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GE Energy

Hydrogen and Carbon Dioxide Gas Control System
Packaged Generators

The below will be found throughout this publication. It is important that the significance of each is thoroughly understood by those using this document. The definitions are as follows:

NOTE

Highlights an essential element of a procedure to assure correctness.

CAUTION

Indicates a potentially hazardous situation, which, if not avoided, could result in minor or moderate injury or equipment damage.

WARNING

INDICATES A POTENTIALLY HAZARDOUS SITUATION, WHICH, IF NOT AVOIDED, COULD RESULT IN DEATH OR SERIOUS INJURY

*****DANGER*****

INDICATES AN IMMINENTLY HAZARDOUS SITUATION, WHICH, IF NOT AVOIDED WILL RESULT IN DEATH OR SERIOUS INJURY.

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I. GENERAL DESCRIPTION

This manual provides operation and maintenance instructions for the H_2/CO_2 piping and other equipment hich is external to the generator. Packaged generators are generators with external equipment skids all fitted into one unit. Such generators are 7FH2 Leads Up, 7FH2B Leads Up, and 9EC.

A. Why Hydrogen

The generator interior components are cooled by convection, whereby a gas transports heat to the generator gas/water heat exchanger. Generator windage losses are greatly reduced when hydrogen rather than air is the gas inside the generator because hydrogen has a lower density. In addition, compared to air, hydrogen has greater thermal conductivity and convection coefficients. The generator gas thermal capacity is further increased by the use of pressurized hydrogen. The sealed environment necessary to contain hydrogen has the secondary benefit of keeping the generator parts clean.

Also, hydrogen, rather than air, greatly reduces armature insulation deterioration caused by corona.

B. Explosion Hazard

Hydrogen must be handled carefully to prevent catastrophic oxidation. The gas control valves provide a means for safely handling hydrogen.

C. Inert Intermediate Gas

An inert gas, carbon dioxide, is used as an intermediate gas so that air and hydrogen do not mix inside the generator. The purging procedure for the generator has carbon dioxide introduced to displace the air, then hydrogen introduced to displace the carbon dioxide. The generator is then pressurized with hydrogen and the pressure is maintained automatically with a control valve. The generator may remain pressurized with hydrogen during short outages even if the shaft is not on turning gear. Prior to opening the generator for maintenance, the hydrogen is depressurized and then carbon dioxide is introduced to displace the hydrogen. Air is then introduced to displace the carbon dioxide and the end shields can be opened. During an emergency it is important to at least purge the generator of hydrogen by introducing carbon dioxide.

Gas control during the purge operations will be automated or can be performed manually at the gas control valve station.

D. Essential Parts of the Gas Control System

The gas control system has these primary parts:

1. Generator, with gas piping connections
2. Gas piping with valving
3. Gas control valve assembly
4. Purge control valve assembly
5. Hydrogen Control Cabinet, primarily for gas purity analysis
6. Hydrogen gas storage

7. Carbon dioxide gas storage

8. Liquid detectors

Figure 1 represents a typical generator gas control system with all possible accessories.

E. Gas Storage

The hydrogen and purge control valve assemblies are located in the CAB assembly along with the liquid level detector; seal oil drain float trap, hydrogen control panel, generator core monitor, and humidity dew point sensor. It is good to place the gas dryer (if there is one) in the vicinity of the CAB assembly to reduce the number of hydrogen zones in the power plant.

F. Gas Valve Station

The gas control valves are located in the gas control valve station of the power plant. It is good to place the gas dryer (if there is one), liquid detectors, seal oil drain float trap and other equipment in the vicinity of the gas control valves to reduce the number of hydrogen zones in the power plant. The hydrogen control cabinet or a generator gas purity display or other means of monitoring hydrogen purity should be available at the gas control valve station.

II. WARNINGS CONCERNING THE USE OF HYDROGEN

Hydrogen and air form a highly explosive mixture if concentrations are between 4.1% and 74.2% hydrogen by volume in air.

When assembled completely and operated in the proper manner the generator casing, which forms the hydrogen container, is a gas tight enclosure. In the very unlikely event of an explosion, the casing is strong enough to limit the destructive effect to the generator casing and the enclosed parts.

A. General Rules for Safe Handling of Hydrogen

Precautions must be taken to safeguard against a hydrogen explosion.

1. Never permit an explosive mixture to exist.

2. Eliminate any possible source of ignition.

B. Unknown Contaminant is Assumed to be Air

Any unknown contaminant in the hydrogen gas shall be assumed to be air. The exception is if the hydrogen is supplied directly from a hydrogen generation device which derives the hydrogen by splitting water into hydrogen and oxygen, then the policy may be to assume that any unknown contaminant is pure oxygen. Hydrogen and oxygen form an explosive mixture with approximately 96% hydrogen (4% oxygen) by volume.

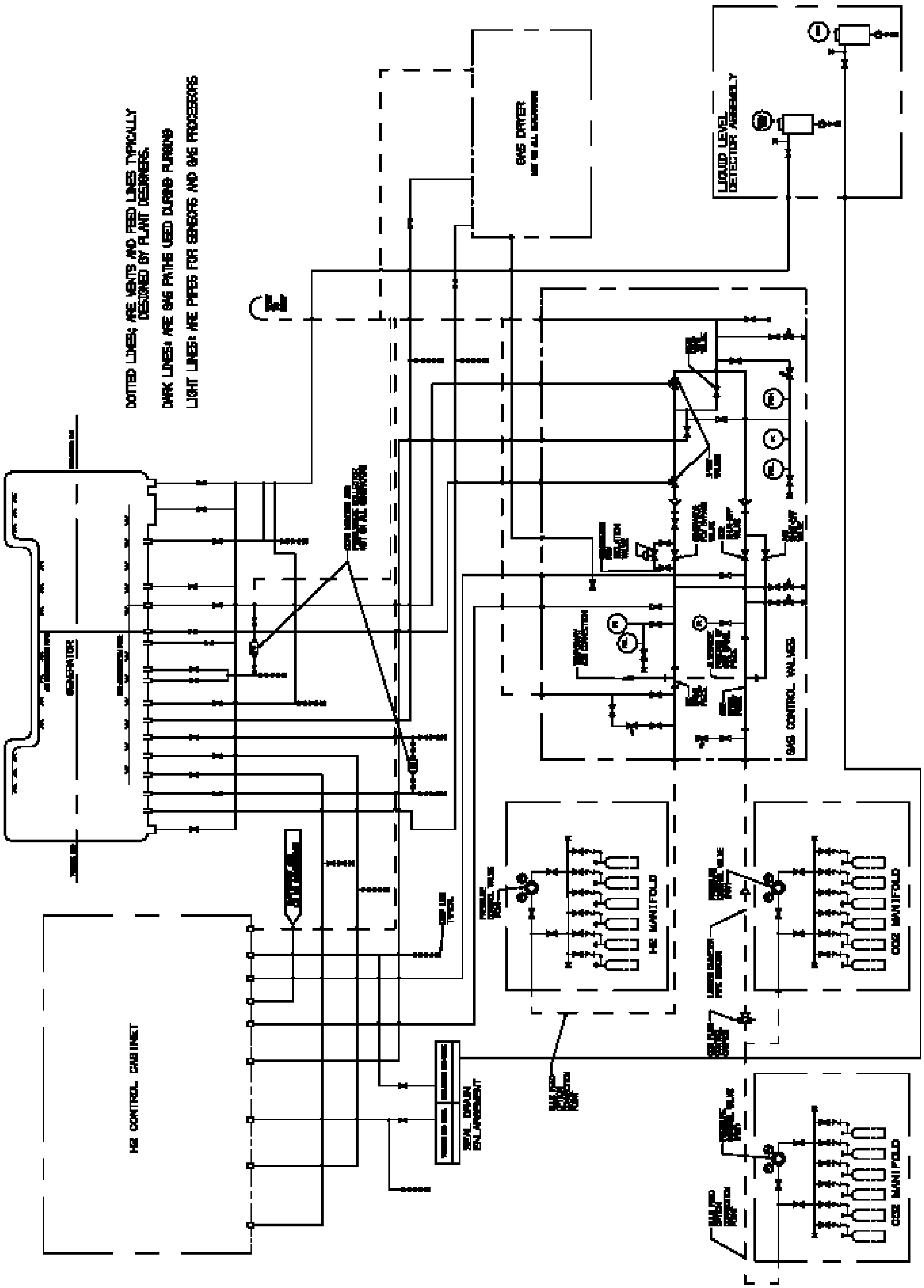

Figure 1. Typical Generator Gas Control System. Valves and Other Components used During Purging are Identified

During the carbon dioxide purge the contaminant is known to be carbon dioxide. If the seal oil is not being vacuum treated and the seal oil system is operating normally, the contaminant may be assumed to be air. At any other time, the contaminant is not known and shall be assumed to be air except as noted immediately above.

C. Rules for Safe Handling of Hydrogen

The procedure for purging the generator is designed to prevent explosive mixtures. The purging steps of removing spool pieces, disconnecting bottles, and disconnecting the air supply must be strictly adhered to. In addition:

1. Do not have a permanent air supply connected to the generator, the hydrogen control cabinet, or any other device connected to the generator or gas piping. This practice prevents the possibility of an explosive mixture inside the generator due to operator error or valve leakage.

2. The generator and all piping must be pressure tested with air or CO_2 for leaks prior to pressurizing the generator with hydrogen.

3. Hydrogen pressure inside the generator must always be higher than ambient pressure to prevent air from leaking in. If automatic controls are inoperative, the operator must manually maintain pressure. Additionally, the seal oil systems require a casing pressure of 2 psig minimum to drain correctly from the seal drain enlargement tank to the bearing drain enlargement tank.

4. No welding may be done on the gas system or seal oil system while there is hydrogen in the generator.

5. The hydrogen is sealed at the shaft to casing interface by oil film seals. The operator must be familiar with the shaft seal oil system prior to operating the generator gas system.

6. Avoid having high pressure hydrogen escape to the room because it can ignite easily due to self-generated static charges, any open flames, welder torch, cigarette, etc.

7. Hydrogen flame is nearly invisible. If an operator suspects hydrogen is escaping into the work area and decides to feel for a gas escape flow, he should not use his hand or anything combustible such as clothing.

D. Maintenance of Hydrogen Equipment

Components of the gas control system which are intended for maintenance while the generator is pressurized are listed in a later section of this publication. Prior to maintenance the operator should use, if available, two valves rather than only one to isolate the work area from high pressure hydrogen. Also, prior to opening a joint in a gas line, the operator should use, if available, a vent valve to depressurize the equipment. Some components might not have the vent valve or the second set of isolation valves close to the work site.

E. Hydrogen Zone

Electrical equipment in the vicinity of joints in hydrogen piping should not be sources of ignition. The local or national codes pertaining to explosive atmospheres vary, and should be investigated if the operator is suspicious of potentially sparking electrical equipment located in the vicinity of the hydrogen equipment.

