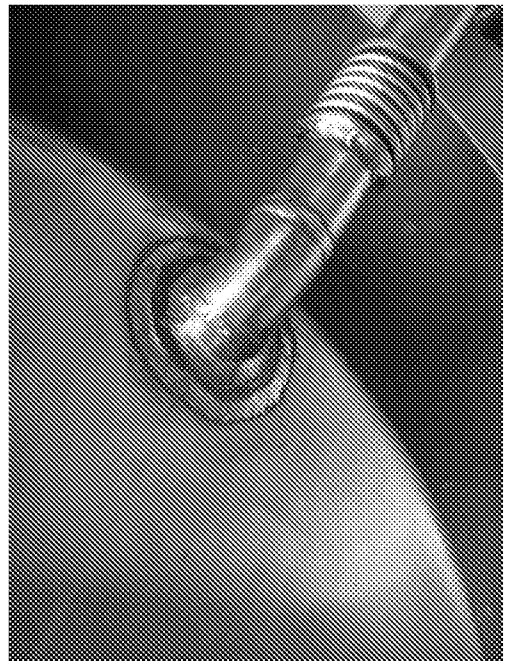


Figure 15 a)



Figure 16 b)

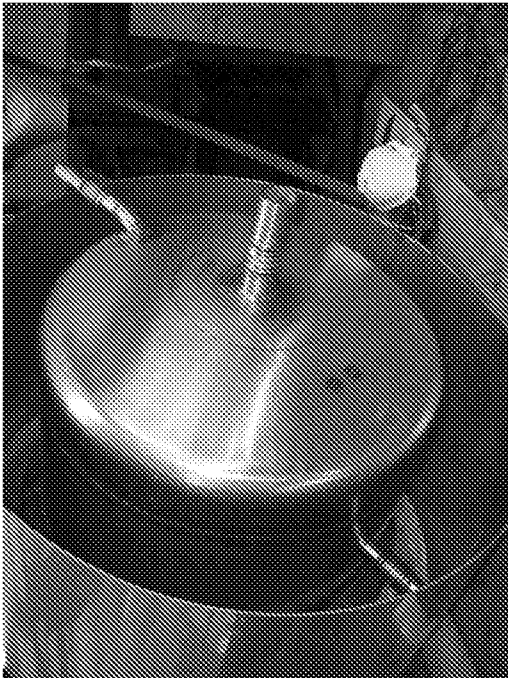


Figure 16 c)

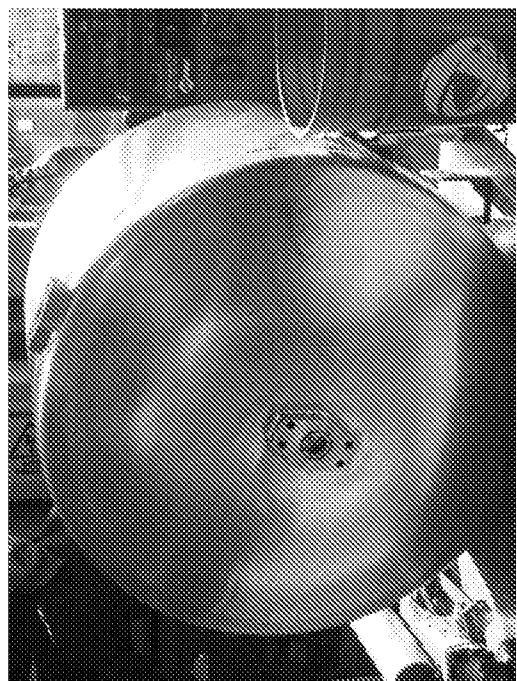


Figure 16 a)

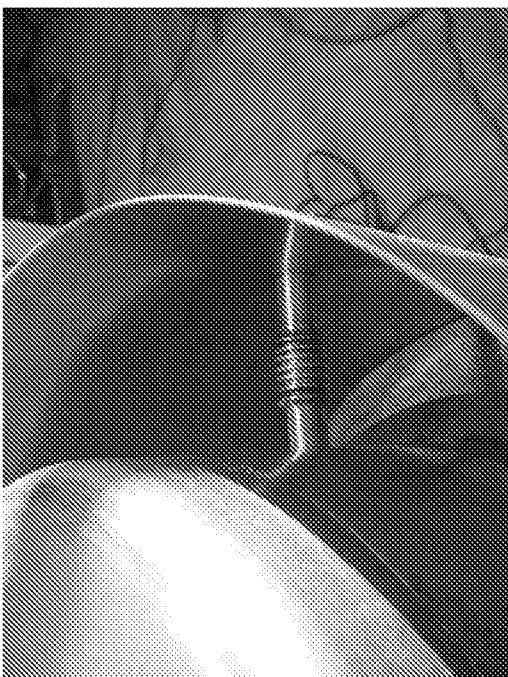


Figure 17 a)



Figure 17 b)