As a minimum, a Division 2 (or Zone 2) H_2atmosphere extends horizontally for 1.2 meters for 5 psig to 60 psig (35 to 414 kPag, 0.352 to 4.22 kg/cm^2) piping and 1.8 horizontally meters for 75 psig to 150 psig (517 to 1,034 kPag, 5.27 to 10.55 kg/cm^2) piping. It extends down 0.2 meters and up 4.2 meters. Potential small leak sites are non-welded joints in piping, including flanges, valves, threaded joints, and O-ring and compression fittings. The extent of the explosive atmosphere does not penetrate walls or other similar barriers. Each piece of electrical equipment in the explosive atmosphere should have one of the following:

1. explosion-proof housing with conduit or cable sealing
2. intrinsically safe circuit
3. hermetically sealed contacts
4. non-sparking components
5. non-inductive circuit
6. forced ventilation from a non-contaminated air source
7. purging with pressurization

III. GENERAL DESCRIPTION OF THE GAS CONTROL SYSTEM

A. The Rotor Fan

The generator gas is circulated inside the generator by a fan on each end of the rotor. The fan creates a differential pressure of several inches of water. The fan-blown hydrogen cools the generator rotor windings, armature windings (unless these are separately cooled by water), and armature magnetic laminations. The fan-blown hydrogen also is forced through a cooler, where it loses the heat it picked up from cooling the generator electro-magnetic components. The fan differential pressure is used by external gas system analyzers which require a small flow rate and a need to return the gas to the generator. Examples of possible equipment that use the fan differential pressure are (not supplied with every generator): gas dryers, over-heating particle detectors (core monitor/pyrolysate collector), humidity senor, and gas analyzers.

B. CO_2 as Intermediate Gas

The generator has a large open internal volume (1,000 cubic feet [30 m^3] or more). This volume contains hydrogen during normal operation. It contains air during maintenance outages. An inert gas is put into the generator volume as an intermediate gas so that air and hydrogen do not mix inside the casing. Carbon dioxide is used as the inert gas because it has a substantially higher density and lower thermal conductivity compared to hydrogen or air. The substantially different properties are used by the gas analyzer (inside the hydrogen control cabinet) so that gas concentrations during purging can be monitored.

C. Distribution Pipes

Along the top of the generator interior is a long pipe with holes which act as a manifold for admitting hydrogen. Similarly, along the bottom of the generator interior is a long pipe with holes for admitting carbon dioxide. These are called the hydrogen distribution pipe and the carbon dioxide distribution pipe, respectively. During a purge operation, when gas enters through one of the pipes, the gas which is being displaced from the generator exits out the other pipe.

D. Gas Control Valves

The piping between the gas supply and the generator typically has a set of valves which will be used when purging the generator. During this purge operation, the operator will look at the hydrogen control cabinet (or a remote display) so that he can monitor the purging process.

E. Casing Liquid Detector

Drain ports are located in the low points of the generator. Liquid that enters these ports is routed to the generator casing liquid detector.

F. Shaft Sealing

The rotor of each generator extends beyond the generator casing at both the turbine end (TE) and the collector end (CE). These two shaft to casing interfaces are sealed against hydrogen escape with oil film shaft seals. The shaft seals are located inside of the bearings. The shaft seals require a continuous supply of clean, cool oil as supplied by the seal oil system.

G. Seal Oil Draining

Used seal oil inside the generator will drain to seal oil drain enlargements (one on the CE and one on the TE) where hydrogen bubbles can come to the surface of the oil, and then to a common float trap valve which reduces the oil pressure from generator pressure down to bearing drain pressure and prevents hydrogen from escaping with the oil.

H. Oil Deflectors

There are three gas cavities inside the generator called:

1. The turbine end seal cavity
2. The generator casing (where the generator windings are)
3. The collector end seal cavity

Seal oil is restricted to the end cavities. These cavities are separated from each other by oil deflectors, which are extensions of the casing that have a small clearance between the static hardware and the rotor.

I. Gas Flow Between Cavities

Gas flow into and out of the cavities is limited to:

1. New clean hydrogen being introduced to the generator casing
2. Gas to the hydrogen cabinet, en route to the scavenging valves and the cell blocks, being taken from all three cavities but especially the end cavities because of the scavenging valves (vacuum treatment seal oil system generators might not have a scavenging capability)
3. The end cavities are not connected to each other to the extent that gas cannot travel from one end to the other, therefore gas flow is limited to traveling from the generator casing to the end cavities

J. Scavenging to Retain H_2 Purity in the End Cavities

The end cavities include the seal oil drain enlargements. In these containers there is a net transfer of air escaping solution from the oil and also hydrogen entering solution into the oil. The resulting effect is that the end cavities have a relatively high concentration of air.

For generators which have non-vacuum treated seal oil, the hydrogen cabinet has scavenging valves through which the contaminated hydrogen is slowly exhausted to a vent. New clean hydrogen from another part of the hydrogen system piping enters the generator casing to replace the scavenged gas. By this process, the air contamination in the end cavities remains at a safe low level to avoid the gas from being a combustible mixture. Also, the flow of gas across the thin gap of the inner oil deflector retards the passage of the air contamination from entering the generator casing. Air contamination in the generator region decreases generator performance.

K. Vacuum Seal Oil Systems

Some generators have the seal oil treated in a vacuum chamber prior to the oil being exposed to the generator gas. These generators would not require the scavenging valves to be open except during the abnormal operation when the vacuum chamber does not have a vacuum or otherwise is not being used. The hydrogen control cabinets provided with these generators might not be connected to the seal oil drain enlargements.

The air is removed by continuously scavenging a small quantity of hydrogen and discharging it to the atmosphere from the two ends of the seal drain enlargement. The scavenged hydrogen is piped through flowmeters, filters, moisture indicators, and flow control valves in the hydrogen control panel in order that the rate of scavenging can be controlled. This outward flow of hydrogen from the seal drain lines induces a corresponding outward flow of hydrogen from the generator casing through the radial casing clearance between the oil deflector and the shaft, thereby reducing to a very small value the inward diffusion of air from the seal oil into the generator casing. Through the operation of this system of continuous scavenging, a hydrogen purity approximately between 95-98% is maintained in the generator casing, and a purity level of above 87% is maintained in the space between the oil deflector and the shaft seal with the waste of a relatively small amount of hydrogen.

L. Gas Purity Monitoring

The generator gas in the end cavities should be monitored in generators which do not have vacuum treated seal oil. If the seal oil is vacuum treated, then it would be acceptable to monitor only the generator casing gas. During the purging operation, the gas purity of the venting gas (the gas exiting the generator) should be monitored.

IV. GAS CONTROL VALVE EQUIPMENT

The gas control valves provide the operator with an efficient and safe means of handling hydrogen. The gas control valves can be roughly placed into these categories:

1. H_2 Gas Storage (perhaps nothing more than a bottle manifold)
2. CO_2 Gas Storage (perhaps nothing more than a bottle manifold and flow orifice)
3. H_2 Gas Control Valves (part of the gas control valve assembly)
4. CO_2 Gas Control Valves (part of the gas control valve assembly)
5. Purging Gas Control Valves (part of the gas control valve assembly)

6. Liquid Detectors
7. Interconnecting Pipes and Valves

A. General

The gas control system has the following principal functions:

1. To provide means for safely putting hydrogen in or taking hydrogen out of the generator, using carbon dioxide as a purging medium.

2. To maintain the gas pressure and purity in the machine at the desired values.

3. To indicate to the operator at all time the condition of the machine with regard to the gas pressure, temperature, purity, and scavenge gas flow rate. The presence of liquid in the machine is also indicated by an alarm.

The oil supplied to the shaft seals is taken from the turbine oil system and contains an appreciable amount of air in solution, about one percent by volume. The air will largely be given up to the hydrogen as the oil from the seals enters the hydrogen atmosphere. If all of the air liberated from the seal oil were permitted to pass into the generator casing a large amount of fresh hydrogen would have to be continuously wasted in order to maintain the hydrogen purity in the casing at a satisfactory value. However, if most of the air liberated from the seal oil can be removed before it can pass, by diffusion, into the generator casing through the space between the oil deflector and the shaft, a considerably smaller amount of hydrogen will be required to maintain the hydrogen purity in the casing at a satisfactory value.

Air is removed by continuously scavenging a small quantity of hydrogen and discharging it to the atmosphere from the two ends of the seal drain enlargement. The scavenged hydrogen is piped through flowmeters and control valves in the hydrogen control cabinet in order that the rate of scavenging can be controlled. This outward flow of hydrogen from the seal drain lines induces a corresponding outward flow of hydrogen from the generator casing through the radial casing clearance between the oil deflector and the shaft, thereby reducing to a very small value the inward diffusion of air from the seal oil into the generator casing. Through the operation of this system of continuous scavenging, a hydrogen purity approximately between 95-98% is maintained in the generator casing, and a purity level of above 87% is maintained in the space between the oil deflector and the shaft seal with the waste of a relatively small amount of hydrogen.

B. Hydrogen Control Cabinet

The hydrogen control cabinet (DHCP - see Figure 2) is designed for use on the hydrogen cooled generators. It is designed to operate in Class 1, Division 1, Group B hazardous areas. The DHCP's main purpose is to analyze and, in real time, display the hydrogen gas purity on built-in numeric displays. The local display panels, flowmeters, moisture indicators, pressure gauges, and differential pressure gauges are visible through clear poly-carbonate windows and accessible through hinged doors.

The major components of the hydrogen control cabinet include:

1. Two completely independent, interactive gas analyzers

2. Two hydrogen gas flow indicators with metering valves

3. One total hydrogen gas flow indicator

4. One hydrogen gas pressure transmitter and gauge
5. One fan differential pressure transmitter and gauge
6. Three hydrogen gas purifiers
7. Three moisture indicators
8. Four metering valves
9. Numerous isolation valves
10. Solenoid valves and alarm/status relays

If either of the end analyzers notice the purity is falling below a certain point for more than one minute, the scavenging solenoid valves FY-2971 & FY-2973) will energize and an alarm will sound. The other analyzer will then be used to confirm the alarm by porting the gas from the analyzer with the low purity gas.

For more in-depth instruction, reference the HCC Instruction Manual.

C. Hydrogen Control Valves

The hydrogen control valves assembly (Figure 3andFigure 4) is used to control the gas pressure in the generator casing.

Gas is supplied to the control valve assembly at a pressure of 55 to 75 psig (379–517 kPa [gauge]) (3.87 to 5.27 kg/cm^2 [gauge]). A machine gas pressure regulator (R2) reduces the gas pressure before it is admitted to the generator casing. A 0 to 100 psig (0–703 kg/cm^2 [gauge]) pressure gauge (63 HVG-1) is provided to observe the gas pressure being delivered to the control valve assembly.

The upper portion of the assembly contains three machine gas pressure switches (63 GH-1, 63 GL-1, 63 GK-1), a machine gas pressure gauge (HVG-2), a hydrogen shutoff valve (65) and two hydrogen shutoff solenoids (20HH-1, 20HH-2).

The pressure switches are set above and below the operating machine gas pressure and are used to actuate an alarm if the set point is exceeded.

The hydrogen gas shutoff solenoids located on the hydrogen gas control valves assembly are normally closed, latched open solenoids. Their function is to shut off the hydrogen gas supply during an automatic purge cycle. The solenoids must be manually opened to allow the hydrogen to flow.

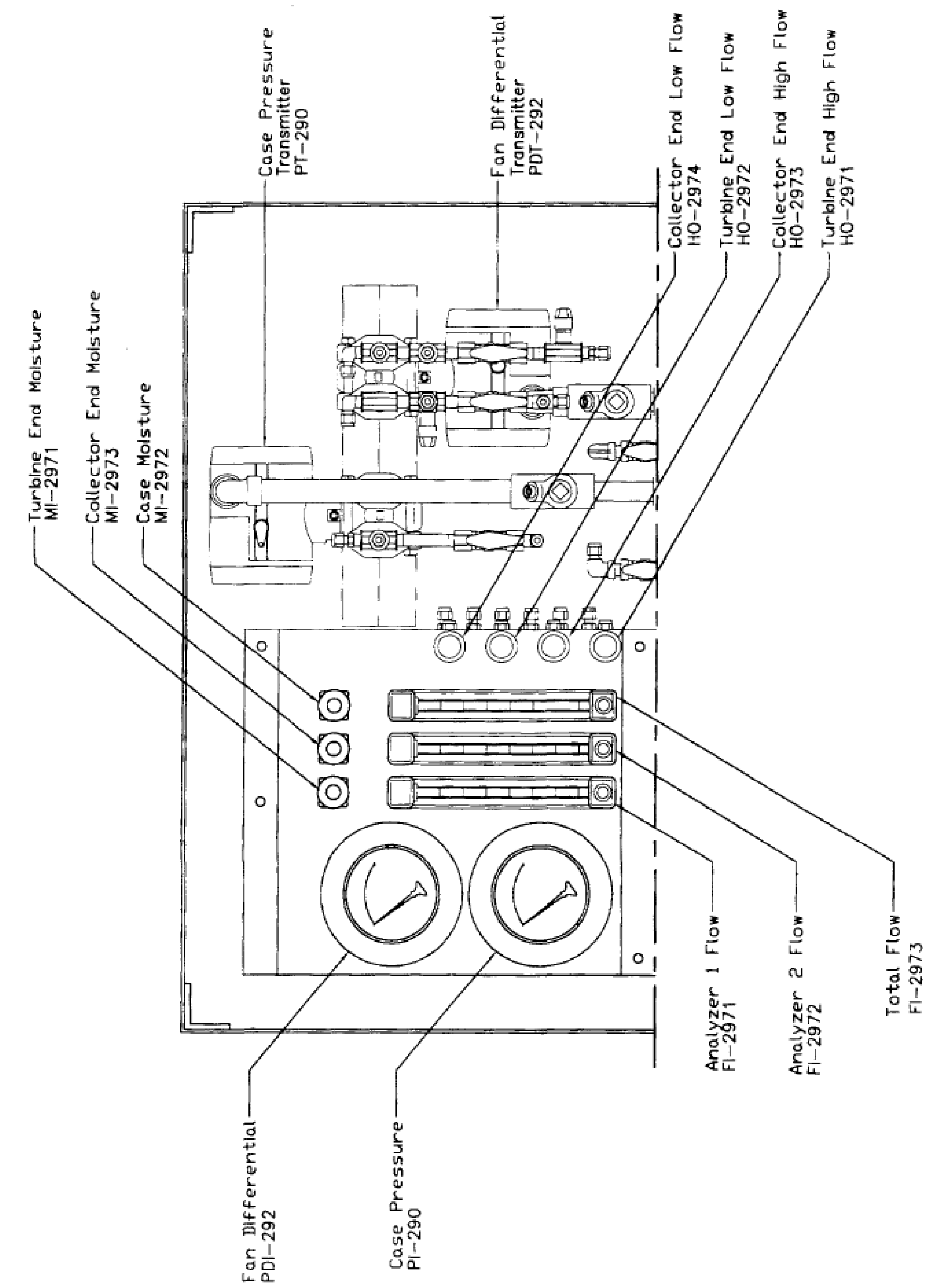

Figure 2. Gauge Panel Transmitter Detail

Hydrogen is admitted to the generator casing through a perforated distribution pipe inside the casing extending the length of the top.

When filling the casing for the first time, the manual bypass valve (62) is usually used to speed up the filling operation by bypassing the gas regulator. When bypassing the regulator this way, the casing pressure must be watched carefully so that the pressure in the generator casing does not exceed 45 psig (310 kPa [gauge]) (3.16 kg/cm^2 [gauge]).

D. Purging Control System

It is necessary to avoid an undesirable hydrogen-air mixture when initially charging the casing with hydrogen, or after removing the hydrogen from the casing before opening it to the atmosphere. An inert gas is used to purge the casing of air before admitting hydrogen and also to purge the casing of hydrogen before admitting air.

Carbon dioxide is used for this purpose and is admitted into the casing through a perforated distribution pipe extending the length of the bottom of the casing.

When removing either air or hydrogen from the casing, carbon dioxide is admitted to the bottom of the casing through the carbon dioxide feed pipe and the air in the casing is discharged to the atmosphere through the hydrogen feed pipe. Carbon dioxide is admitted until a mixture of 30% air in carbon dioxide is obtained in the gas discharged to atmosphere. Hydrogen is then admitted to the casing through the carbon dioxide feed pipe. When a mixture of 95% hydrogen in carbon dioxide is obtained in the gas discharged from the casing, the generator may be placed in operation.

For removal of hydrogen from the casing with carbon dioxide before opening the casing to the atmosphere, carbon dioxide is admitted until a mixture of 5% hydrogen in carbon dioxide is obtained in the discharge gas. The carbon dioxide in the casing may then be removed by admitting air to the bottom of the casing and discharging the carbon dioxide to the atmosphere through the carbon dioxide feed pipe. The valves in the hydrogen and carbon dioxide feed piping for control of the purging operations are located under the hydrogen control valve assembly.

A purging control valves assembly (Figure 5andFigure 6) is used to control the purging operations. The assembly consists of several control valves, a three-way valve (SV-1), an air test connection, a connection for checking purging gas purity (57), removable spool pieces (“A”) and (“B”), a vent solenoid valve (20GK-1) and a carbon dioxide solenoid valve (20PM-1). The spool pieces can be removed to isolate the generator and its piping from the hydrogen and carbon dioxide supplies. The vent and carbon dioxide solenoid valves are normally open, latched closed valves which are used to vent hydrogen and supply carbon dioxide during an automatic purge cycle.

The 7FH2 gas turbine driven generator is equipped with an H_2 CO_2 Auto Purge Control System. This feature is on all gas turbine driven 7FH2 generators, since it is possible that the 7FH2 generator may be remotely operated. Since there may be no personnel at the generator, the auto-purge is provided as power plant protection. If the gas analyzers register that the purity of the H_2 has fallen below 80%, the seal oil differential pressure is low, or there has been an AC power outage, the system will begin timing the event. If after six seconds the purity or the pressure haven't risen, or after 20 minutes the AC power hasn't resumed the system will check if the HCC is running under normal conditions. If not, the solenoids will energize and initiate an automatic turbine shutdown and alarm. Once the turbine is turning at gear speed, the automatic hydrogen purge will commence.