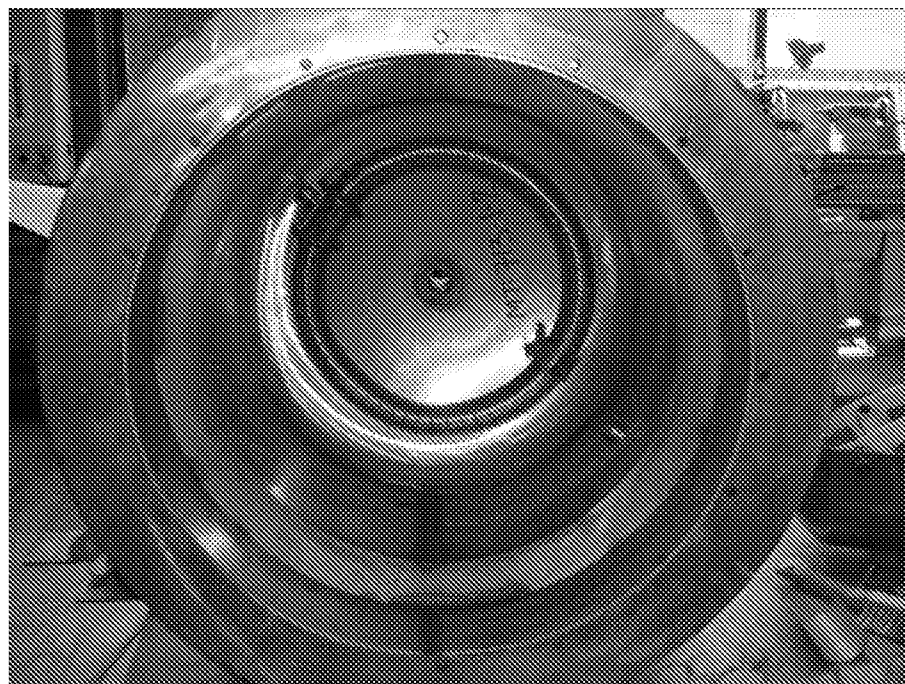


Figure 18

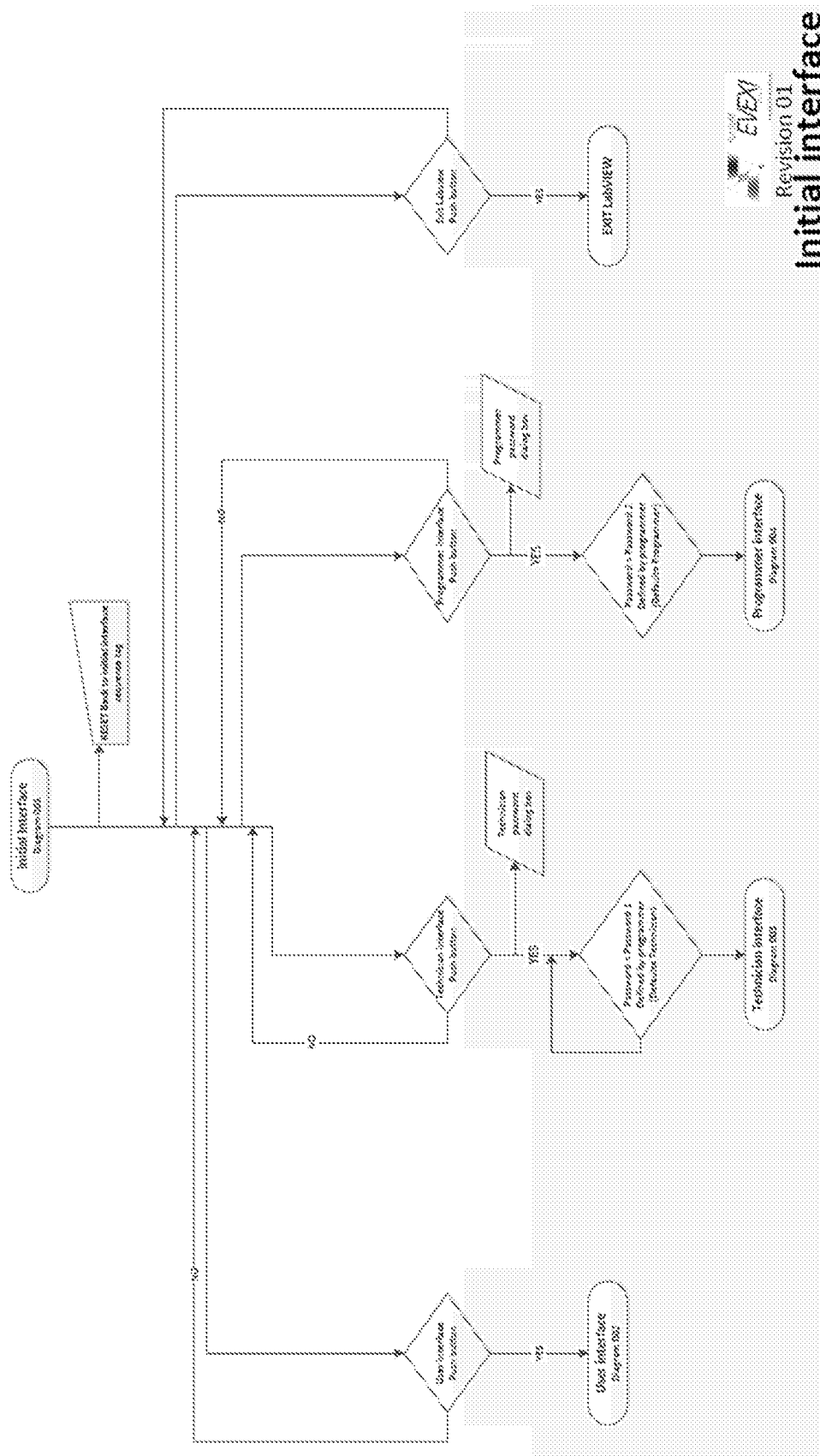
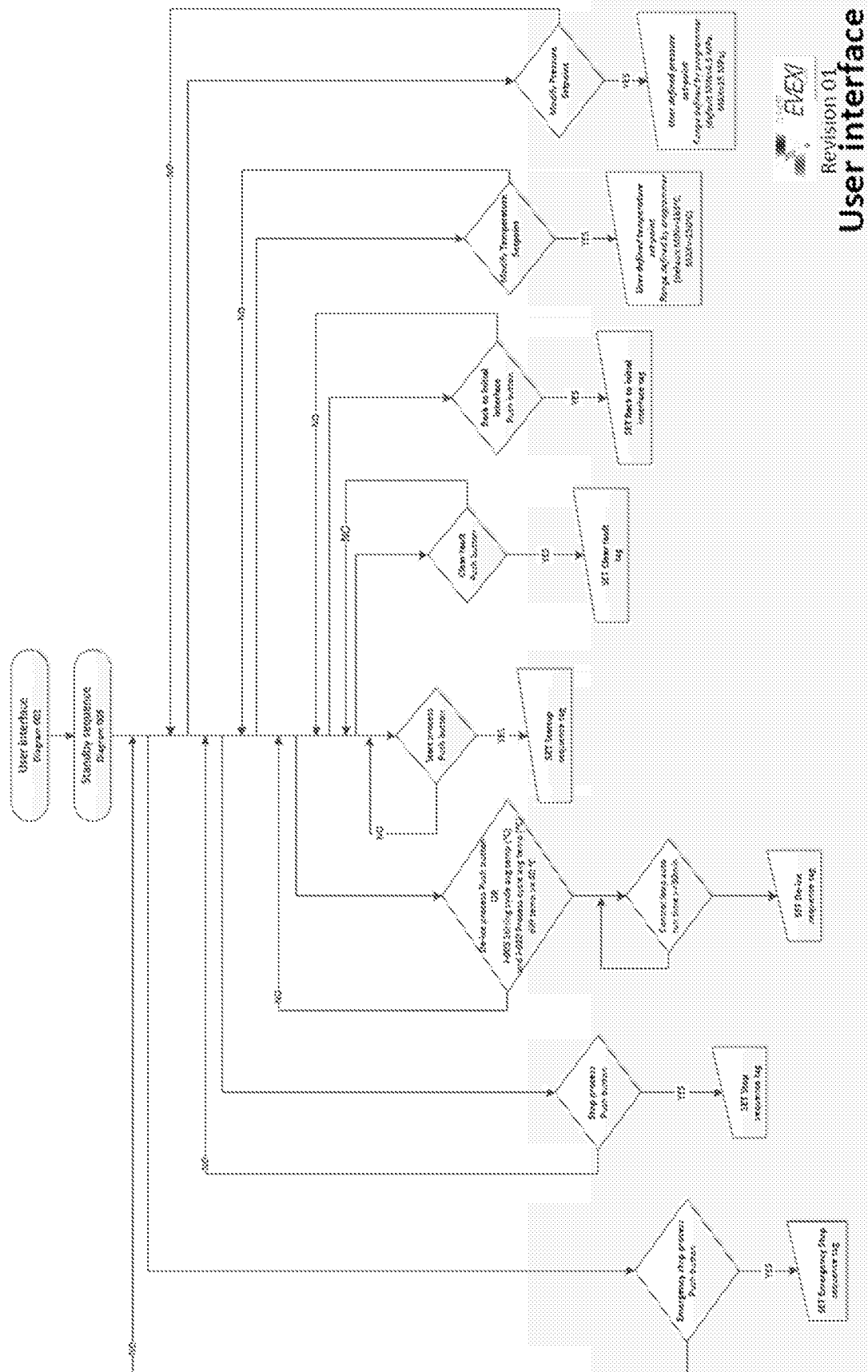