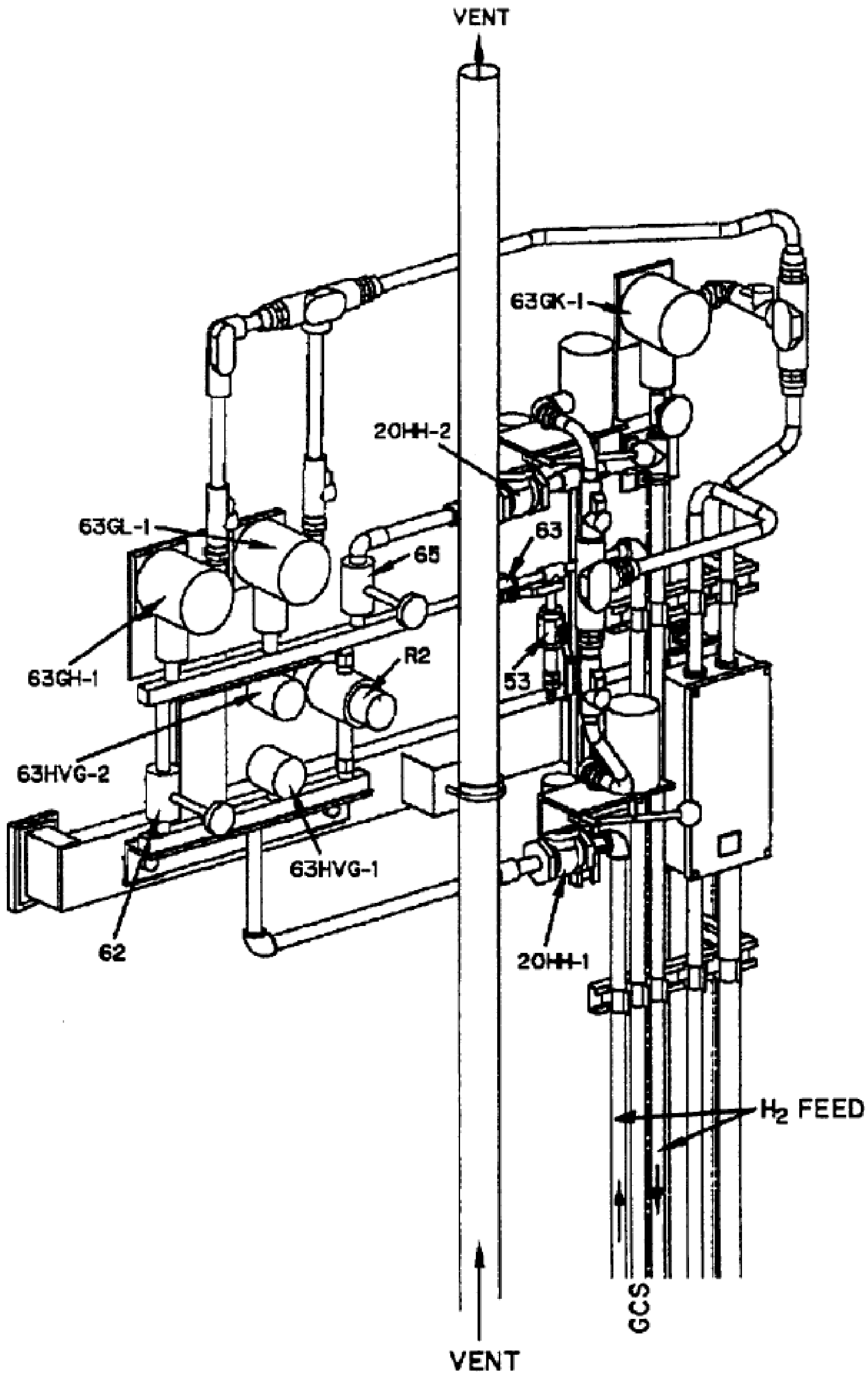

Figure 3. Hydrogen Control Valves Assembly

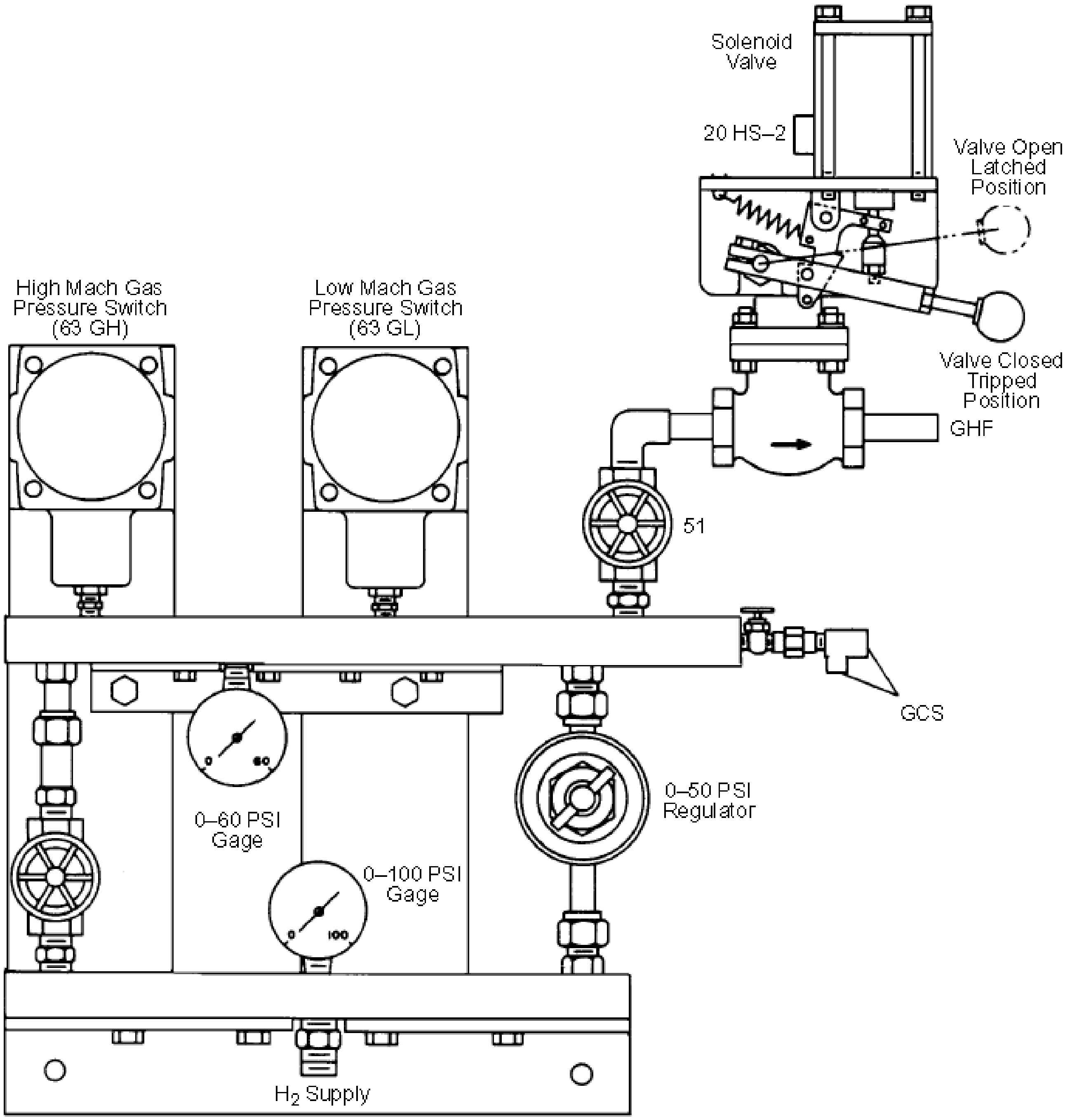

Figure 4. Hydrogen Control Manifold and Valves

E. Purging Control Gas Analyzer

A portable gas analyzer is not required as the hydrogen control panel has the ability to monitor the purging operations. This equipment is strictly optional. It can be used to supervise the purging operations. The gas analyzer operates on the principle of thermal conductivity and must be calibrated before each stage of the purging operation.

F. Liquid Detectors

(See Figure 5)

1. Seal Drain Oil Level, 71SD-1

A Magnetrol float switch is used to alarm if the seal drain enlargement level is too high. The float switch may be tested by closing valve (74), removing the pipe cap and pouring water in until the float switch actuates. After testing, remove drain cap and drain float switch. Replace both caps and open valve (74).

2. Generator Liquid Detector, 71 WG-1, 2

A Magnetrol float switch with two levels of indication is used to detect liquid in the generator. When the first level is reached, an alarm is sounded; if corrective action is not taken and the level continues to rise, a second switch is actuated which will provide a signal to the GTD logic. This logic in turn will initiate a shutdown of the unit.

CAUTION

This device cannot be tested while the unit is running, or while the unit is charged with hydrogen. With the unit shutdown and with the air in the generator, this device may be tested as follows: Close valve (72), remove pipe cap and pour in water until the float switches actuate. After testing, remove drain cap and drain the float switch. Replace both caps and open valve (72).

G. Features of Bottle Manifolds

If a hydrogen gas bottle manifold (Figure 8) is provided, it has these features. The carbon dioxide bottle manifold has the same features:

1. Pigtails

One for each hydrogen gas bottle. There is a check valve on the manifold end fitting of each pigtail.

2. Globe Valve

One for each hydrogen bottle.

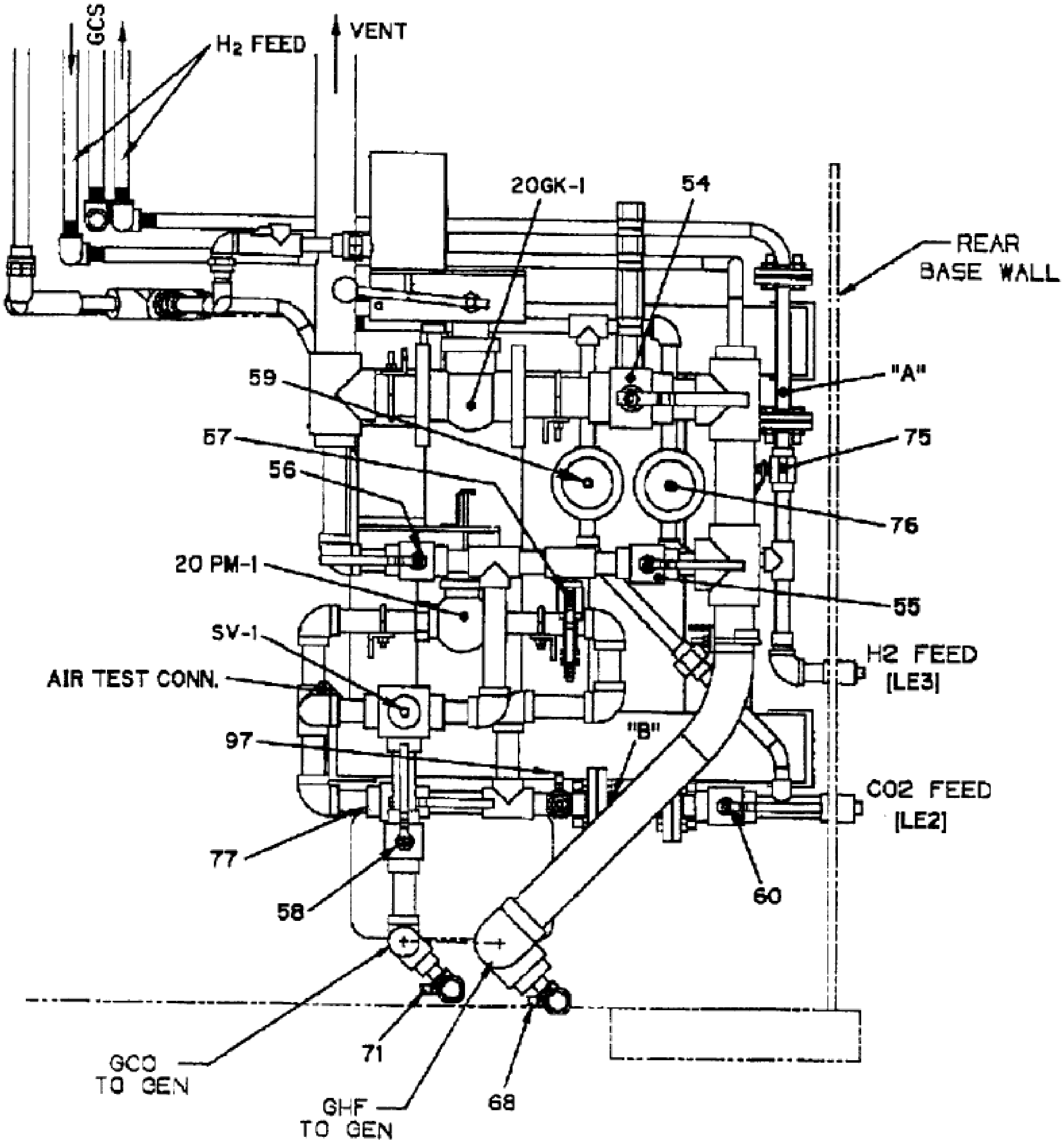

Figure 5. Purging Control Valves Assembly

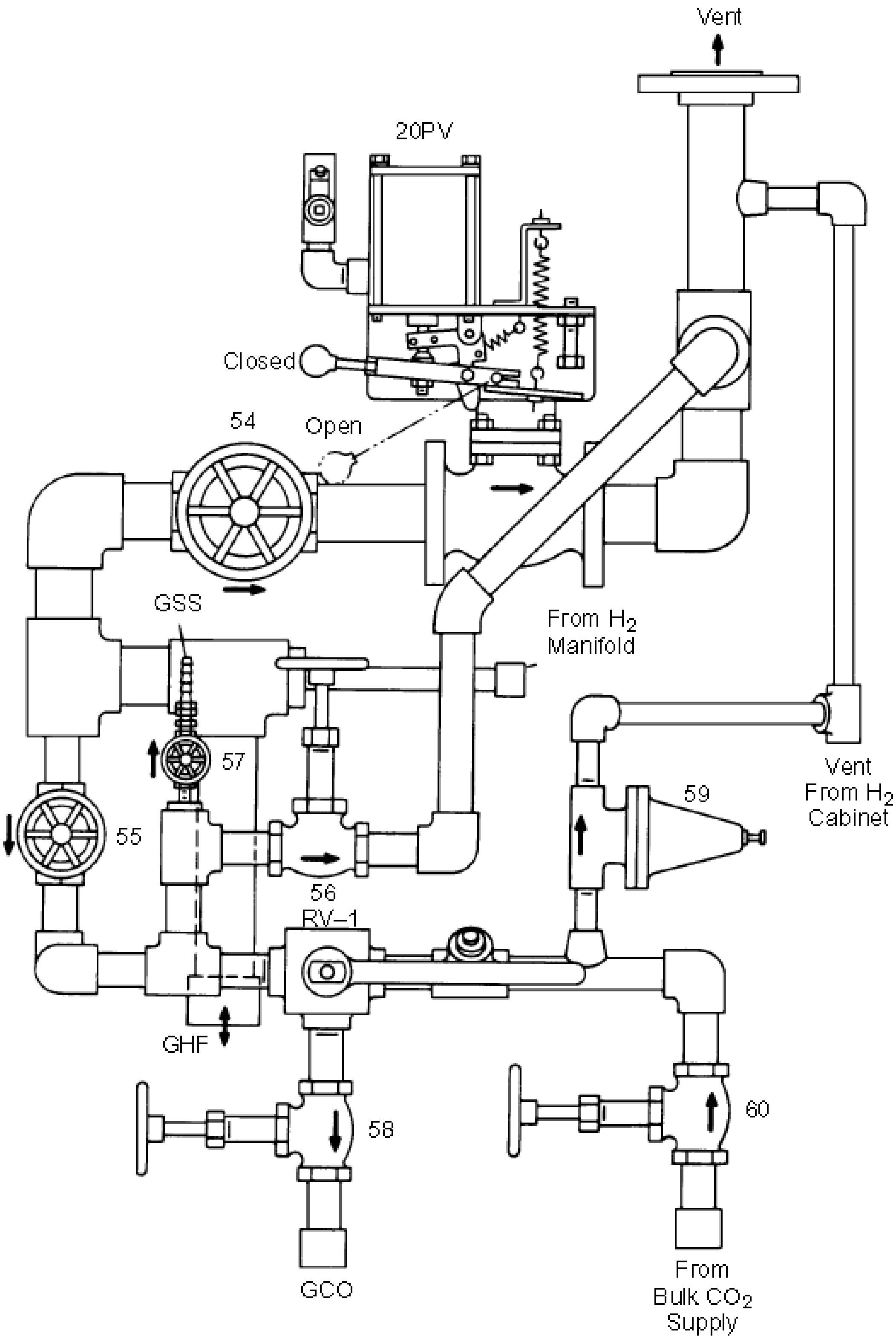

Figure 6. Purging Control Manifold

3. Pressure Regulator Valve

This valve drops the pressure from the high bottle manifold pressure down to approximately 125 psig (862 kPag, 8.79 kg/cm^2) for hydrogen gas and 125 psig (862 kPag, 8.79 kg/cm^2) for carbon dioxide gas as required by the downstream flow regulation restriction. Gauges are provided on the regulator valve.

4. Pressure Regulator Bypass Valve

The bypass valve should be opened or closed completely and not put into a partially opened position.

H. Features in the Gas System Piping

1. CO_2 Flow Regulation Orifice

The CO_2 piping upstream of the gas control valves will have a flow regulation orifice to control flow rate during the purge step which admits CO_2 into the generator. Downstream of this orifice there should be a section of large diameter pipe where solid CO_2 precipitation can accumulate.

Please note that GE supplies the flow regulation orifice and section of large diameter pipe with the 7FH2 gas turbine driven generators.

2. Drip Legs

Low points in pipe runs are provided with one or two valves. Accumulated liquid can be drained. If there is only one valve, then either the pipe must be isolated or the generator degassed prior to draining the liquid. If there are two valves, then the liquid can be drained by alternating the valves between open and closed. Drip legs are placed in piping so that condensation and other contamination is routed away from sensitive equipment.

3. Valves on the Underside of the Generator

There are several types of gas connections to the generator: low point drains, gas feeds and vents, and pipes to gas sensing and gas processing equipment. Many of these have isolation valves at the generator connection to assist in maintenance.

4. Equipment Isolation Valves

Most pieces of equipment have isolation valves so that they may be repaired on line.

V. OPERATION

A. Operator Activities: Start-Up

1. Pre-Start-Up

a) Read the warnings concerning the explosiveness and combustibility of hydrogen which is in an earlier section of this document.

b) Ensure the piping to the cabinet and the piping of the gas valves used for gas control are correctly installed.

c) Ensure the external wiring of gas system electrical equipment is correctly installed.

d) Inspect the gas system equipment for damage. Drain out liquid which may have accumulated in the piping.

e) Be familiar with the operation of the seal oil system and the generator gas control system.

f) Be familiar with the use of the hydrogen control cabinet for gas purity monitoring.

g) Ensure there is enough CO_2 available to purge out the air plus enough CO_2 to purge out hydrogen should there be an emergency.

h) Ensure the gas valves are in the correct position for the admission of carbon dioxide.

i) Energize the hydrogen control cabinet and prepare it for use.

j) Energize all seal oil pump motors, including all AC and DC, and all primary, backup, and emergency pump motors.

2. Leak Test Piping

After installation and prior to introducing hydrogen to the gas system equipment, all parts of the gas system should be air tested to ensure there is no leakage. A similar, perhaps coinciding, test should be performed to the generator casing and end shields. The air test may be performed with CO_2 after purging out the air if additional CO_2 is available to be used to increase the pressure to a usable level for leak testing.

Leaks can be identified by applying a soapy solution to the joints and welds. A typical solution would be liquid soap, glycerin and water. Bubbling will indicate leakage.

3. Start-Up

The seal oil system should be started when the admission of carbon dioxide into the generator casing has raised the internal pressure to 2 psig. The pressure forces the seal oil to drain through the float trap valve flow restriction. Initially, as pressure builds, seal oil may begin to flood the seal oil drain enlargement. It is important that the seal oil not build up to the extent that it floods the generator. Therefore an operator should manually bypass the float trap temporarily until the generator casing pressure is 15 psig.

4. Start-Up Steps:

a) Manually open the float trap bypass valve. (See Section VI.L.1. Page 38 for further float trap bypass instructional details.)

b) Start pressurizing the generator casing with CO_2.

c) Turn on the seal oil supply system once the carbon dioxide pressure reaches 2 psig.

d) As the pressure inside the generator increases, the float trap bypass valve should be manually closed, starting no earlier than 5 psig and reaching full closed position at 15 psig.

NOTE

The solenoid valve FY-2981 selector switch must be in the “Purge” position while performing filling and purging operations.

VI. PROCEDURE FOR OPERATION

A. Fill and Test with Air (also see Station Designer’s Handbook for applicable GEK on air leakage test)

1. At the initial start-up and whenever covers or piping have been disturbed, it is recommended that the unit be given a leak test using air.

2. Air, in the form of commercial “Dry Air” cylinders or air from a compressor with a dryer, should be piped to the AIR TEST CONNECTION through an appropriate regulator and valve system.

3. Make sure that the purging control valves throughout the system are in their correct position (See Table 1.) for Fill/Test with air.

NOTE

Some of the valves mentioned are not shown in Table 1. Check the Generator Gas Control Piping Diagram for the availability and location of all valves.

4. Activate the air supply. Set the pressure regulator for 10 psig. Open valve 58 and admit air into the system.

5. Slowly increase the pressure on the system to approximately 10 psig. Close valve 58. Check to see if the system appears to be holding pressure by monitoring the system pressure gauge. If the pressure loss is relatively rapid, search for the leak using a soap based leak detector; vent the system, repair any leaks found, and re-pressurize.

6. If desired, the air pressure leakage test can be made at higher pressures (up to the rated hydrogen pressure of the generator) to obtain more sensitivity to leaks.

7. When the air leakage test is satisfactory, close valve 58 and open valve 56 to vent the air pressure down to atmospheric pressure. Disconnect the air supply.

CAUTION

In order to minimize the possibility of mixing air and hydrogen, the air supply must not be permanently connected to the system. Use temporary connections only!

CAUTION

In order to minimize the possibility of mixing air and hydrogen, the hydrogen pipe section “A” must be removed when the system is charged with air.

B. Remove Air and Fill with CO_2

1. CO_2 can be supplied to the system from cylinders through a separately standing manifold or from a bulk feed supply.

2. The valves should be set as put forth in Table 1.

3. Valves HO-2971, HO-2972, HO-2974, and HO-2973 should be left as determined in the air leakage test (reference Station Designer's Handbook for applicable GEK on air leakage test).

4. The hydrogen pipe section "A" must not be installed. The CO_2 pipe section "B" must be installed.

5. If you have a portable gas analyzer calibrate it to measure the percentage of air in carbon dioxide as outlined in the Thermal Conductivity Gas Analyzer publication. CO_2 gas for the calibration may be obtained through valve 97 or Certified calibration gas.

NOTE

To insure the minimum waste of CO_2, the rate at which CO_2 is discharged from the individual cylinders should be limited to about 50 cfm (24 liters/s) or at flow rate that does not freeze CO_2.

6. Adjust the regulator on the CO_2 manifold or the bulk supply to 10 psig. Slowly open valve 60 to admit CO_2 into the system. Open and throttle valves 58 and 56 to maintain a slight positive total pressure in the generator casing (2.0 to 5.0 psig). Monitor the vented gases at valve 57 to determine the percentage of air in CO_2, using the air/carbon dioxide scale of the gas analyzer.

7. When the percentage of CO_2 is greater than 70% at valve 57, close valve 56. Adjust the regulator to maintain the two to five psig pressure on the system. Open valve 53. Bleed and check for purity at valve 53. Close valve 53.

8. When the purity at valve 53 is less than 30% air in CO_2, (remove blank flange at "A"), open valve 20GK-1 and valve 20HH-1 for several seconds. Close valve 20HH-1 and valve 20GK-1. The pipe section "A" can now be installed in the hydrogen input line.

9. Bleed gas past valve 9 until the purity at the "Test" tap on the control panel is less than 70% CO_2. Cap the "Test" tap.

10. Disconnect the piping to the optional fan differential pressure gauge and open valves 5 and 6 to check purity. Bleed and check until the gas purity is less than 30% air in CO_2. Replace piping to the gauge or plug as appropriate. To ensure circulation of CO_2 gas throughout the GFP-2 and GFS-2 gas piping open valves HV-2977, 81, and 81A along with removing it's pipe plug for several seconds to allow the gas to flow thru the piping thus pushing out any possible residual air in the piping then close both valves and replace the pipe plug. Open valve 82 and 82A along with removing its pipe plug for several seconds then close valves and replace the pipe plug.

11. Operate solenoid scavenge valves FY-2971 and FY-2973 for 30 seconds each to let CO_2 flow through throttled valves HO-2971 and HO-2973.

12. Close valves HV-2976 and HV-2975 and open the piping at the system pressure gauge. Open valve 3 and let gas flow for 30 seconds. Close valve 3. Reconnect the gauge and open valve 3.

13. Open, bleed, and check for purity at all drain valves including 68, 71, 81, 81A, 82, 82A, 83, 83A, 83B, 83C, 84, 84A, 84B, 84C, 85, 86, 92, 93, 94, 103, 103A, 107 and 107A..

14. If a Pyrolysate Collector is installed, open valve 112 and let the gas flow for 2 minutes. Close valve 112.

15. If a Gas Dryer is installed, open valve 90 and 91 for 2 minutes, then close. Open and bleed gas out of drain valves 92 and 93 for several seconds then close.

C. Remove CO_2 and Fill with Hydrogen

1. The hydrogen source can be either from cylinders in a hydrogen manifold system or from a bulk feed. The regulators on the manifold or the bulk feed source should be set to give no more than 125 psig pressure at the input to the hydrogen control valves.

2. Valves HV-2979, HV-2980, HV-2981, HV-2982, HO-2971, HO-2972, HO-2973, and HO-2974 should be left as determined while filling with CO_2. See Table 1 for all valve positions.

3. The hydrogen pipe section “A” must be installed. The CO_2 pipe section “B” must be installed. The AIR TEST CONNECTION must not have anything connected to it.

4. Open solenoid valve 20HH-1 and slowly open valve 75. Check to assure that the pressure on gauge 63HVG-1 is less than 75 psig. Adjust the source regulators if necessary.