Figure 19



Revision 01
User interface

Figure 20

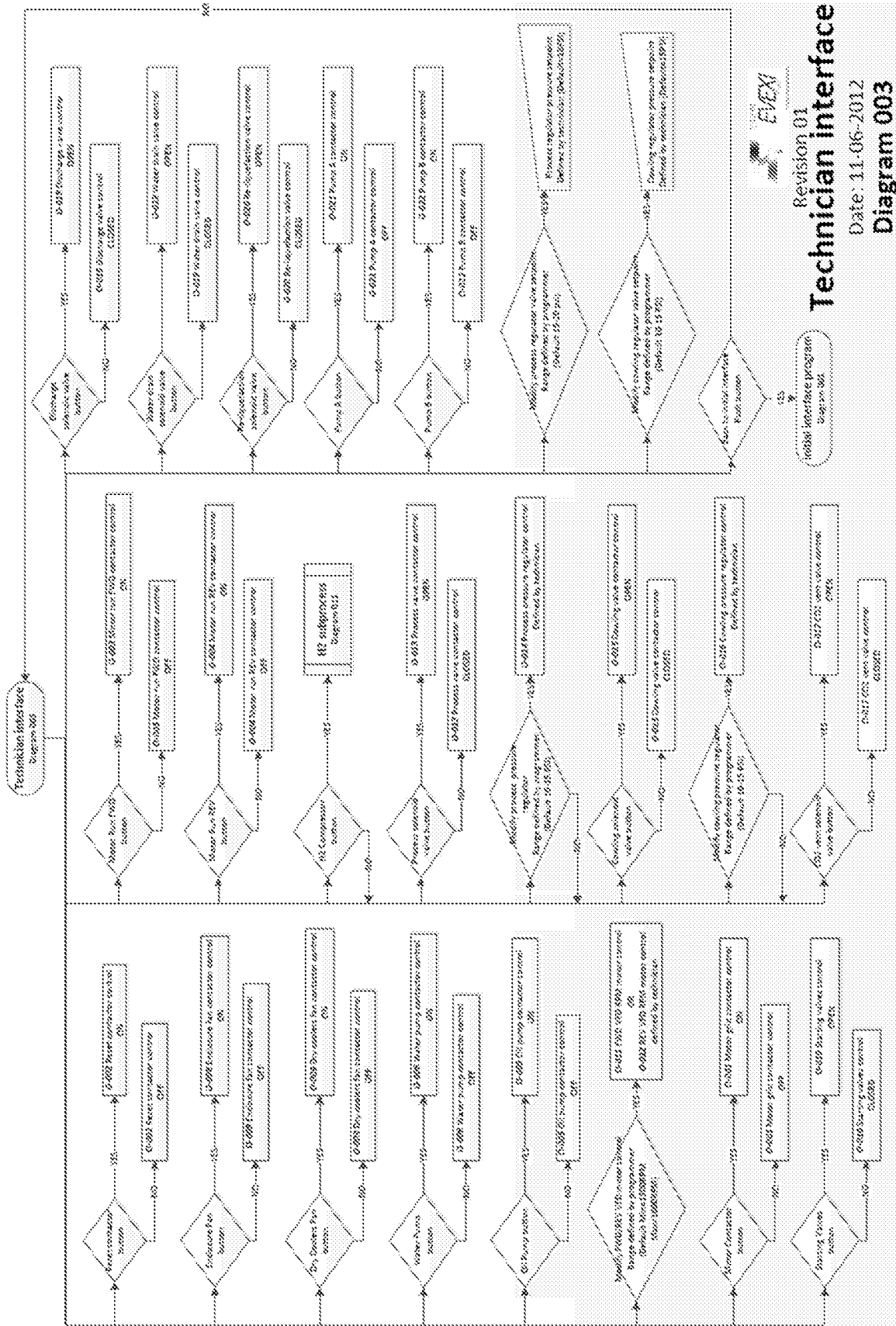


Figure 21

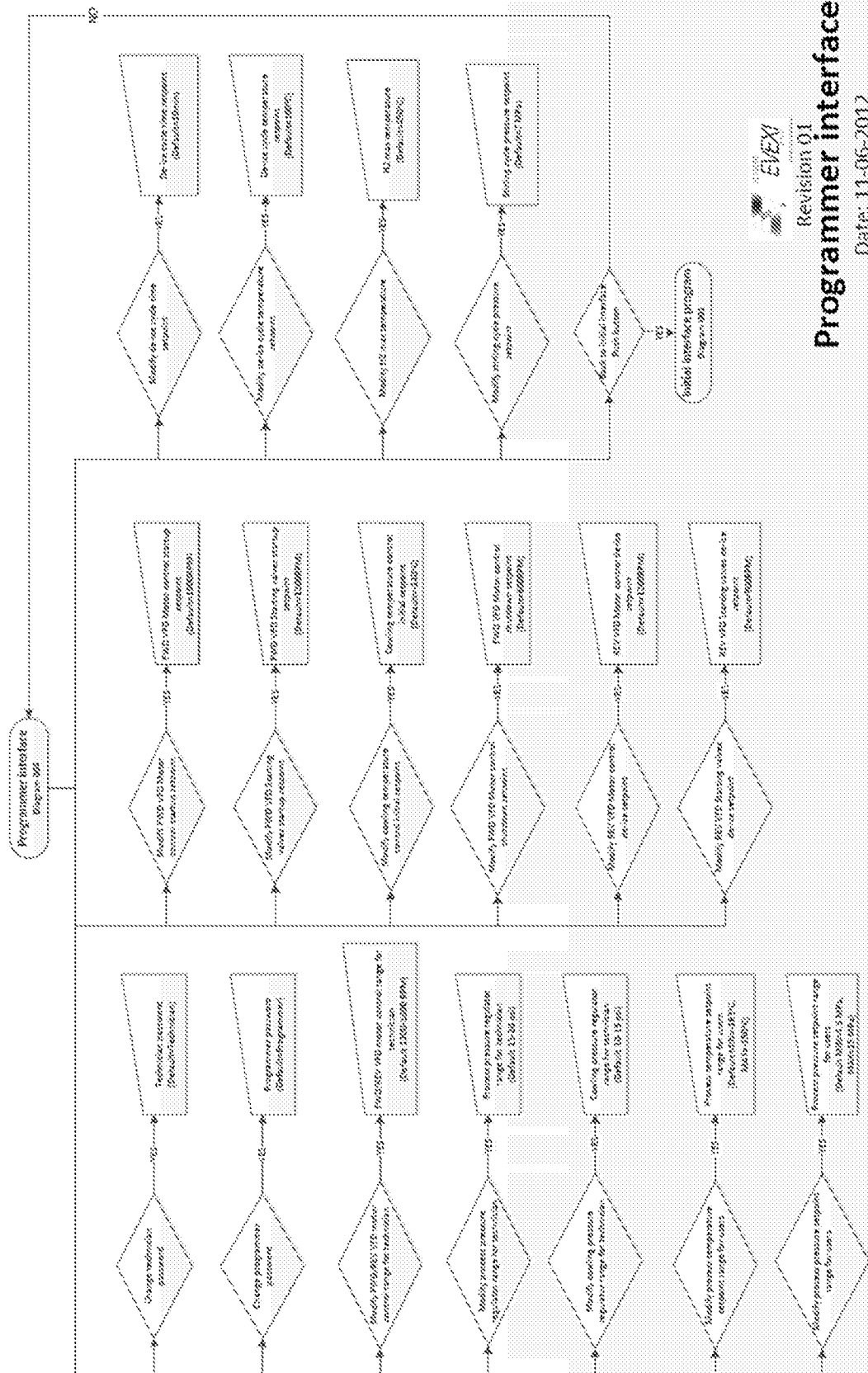