5. If you have a portable gas analyzer calibrate it to measure the percentage of hydrogen in carbon dioxide. Refer to Thermal Conductivity Gas Analyzer publication for calibration procedure. Otherwise calibrate the gas purity analyzers on the Hydrogen Control Panel for H_2 gas obtained from valve 63.

6. Connect the sensing tube of the analyzer to the GSS connection located on the purging control manifold adjacent to valve 57.

7. By throttling valve 62 or adjusting pressure regulator, R2, and by throttling valve 56, adjust the flow of hydrogen into the generator to 20 to 25 cfm (8 to 10 minutes for a 200 cu-ft cylinder), while holding the casing pressure in the range of 2.0 to 5.0 psig. Toward the end of the filling operation, it may be necessary to throttle vent valve 56 to maintain the required pressure in the generator, due to the reduced pressure loss in the discharge line with increasing hydrogen content of the discharged gas.

8. Monitor the gas flow from the seals. Throttle FI-2971’s and FI-2972’s metering valves as required to maintain between approximately 500 to 600 SCCM flows through QT-290A and QT-290B. Expect a significant change in flow as the hydrogen content of the system increases. Note: The flow rates should be set so that the end cavity generator gas purity is maintained substantially above the Upper Explosion Level for H_2 in air (87-90% H_2 in Air in the end cavities and 95-98% H_2 in Air in the generator casing).

9. While filling the generator, monitor the purity of the gas leaving the generator. When using a portable gas analyzer, check for the percentage of hydrogen in carbon dioxide at the tap adjacent to valve 57. Fill until the percentage of hydrogen in carbon dioxide exceeds 90 percent.

NOTE

The amount of hydrogen required to produce a 90 percent concentration in the generator casing is approximately 1.75 times the casing volume at 0.5 psig casing gas pressure.

10. Increase the hydrogen gas pressure to the desired operating pressure by setting pressure regulator R2. This information is found on the Generator data plate.

11. During the pressure build up, it is necessary to monitor and correct, if required, the various system components such as, see applicable GEK's:

    a. Seal differential pressure

    b. Seal gas flow

    c. System pressure

    d. Gas purity

    e. Hydrogen input flow

12. When the desired operating pressure is reached, refer to the Hydrogen Control Cabinet Operating Instructions publication for setup of the hydrogen control cabinet.

D. Setting the System for Automatic Operation

1. The valves should be in the positions shown in Table 1 for normal operation.

2. Assure that regulator R2 is set to give the desired operating pressure.

3. Assure that seal gas flow through the hydrogen control panel is adequate to maintain purity levels within acceptable limits.

CAUTION

Make sure the supply of carbon dioxide is adequate to completely purge the generator.

E. Remove Hydrogen and Fill with CO_2

1. Make sure that valve FY-2981 is in the "Purge" position and valves 55 and HV-2983 are opened. See Table 1 for all valve positions.

2. If you have a portable gas analyzer calibrate it to measure the percentage of hydrogen in carbon dioxide as outlined in the Thermal Conductivity Gas Analyzer publication. Otherwise use the gas purity analyzers on the Hydrogen Control Panel for measuring the purge gas at valve 55.

3. Monitor the seal oil/gas differential pressure to assure that the seal oil pressure is nominally 5.5 psi greater than the gas pressure during the venting operation.

4. CO_2 manifold pressure is set for 10 to 15 psig.

5. Throttle valves 56 and 58 to obtain a two to five psig positive pressure on the system and maintain the feed rate. Monitor the percentage of hydrogen in the vented gases at valve 57 using the hydrogen in carbon dioxide scale of the gas analyzer.

6. Admit CO_2 until the concentration of hydrogen in CO_2 at the valve 57 tap becomes less than 5 percent. The amount of CO_2 required will be about 2.0 times the gas volume of the generator casing.

7. Purge part of the hydrogen control valves assembly by opening valves 20HH-2, 53, 62, 63, 65, and 20HH-1 for a few minutes. Close valve 53, 62, and 20HH-1.

8. Miscellaneous vent and drain lines (eg., 20GK-1, 68, 71, etc.) can be purged in the same manner as described in sections for removing air and filling with CO_2.

9. Remove the hydrogen pipe section “A”, open solenoid valve 20HH-1, open valve 62 for a short time to purge the hydrogen input pipes. Install the blank flanges.

10. Shut off the CO_2 supply. Close valve 60. Remove the CO_2 pipe section “B” after generator is vented to atmospheric pressure. Install the blank flanges.

F. Remove CO_2 and Fill with Air

1. Table 1 shows the valve set-up for this operation. The valves on the control panel should be left in the positions set in the previous CO_2 operation. Dry air as described above in section VI.A.2 should be used.

2. Set the regulator on the air supply for approximately 10 psig. Admit air into the system by opening the valve on the air supply. Vent CO_2 by throttling valve 56. Adjust the air regulator and valve 56 to maintain a pressure of 2.0 to 5.0 psig on the system.

3. Air should be admitted until a concentration in excess of 95% air in CO_2 is obtained at the tap adjacent to valve 57. Valves 63, 20HH-2, 65, and 53 should be opened and the concentration checked at the tap adjacent to valve 53.

4. As long as the pressure is maintained in the generator system and/or the generator is rotating, keep the seal oil system operating and the generator system pressure in the 2 to 5 psig range. When it is decided to shut down, reduce the pressure in the generator system to atmospheric, stop any rotation of the generator and turn off the seal oil system.

5. Disconnect the air supply, open all generator vent valves. Let the generator pressure bleed down to 0 psig before removing any covers or piping.

6. Covers must be removed with care. Piping must be opened with caution. Prior to entering the generator casing, covers on both ends of the generator should be removed and dry air blown in one end of the generator and out the other for 30 to 60 minutes.

CAUTION

After the generator is purged of hydrogen, and before any generator internal maintenance commences, the hydrogen and carbon dioxide supplies must be disconnected from the generator gas piping. The removable spool piece sections designated as “A” on the hydrogen feed line (GHF-2) and “B” on the carbon dioxide feed line (GCO-2) are to be removed and blanking flanges installed. This is done to prevent hydrogen or carbon dioxide from entering the generator casing and causing a life hazard because of leaky valves or possible misoperation of valves.

WARNING

THE PRESSURE WITHIN THE GENERATOR CASING MUST BE AT ZERO (ATMOSPHERIC PRESSURE) BEFORE REMOVING ANY ACCESS COVERS OR PIPING TO THE GENERATOR.

CAUTION

It is not recommended that permanent air connections for the purposes of purging should ever be used, because of the danger of accidental admission of air into hydrogen and the possibility of creating an explosive mixture.

*all valves mentioned are shown on the attached P&ID

O=Open; C=Closed; T=Throttle; D=Drain

Table 1. Purging the System

Hydrogen Control Cabinet	Fill/Test Air	Air to CO_2	CO_2 to H_2	Normal	H_2 to CO_2	CO_2 to Air
HV-2971	C	C	C	O	CTC	CTC
HV-2971A	C	C	C	C	CTC	CTC
HV-2972	C	C	C	O	C	C
HV-2972A	C	C	C	C	CTC	CTC
HV-2973	C	C	C	O	C	C
HV-2973A	C	C	C	C	CTC	CTC
HV-2972	C	C	C	O	C	C
FY-2972	O to FY2981	O to FY2981	O to FY2981	Cycles from HV-2972/QT–290 and FY-2981/QT- 290A per control logic	O to FAY2981	O to FY2981
HV-2977	C	CT	C	C	C	C
HV-2975	C	O	O	O	O	O
HV-2978	C	C	C	O	C	C
HV-2974	C	C	C	O	C	C
FY-2974	O to FY-2981	O to FY-2981	O to FY-2981	Cycles from HV-2972/QT-290A and FY-2981/QT- 290A per control logic	O to FY-2981	O to FY-2981
HV-2984	C	C	C	C	C	C
HV-2987	C	C	C	C	C	C
FY-2975	O	O	C	C	C	C
FY-2976	O	O	C	C	C	C
HV-2979	O	O	O	O	O	O
HV-2979A	T	T	T	T	T	T
HV-2981	O	O	O	O	O	O
HV-2981A	T	T	T	T	T	T
FY-2971	C	COC	COC	C	COC	COC
FY-2973	C	COC	COC	C	COC	COC
HO-2971	T	T	T	T	T	T
HO-2972	T	T	T	T	T	T
HO-2973	T	T	T	T	T	T
HO-2974	T	T	T	T	T	T

Hydrogen Control Cabinet	Fill/Test Air	Air to CO_2	CO_2 to H_2	Normal	H_2 to CO_2	CO_2 to Air
16 (Turbine End High Flow)	T	T	T	T	T	T
17 (Turbine End Low Flow)	T	T	T	T	T	T
18 (Collector End High Flow)	T	T	T	T	T	T
19 (Collector End Low Flow)	T	T	T	T	T	T
HV-2980	O	O	O	O	O	O
HV-2982	O	O	O	O	O	O
MI-2971	N/A	N/A	N/A	N/A	N/A	N/A
MI-2972	N/A	N/A	N/A	N/A	N/A	N/A
MI-2973	N/A	N/A	N/A	N/A	N/A	N/A
HV-2976	C	O	O	O	O	O
FY-2977	O	O	O	O	O	O
FY-2978	O	O	O	O	O	O
FY-2979	O	O	O	O	O	O
FY-2980	O	O	O	O	O	O
FY-2981	O (in “Purge”)	O (in “Purge”)	O (in “Purge”)	O (in “CASE”)	O (in “Purge”)	O (in “Purge”)
HV-2983	C	O	O	C	O	O
HV-2985	C	C	C	C	C	C
HV-2986	C	C	C	C	C	C
Hydrogen Control Valves						
20HH-1	C	COC	CO	O	OC	C
20HH-2	O	O	O	O	OC	CO
62	O	O	C	C	CO	C
63	O	O	C	C	CO	CO
63HVG-1	N/A	N/A	<75PSIG	N/A	N/A	N/A
63HVG-2	N/A	N/A	N/A	N/A	N/A	N/A
65	O	O	O	O	OC	CO

Hydrogen Control Cabinet	**Fill/Test Air**	**Air to CO_2**	**CO_2 to H_2**	**Normal**	**H_2 to CO_2**	**CO_2 to Air**
75	C	CO	CO	O	OC	C
76	C	C	C	C	C	C
53	C	CTC	C	C	CT	CT
A	NOT INSTALL	N-INSTALL/ IN	INSTALL	INSTALL	NOT INSTALL	RMV/BLANK
R2	N/A	N/A	MIN	AT OPT PRES.	N/A	N/A
Purging Control Valves						
20GK-1	C	COC	C	C	CO	CO
20PM-1	O	O	C	C	CO	C
54	O	O	O	O	O	O
55	O	O	C	C	CO	C
56	CO	CTC	CT	C	CT	CT
57	C	CT	CT	C	CT	
58	CT	CT	O	O	OT	
59	C	C	C	C	C	
60	C	CO	O	O	OC	
71	DC	CT	C	C	CT	
77	O	O	C	C	CO	
97	DC	C	C	C	C	
B	INSTALL	INSTALL	INSTALLED	INSTALLED	NOT INSTALL	RMV/BLANK
SV-1	CO_2 IN	CO_2 IN	VENT/CO_2	CO_2 IN	CO_2 IN	VENT
Liquid Level Detector						
72	O	O	O	O	O	O
74	O	O	O	O	O	O
H_2 Manifold						
68	C	C	C	C	CT	CT
70	O	O	O	O	O	O
CO_2 Manifold						
51	C	C	-	-	-	-
Piping						
61	O	O	O	O	O	O
64	O	O	O	O	O	O
68	DC	CT	C	C	CT	CT
69	O	O	O	O	O	O

Hydrogen Control Cabinet	Fill/Test Air	Air to CO_2	CO_2 to H_2	Normal	H_2 to CO_2	CO_2 to Air
70	O	O	O	O	O	O
81	DC	C	C	C	C	C
82	DC	C	C	C	C	C
83	DC	C	C	C	C	C
84	DC	C	C	C	C	C
85	DC	C	C	C	C	C
86	DC	C	C	C	C	C
90	O	O	O	O	O	O
91	O	O	O	O	O	O
92	DC	C	C	C	C	C
93	DC	C	C	C	C	C
94	DC	C	C	C	C	C
95	C	COC	C	C	CO	CO
96	C	O	C	C	CO	CO
31	O	O	O	O	O	O
32	O	O	O	O	O	O
111	O	O	O	O	O	O
112	C	COC	O	O	O	O
120	C	C	C	C	C	C

G. Shut Down

Prior to turning off the seal oil system, the generator should be purged so that hydrogen is not present in a dangerous concentration. If maintenance activity is required inside, beneath, or near the generator, or if the down time will be more than a few hours, then the carbon dioxide should be purged out and replaced with air. After the purging steps are complete:

1. Reduce the Carbon Dioxide pressure by venting.

2. As the pressure inside the casing falls to 15 psig, begin to open manually the float trap bypass valve. The valve should be completely open when the internal pressure reaches 5 psig.

3. Turn off the seal oil supply system when the internal pressure reaches 2 psig. This prevents flooding of the generator or hydrogen control cabinet with oil.

4. Open the generator vent valve.

5. Do not open the generator end shields or other access covers until the operator is sure that there is no pressure inside the generator.

6. Use compressed air or large fans to blow CO_2 out of low spots in the generator after opening the generator.

H. Generator Gas Purging and Normal Operation

The generator is purged with gases before and after normal operation of the generator. The table below lists some general characteristics of the operations that must be performed.

Please read the clarifying notes below the table.

Table 2. Miscellaneous Data on Purging and Normal Operations

Activity	Air to CO_2	CO_2 to H_2	H_2 fill	Normal	Degas	H_2 to CO_2	CO_2 to Air
Estimated Time (hrs)	0.5	2	1	N/A	0.5	1	N/A
Recommended Flow Rate (sm^3/hr)	3.4	1.4	N/A	N/A	N/A	3.4	N/A
(scfm)	120	50	N/A	N/A	N/A	120	N/A
(minutes per bottle)	3	5	N/A	N/A	N/A	3	N/A
Amount of Gas (• Generator Volume)	1	2	n	N/A	0	2	>3

Hydrogen Control Cabinet Controls							
“Mode” Selection (FY-2981)	Purge	Purge	N/A	Normal	N/A	Purge	Purge
“Function” Selection	CO_2 in Air	H_2 in CO_2	H_2 in Air	H_2 in Air	H_2 in Air	H_2 in CO_2	CO_2 in Air
Stop %	70% CO_2	90% H_2	N/A	N/A	N/A	5% H_2	5% CO_2

Gas Valve Station Valve Positions							
3 Way Valves	Down	Right	Right	Right	Either	Down	Down
Main Vent Valve	Partially open	Partially open	Closed	Closed	full open	Partially open	Partially open
Generator PCV Isolation Valve	Closed	Open	Open	Open	Closed	Closed	Closed
Generator PCV Bypass Valve	Closed	Closed	Open	Closed	Closed	Closed	Closed
CO_2 Shut-Off Valve	Open	Closed	Closed	Closed	Closed	Open	Closed
Air Shut-Off Valve	Closed	Closed	Closed	Closed	Closed	Closed	Open
H_2 Spool Piece	Out	H_2 line	H_2 line	H_2 line	H_2 line	Either position	Out
CO_2 Spool Piece	CO_2 line	CO_2 line	CO_2 line	CO_2 line	CO_2 line	CO_2 line	air line

I. General Information on Purging

Estimated Time of Purge = Volume of Generator * Amount of Gas / Flow Rate

1. Recommended Flow Rates of CO_2 and H_2

The recommended carbon dioxide flow rate is 120 scfm (3.4 sm^3/minute) for a 2,800 ft^3(80 m^3) generator internal volume. The recommended hydrogen flow rate is 50 scfm (1.4 sm /minute) for a 2,800 ft^3 (80 m^3) generator internal volume. These flow rates are approximate, and for generator volumes greatly different from 2,800 ft^3(80 m^3), the recommended flow rate would change proportionally with generator volume (for example, twice the flow rate if the generator is twice as large).

2. Automatic Flow Control of CO_2 and H_2 During Purging

The flow rate during purging is automatically controlled by the size of flow restrictions which are integral with the equipment.

3. Bottles may be Discharged Simultaneously

Two bottles would decrease in pressure in about twice the time, three bottles in about thrice the time, relative to the time given on the table above.

4. Manual Generator Pressure Control During Purging

Because of the gas stratification due to buoyancy which occurs inside the generator, there will be very little if any change in gas mixture in the venting gas for the first 2/3of the purge time. During the last 1/3of the purge, the gas concentrations will change rapidly.

The generator vent valve should be positioned and adjusted to hold between 2 and 5 psig (13.8 to 34.5 kPag, 0.14 to 0.35 kg/cm^2) inside the generator. The generator pressure will change, and the valve may need adjusting, during the final 1/3 of the purge because during that time the gas density may change dramatically.

5. Quantifying Gas Quantity

Because gas is compressible and buoyant it is difficult to measure and unnatural to perceive the concept of gas quantity. The mass of a sample of gas does not change, although its volume may change due to the interactions of pressure, temperature, and density. Therefore the best way to quantify gas quantity is by units of mass. However, because gas has little weight and deforms and diffuses, the mass cannot be determined by measurement on a weight scale. And units of mass do not have direct importance because gas is used for its volume, not its mass, in most applications in mechanics.

Therefore, it has become the industry standard to describe gas quantity in units of “standard” volume. The “standard” means that pressure and temperature are assumed to be at 14.7 psia (1 atmosphere at sea level, 101.4 kPaa, 1.034 kg/cm^2a) and 77°F (25°C), respectively. Sometimes the temperature standard is different, so it is important to know the specific standard pressure and temperature which are being used whenever a standard gas volume is given. The actual pressure or temperature of a gas sample may be substantially different from the “standard” conditions, however, the mass of the gas sample can be quantified by pretending it is at “standard conditions.”

For example, a bottle of compressed gas may have only a few cubic feet of physical volume, but have hundreds of cubic feet of "standard" volume worth of gas because the gas can expand to the "standard" pressure.

This measurement system works because there is only one gas density corresponding to a pressure/temperature combination for a particular type of gas, and only one "standard" density for a type of gas. The "standard" volume of a particular gas can therefore be considered a measurement of mass.

"scfm" means "standard cubic feet per minute." "Standard" means the gas mass flow is equivalent to the volumetric flow if the gas were at 25°C (77°F) and 1 atmosphere(14.7 psia, 101.4 kPaa, 1.034 kg/cm^2, which is 0 psig at sea level). The "s" in front of "m^3/hr" also means "standard"

J. Purging with CO_2

1. Low Pressure Means Less Gas Used

During the purge process the generator gas pressure should be between 2 and 5 psig (13.8 to 34.5 kPag, 0.14 to 0.35 kg/cm^2), preferably 2 psig (13.8 kPag, 0.14 kg/cm^2). A lower generator gas pressure requires less purge gas. This is because purging is a gas displacement phenomenon, which is volume driven, and higher pressure gasses have more mass (more gas) per a given volume. For example, a 2,800 ft^3 (80 m^3) generator will require one additional CO_2 bottle of gas to displace H_2 for each psi (each 7 kPa, each 0.07 kg/cm^2) additional gas pressure.

2. Low Flow Rate Means Less Gas Used

Flow rate during the purge is kept low to avoid mixing the gasses inside the generator. The gasses are naturally separated by buoyancy.

3. Nitrogen Content of Air

The 70% CO_2 in air concentration is acceptable because it results in only about 6% O_2, the remainder being the inert gases N_2 and CO_2.

4. Purge Dead Cavities with CO_2

After the generator is purged with carbon dioxide to 70% CO_2 in Air or 95% CO_2 in H_2, the generator gas pressure of a few psig (several kPag, a fraction of a kg/cm^2) should be used to purge the dead cavities of the generator. Most importantly, the seal oil drain enlargements should be purged by simultaneously opening the scavenging valves long enough to vent out 35 ft^3 (1 m^3) of gas. If there are volumes of air or H_2 which cannot be purged using generator CO_2 pressure, then a portable CO_2 supply should be used.

5. Purge Out H_2 after Rotor has Slowed Down

Prior to admitting CO_2, it is recommended to wait until the rotor has decelerated to turning gear or stand still. A rotating shaft will mix the gasses inside the generator. The mixing will destroy the buoyancy layering which keeps CO_2 on the bottom and H_2 on the top. If the generator is to be purged while the shaft is rotating, there should be sufficient CO_2 available to account for the mixing. Th is can be several times the normal amount of CO_2 required for a purge.

6. Water Vapor Fog Layer

During the purge where cold CO_2 replaces ambient temperature air, a layer of condensed water vapor fog forms at the boundary of the two gasses. The optimum CO_2 flow rate was originally calculated based on witnessing the movement of this fog layer.

K. Placing Air into Generator

The Removable Spool Pieces are designed to inhibit the introduction of air while there is hydrogen in the generator and provide a means of absolutely preventing the inflow of dangerous gas while personnel are inside the generator performing maintenance.

1. Air Can Have a High Flow Rate

Air is relatively inexpensive compared to H_2 and CO_2. Therefore, the generator and the purge procedure are not designed to minimize the quantity of air needed.

So that there is no chance of mixing H_2 and air together, air is introduced into the generator through the CO_2 distribution pipe on the bottom of the generator interior. Thus the lighter air is below the heavier CO_2, and the gasses thoroughly mix during purging. Since mixing cannot be avoided, a very high flow rate of air can be used.

2. Air Supply Must Be Typically Disconnected

All air connections to the generator should be disconnected when CO_2 is admitted, and especially when H_2 is inside the generator.

3. Remove Bottles and Spool Pieces Prior to Admitting Air

Prior to admitting air into the generator, totally disable the CO_2 and the H_2 feed lines which connect CO_2 or H_2 bottles to the generator, to the hydrogen panel, and to all other equipment, such as a gas dryer. Closing valves is not sufficient. The bottles should be removed, or the piping disassembled at a spool piece or other fitting. If a workman is working on the generator, a dangerous situation can develop by gas leakage through valves. CO_2 is poisonous at moderately low concentrations and H_2 is explosive at concentrations above 4%.