Figure 22

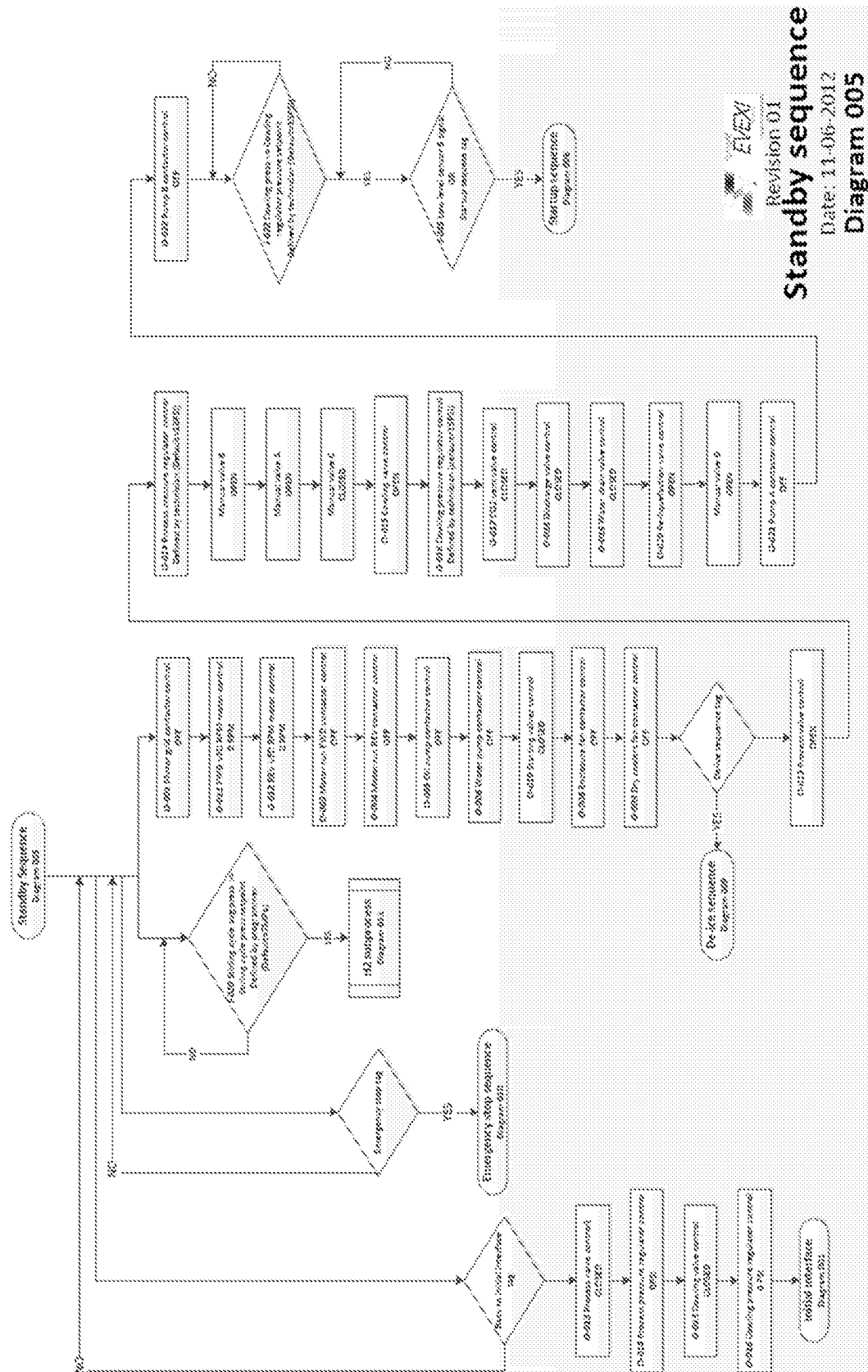


Figure 23

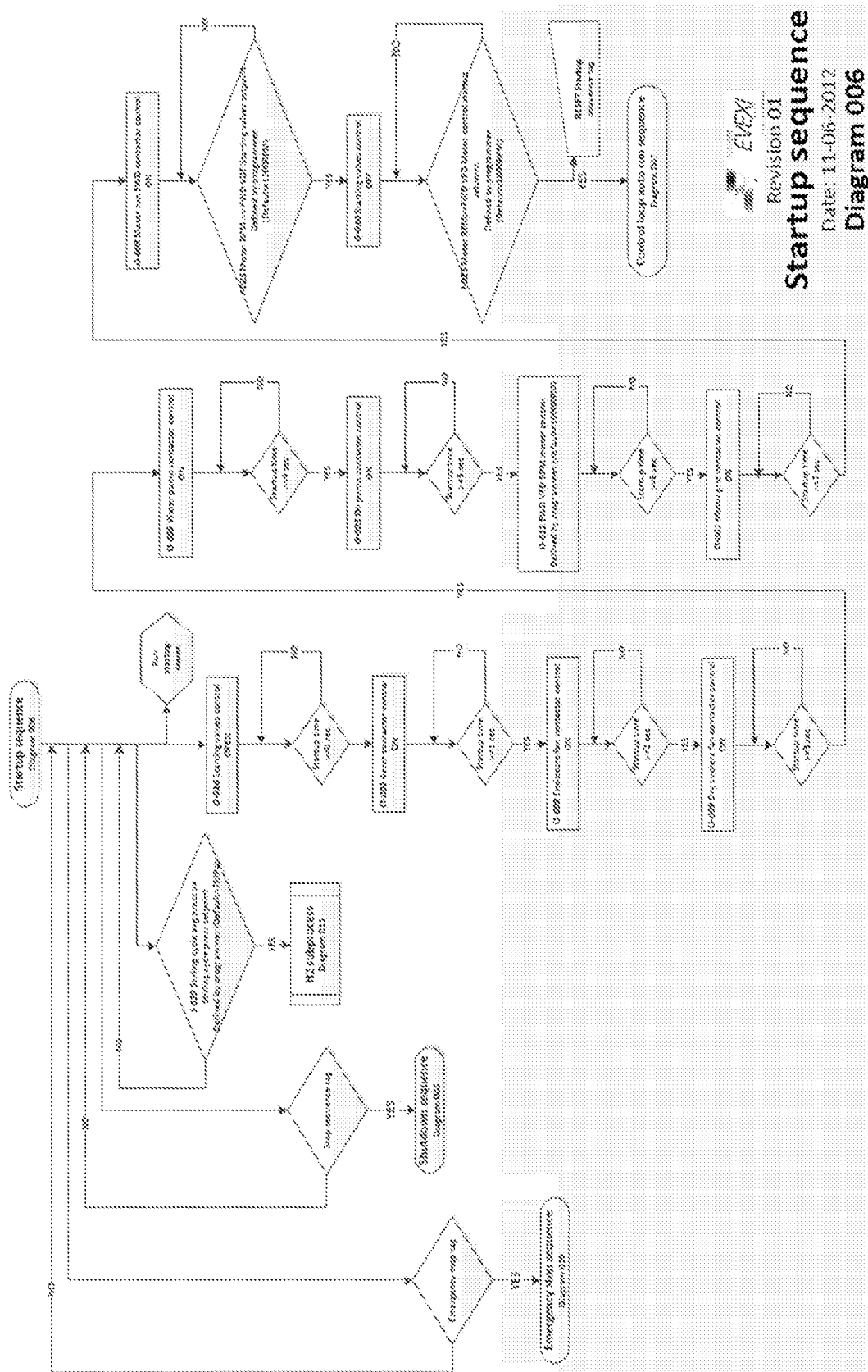


Figure 24

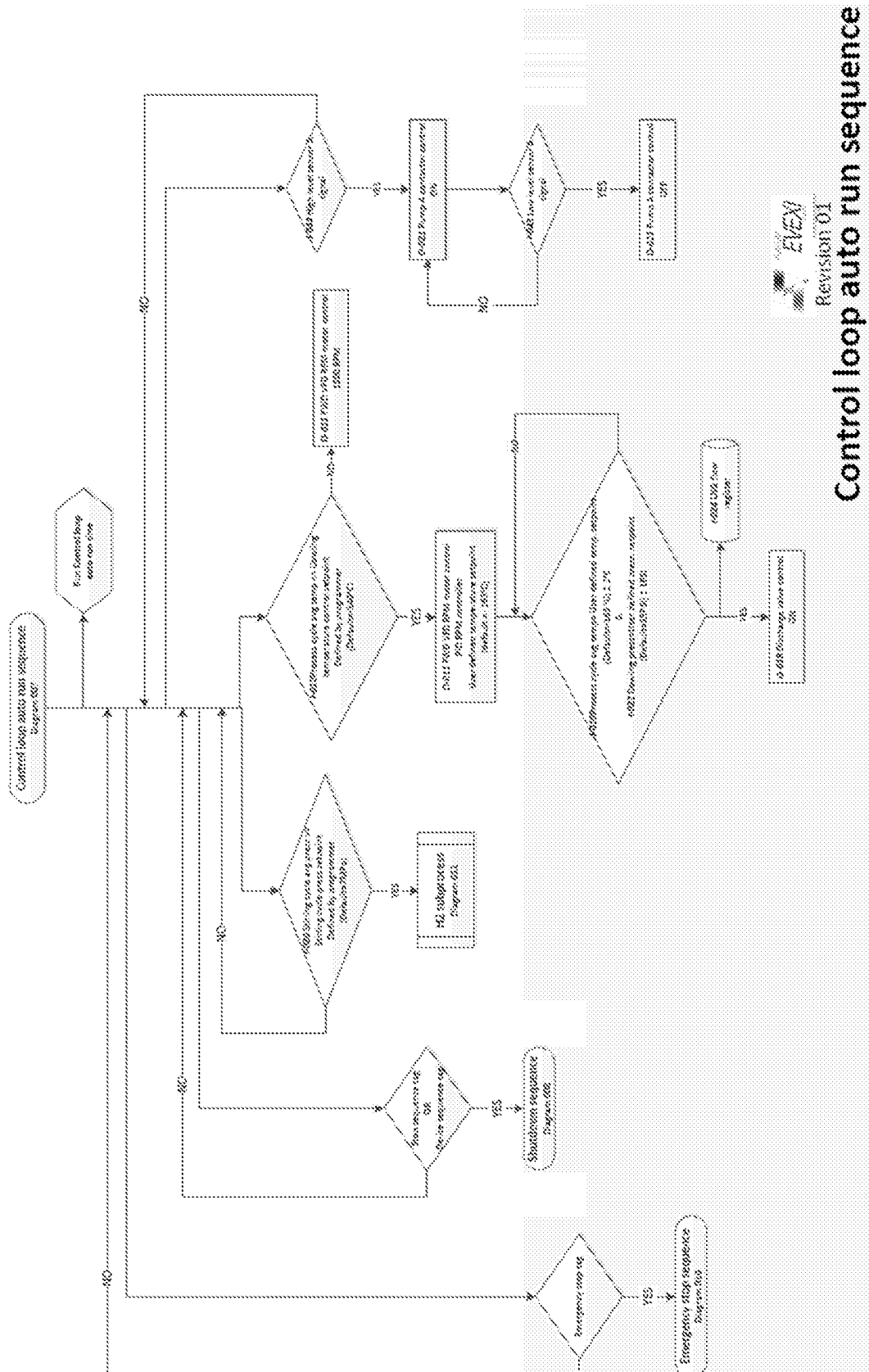


Figure 25

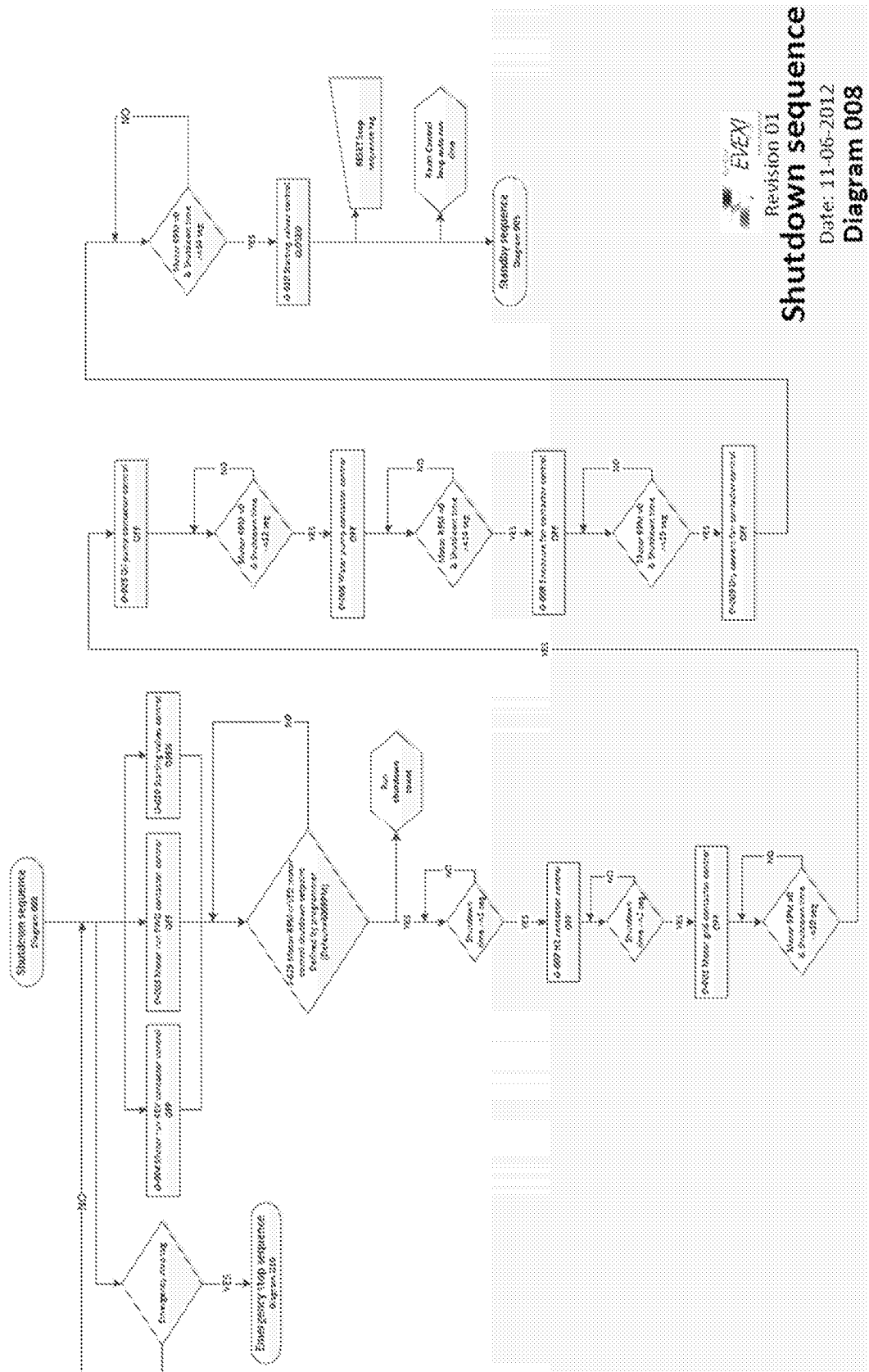


Figure 26

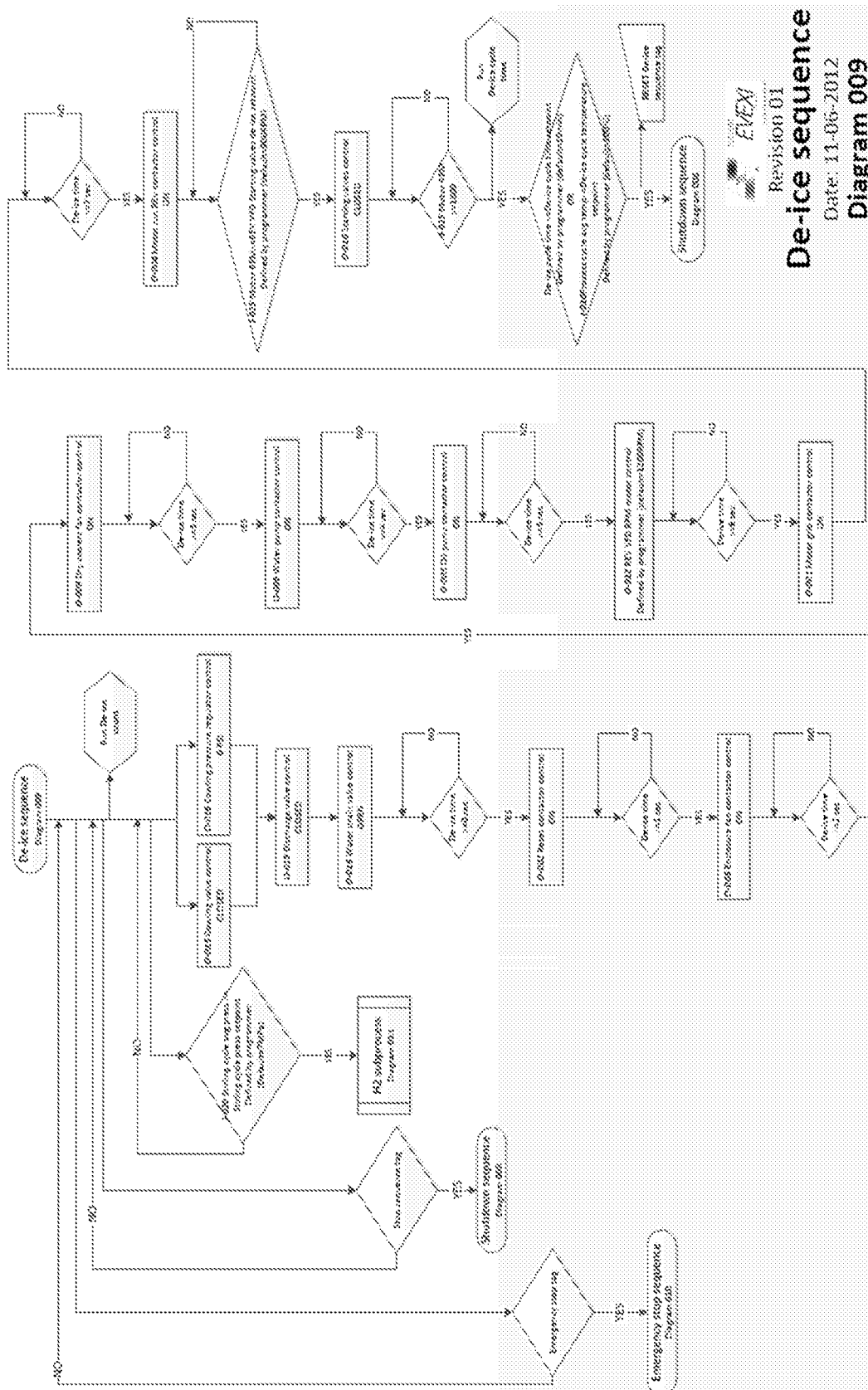


Figure 27

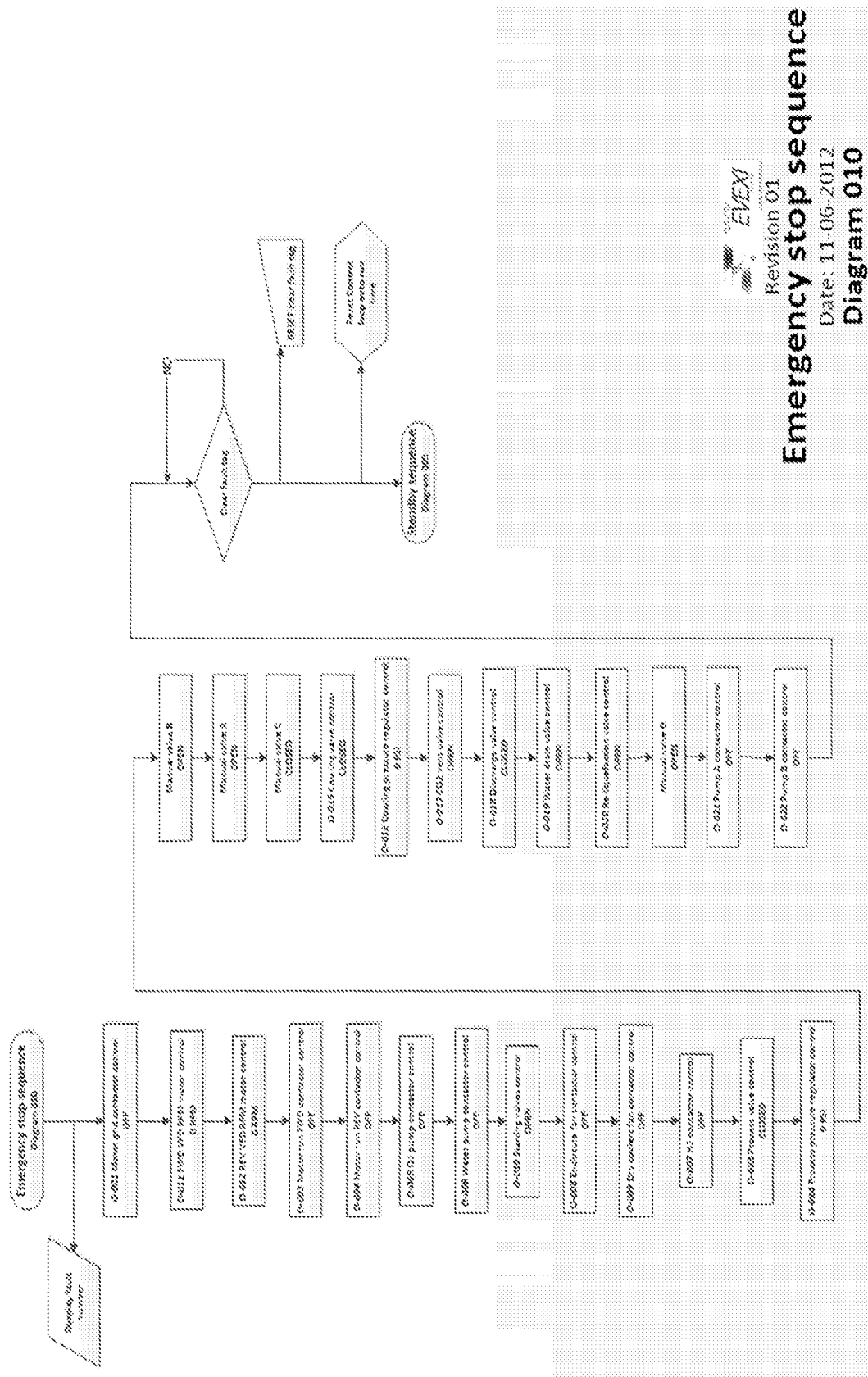


Figure 28

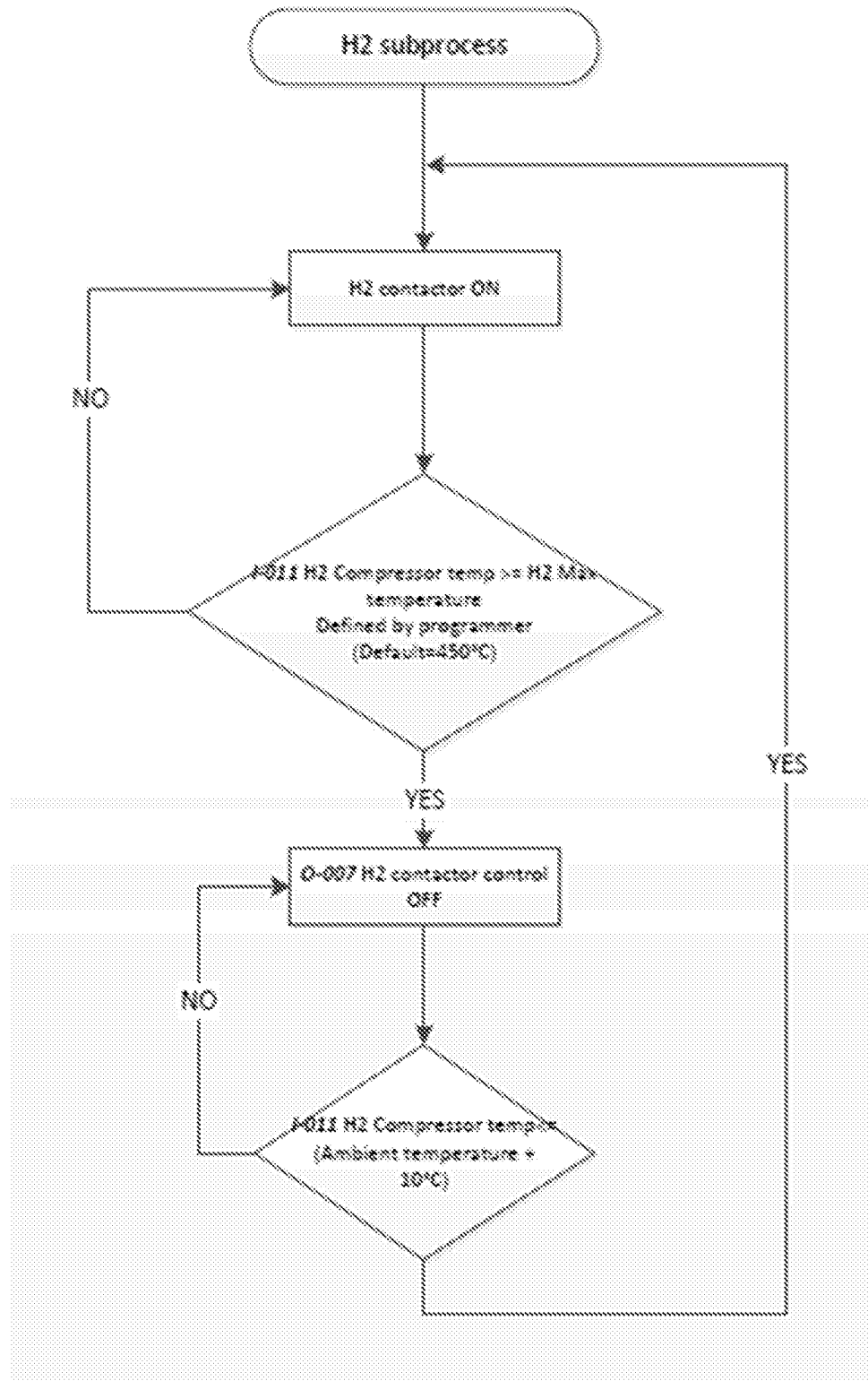


Figure 29

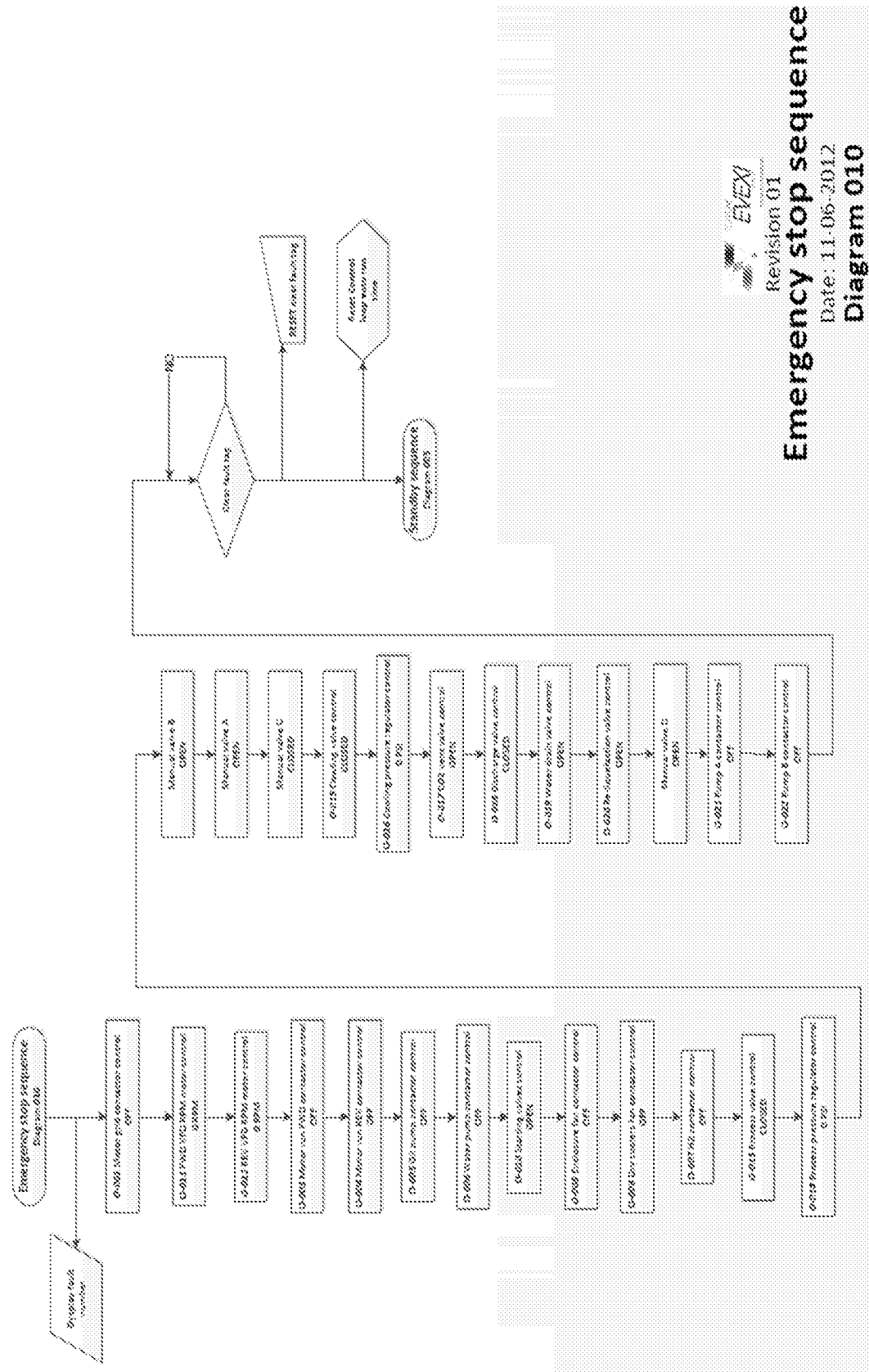


Figure 30

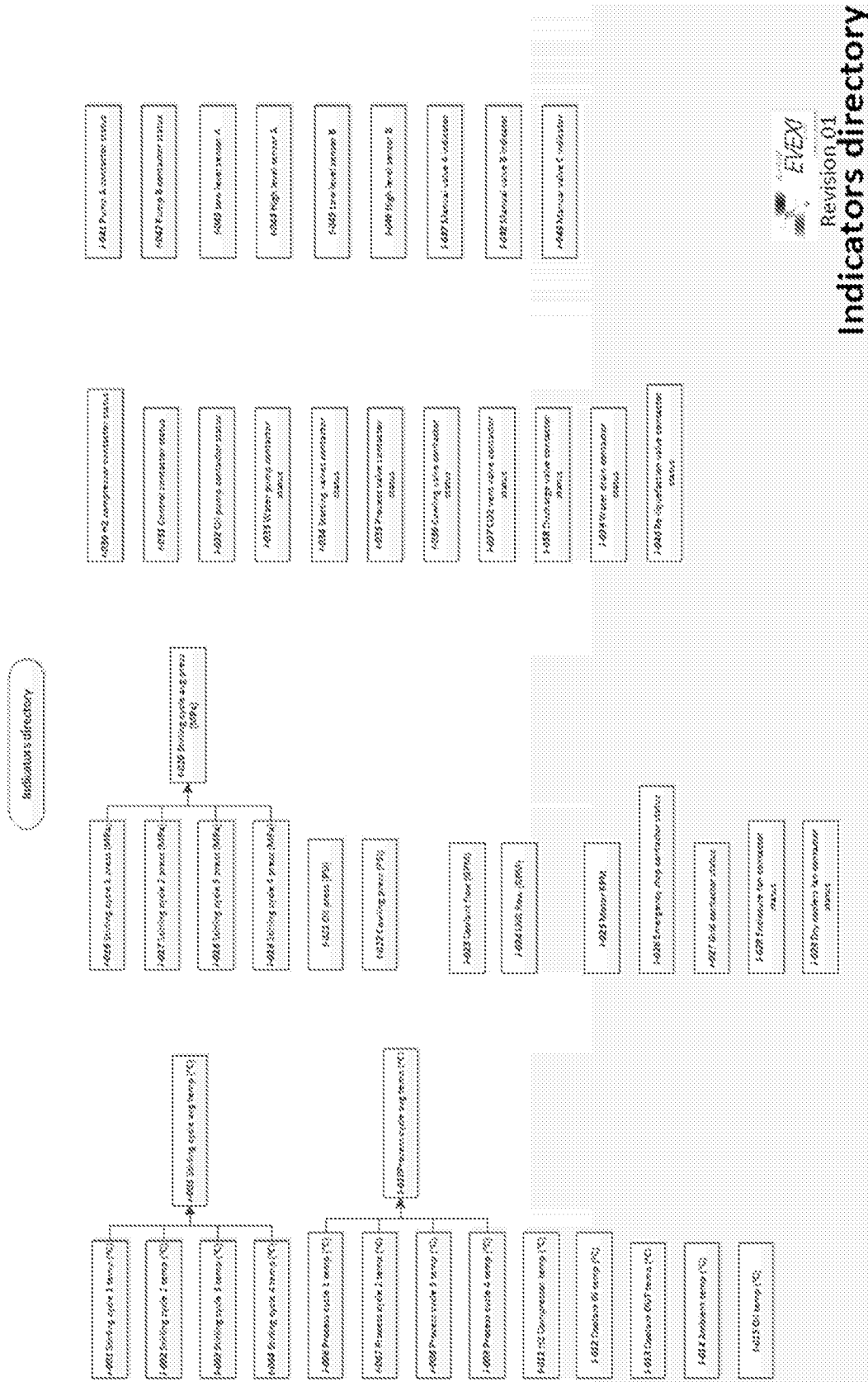


Figure 31

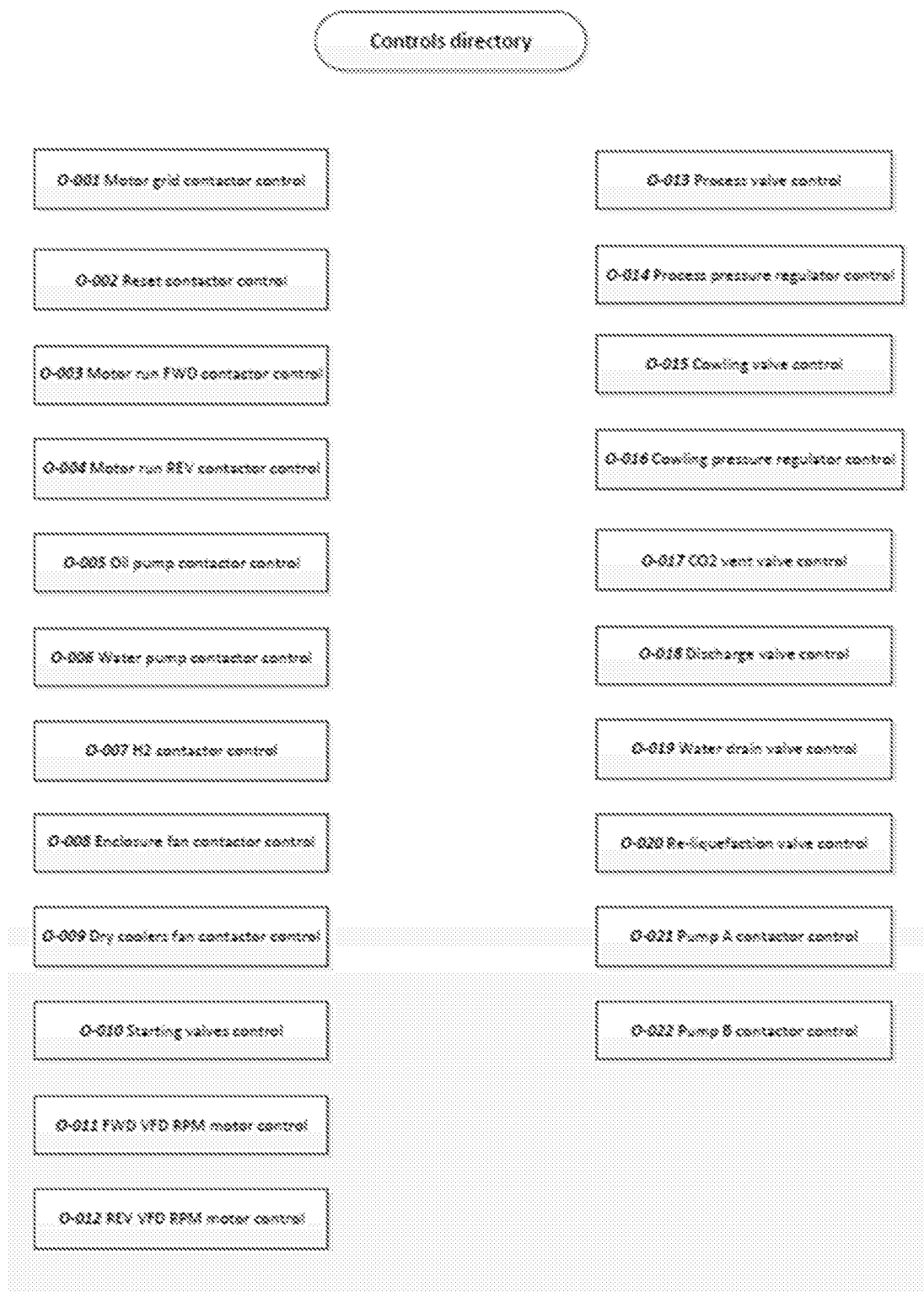


Figure 32 a)

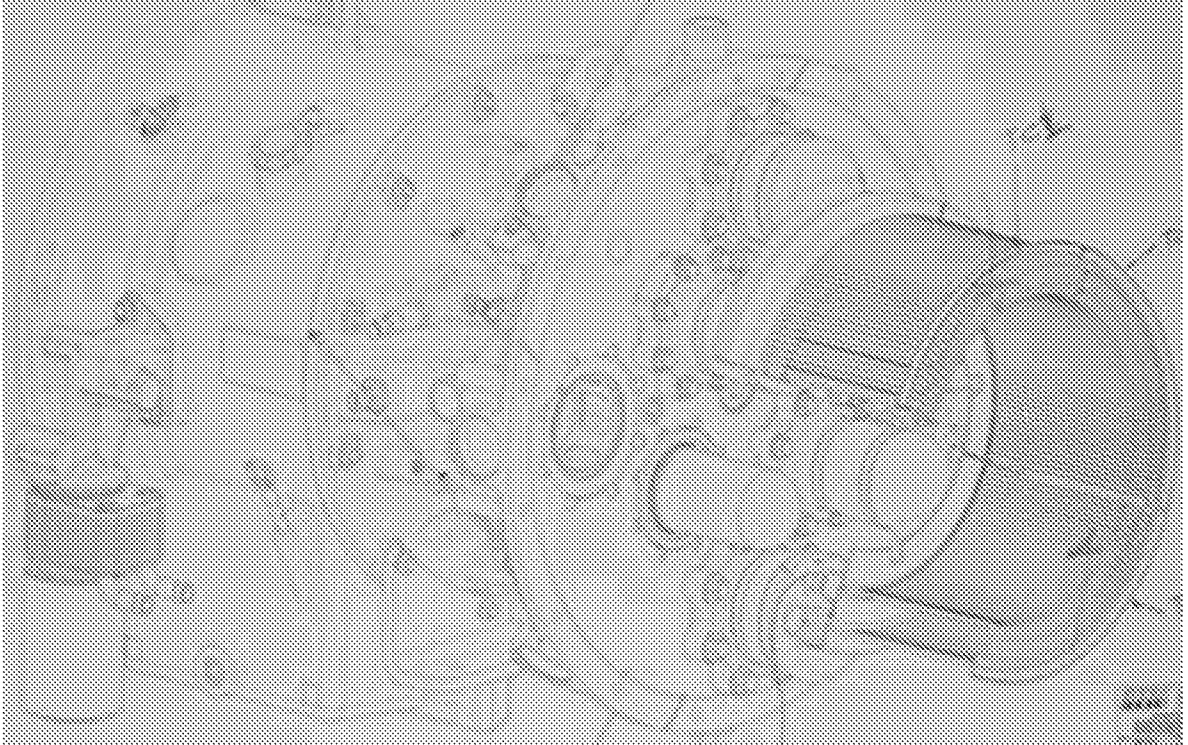


Figure 32 b)