4. Blow out CO_2 from Low Spots in Generator

After the generator is purged with air, some CO_2 will remain in the generator low points. After the end shield, bushing box cover, or other access plate is removed, the generator should be blown free of CO_2, either with a compressed air hose or large fans.

5. Control Condensation During an Outage

During a generator outage the valves in the piping should be closed so that humid atmospheric air does not enter the piping. Humid air will cause condensation to form internal to the piping as ambient temperature fluctuates from day to night. Specifically, the valves on the underside of the generator should be closed. This will prevent corrosion internal to the pipe and water buildup. Water which freezes could cause pipe rupture and a resulting gas leak. Alternatively, to route condensed water to the vent stack, the three way valve handles should be to the right.

L. Turning On and Off the Seal Oil Supply

1. Turning on the Seal Oil System

The seal oil system should not be turned on prior to the generator internal pressure reaching 2 psig of CO_2. At this low pressure, the float trap bypass valve must be open to prevent flooding of the generator or the hydrogen control cabinet. Then the seal oil system may be turned on for the purge. Turning on the seal oil system simultaneous with pressurizing the generator for the purge. While the bypass is used, it is critical that the oil level not fall below the float trap. If this happens and there is hydrogen inside the generator, hydrogen could enter the bearing area through the bearing drain enlargement. As the generator internal pressure rises above 5 psig, the bypass valve should be throttled, until it is fully closed when the generator internal pressure reaches 15 psig.

2. Shutting down the Seal Oil System

After the air purge is complete, the seal oil system could be shut off while the last little bit of pressure is being vented from inside the generator. The seal oil system should not be kept operating if there is no pressure in the generator because the generator may flood with oil because of the flow restriction of the float trap.

M. H_2Purging, Filling, Normal Operation and Degassing

1. CO_2 Must Always Be Available

The CO_2 feed system for the generator should be continuously operational during the H_2 purge and normal operation. It may be necessary to emergency purge out the H_2 at any time.

2. Pressurize the Generator with H_2 to a Slightly Lower Pressure

The generator does not need to be filled to the full operating pressure, but rather about 10% low (relative to absolute pressure). The gas temperature shortly after the purge and filling will be nearly ambient because of the huge thermal mass of the generator electrical components. During operation the generator gas is much warmer. By the perfect gas law, the pressure will increase as the temperature increases given a constant volume for the gas. Therefore, the pressure at the end of a fill should be per the table following:

Table 3. Generator Pressure at the End of Hydrogen Fill Cycles

Pressure During Operation	Psig	15	30	45	60	75
Pressure After H_2 Fill	Psig	12	25.5	39	52.5	66
Pressure During Operation	kPa-g	103	207	310	414	517
Pressure After H_2 Fill	kPa-g	83	176	268	361	454
Pressure During Operation	kg/cm^2	1.05	2.11	3.17	4.22	5.28
Pressure After H_2 Fill	kg/cm^2	0.84	1.79	2.74	3.69	4.64

3. Close H_2 Feed when De-Pressurizing the Generator

When the operator opens the vent valve to de-pressurize the generator, he should also close the hydrogen feed valve in the pipe leading to the generator.

N. Hydrogen Control Cabinet Use During Purge

1. Hydrogen Control Cabinet Settings

The hydrogen control cabinet is the device, which monitors generator gas purity. Purge selection will control valves such that the gas sample is taken from the generator vent. Normal selection will control valves such that the gas sample is taken from the generator itself.

2. CO_2 Contamination of Filters

Be sure the “purge” setting and not the “normal” setting is applied to all applicable gas sensors of the hydrogen control cabinet when purging. This will prevent CO_2 from entering the filter dryers, which are molecular sieves. If CO_2 enters the filter dryers it will slowly bleed out over the first day of normal operation with H_2 in the generator. If this happens the reading will be inaccurate, in that it will indicate more air contamination in the generator gas than is actually present during the first day of operation.

O. Setting the Scavenging Flow Rates

Generators which do not have vacuum treated seal oil should be provided with a means of continuously bleeding out a small flow of generator gas from each of the two seal oil drain enlargements. The seal oil drain enlargements are where air contamination will be introduced into the generator because air comes out of the solution from the seal oil. The gas control valves will automatically introduce clean hydrogen into the generator casing when gas is bled out, with the result of maintaining generator gas purity at an acceptable level.

The scavenge flow rate visual meters and hand operated control valves are typically located on the hydrogen control panel. The flow rates should be set so that the end cavity generator gas purity is maintained substantially above the Upper Explosion Level for H_2 in air. The exact value is dependent on the accuracy of the purity monitoring equipment and the operating philosophy of the power plant (Refer to the International Standard IEC 842 for guidance if no philosophy exists).

1. Start-Up

Initially, before there is any data or precedence on which to base the actual flow rate set point, the valves should be set for removing about 1 scfh (472 ml/min) from each seal oil drain enlargement. After several hours, which is a long time duration to ensure the system has stabilized, the flow rate can be changed. Higher flow rates will improve gas purity, lower flow rates will degrade gas purity.

A high flow rate is not desired from an economic perspective because the scavenged gas is lost to a vent.

2. After a Low Purity Alarm

There are three settings for scavenged gas purity: Control Set Point, Low Alarm, Low-Low Alarm.

The Low-Low Alarm point should not be below 80% H_2 in Air by volume purity.

If the hydrogen purity in an end cavity drops to the low alarm, the operator should re-adjust the scavenging rates to achieve the control set point. It may happen that the flow rate cannot be increased further, in which case the generator should be shut down and purged of hydrogen so that the cause of the problem can be fixed.

3. **Trending**

It is unusual to have a need to increase scavenging. Records should be kept and plotted so that the two end cavity scavenging rates can be trended over long periods of time. Generator shaft seal health, CO_2 valve leaks, and other problems can be identified in this way.

4. **Jumpy Flow Gauge**

If the flow gauge for scavenging gas is jumpy, meaning the flow indicator moves every second or so by itself, then the equipment can continue to operate until the next outage, at which time the cause for the jumpy reading can be investigated and corrected. The correct reading of flow is the average of the jumpy readings. Jumpiness is caused by liquid in the lines (so all drip legs should be drained), or light solid blockage that moves back and forth. Flow through thermister based gas analyzers is also permitted to have some jumpiness.

P. Operating the Generator at Full Speed with Air Inside

During commissioning or another special circumstance, the generator may be required to operate at full speed with air inside the casing. The shaft seals will need oil for lubrication during this operation mode, and therefore the seal oil system must be operating, with the float trap bypass valve manually opened. Without the valve opened, the seal oil which drains to the generator side and out the float trap, may back up into and flood the generator. Therefore, the generator should be pressurized with air to 2 to 5 psig (13.8 to 34.5 kPag, 0.14 to 0.35 kg/cm^2) and the float trap bypassed so that the oil will drain properly. A higher pressure, about 15 psig (103.5kPag) is necessary, if it is not possible to manually monitor the float trap performance.

NOTE

It may not be possible to produce any electrical power under these circumstances. Contact GE Power System Product Services to determine operational limits.

The generator fan differential pressure will increase proportional to gas density. Therefore it may be 3, 4, perhaps 8 times higher than during normal operation with hydrogen inside the generator. The generator fan differential pressure gauge may not be designed for the high differential service, and may be required to be isolated so that its mechanisms do not get damaged. In particular, if the fan differential gauge is a manometer, it must be isolated so that the heavy bromine liquid does not get blown into the generator where it would cause corrosion.

The greater fan differential pressure may cause oil to be drawn into the generator unless the pressure is kept high, and the vent lines - typically used for scavenging - on the two seal oil drain enlargements are slightly open such that air is being vented from out of the generator through them.

The air supply should be clean and dry. A filter and an air dryer should be used. If a hydrogen gas dryer is provided with the generator, it should be isolated from the system and not used unless the gas dryer manufacturer specifically approves of its use as an air dryer.

VII. ALARM RESPONSES

Activation of any alarm requires prompt attention by the operator. Excessive delay in correcting an alarm condition could result in damage to the generator, equipment, and possible injury to personnel.

Alarms in the hydrogen gas system are summarized below.

Operator Investigation: Further deterioration will not cause a generator load reduction nor an unsafe condition:

Small accumulation of liquid in drip legs

Indications concerning humidity or the gas dryer equipment (if part of the gas system)

Operator Investigation: Operator attention is necessary at the soonest convenience:

High Generator Gas Pressure

Low Hydrogen Supply Pressure

High Generator Casing Liquid Detection

Operator Investigation: A generator load reduction or an unsafe condition is possible with further deterioration.

Low Generator Gas Pressure

Low Generator Gas Purity

High Generator Gas Temperature

High-High Generator Casing Liquid Detection

High Seal Oil Drain Enlargement Liquid Detection

Insulation Overheating Particle Detection Alarm (Not provided with all generators)

Manual Shutdown of Turbine-Generator:

Low-Low Generator Gas Purity (<80%)

Seal Oil Differential Pressure Low

No AC Power

Automatic Shutdown of Turbine-Generator:

Low-Low Generator Gas Purity (<80%)

Seal Oil Differential Pressure Low

No AC Power

A. Low-Low and Low Generator Gas Purity Alarms

Assume air is the contaminant. Please read the warnings concerning hydrogen contamination as provided in the beginning of this document. In particular, the contaminant is assumed to be air unless there is reason to suspect pure oxygen may be introduced. A condition to suspect pure oxygen is if the hydrogen source is a hydrogen generation device.

1. Explosion Danger

Low purity is a concern primarily because of the hydrogen explosion danger.

2. Effect of Low Purity in Casing Gas

Low purity gas in the casing will slightly raise generator winding temperatures because air has a relatively low thermal conductivity (about a tenth that of hydrogen's) and air forms larger boundary layer thickness which reduces convection. Also, air in the generator casing increases windage losses and noise. Most generators have fan differential pressure indicators, which will be reading noticeably high if the generator casing gas purity is below 90%.

3. Gas Purity Reading has a Time Lag

There is a time lag between the generator gas purity change and the monitoring of that change due to the volume of gas in the interconnecting piping and the flow rate through that piping, as well as contaminate diffusion which will occur in the piping. Given the flow rate, pipe size and length, gas pressure ratio to ambient, and a factor of 2 to account for diffusion, the operator can calculate the time lag.

For example, a sensing line of 50 feet of pipe 0.5 inch diameter and a generator pressure of 60 psig with a gas flow rate of 2 scfh will have a time lag of 2 * 50 feet * (0.25*pi*0.5*0.5) in2*(60 + 14.7 psia / 14.7 psia) * X/2 scfh = 21 minutes X = unit conversion factors (therefore X=1)

For example, a sensing line of 15.24 meters of pipe 12.7 mm diameter and a generator pressure of 414 kPa-g (4.22 kg/cm^2) with a gas flow rate of 944 ml/minute will have a time lag of 2* 15.24 m *(0.25*pi*12.7*12.7) mm2* (414+101.4/101.4)* X/944 ml/min = 21 minutes X = unit conversion factors (therefore X=1)

Therefore, while troubleshooting, the operator should remember that the purity reading is not current.

4. Non-Vacuum Treated Seal Oil Systems

If there is a purity-low-alarm in an end cavity (not the generator casing), the rate of scavenging should be increased to re-establish the desired set print reading. If purity cannot be maintained between the desired set point and the low-alarm and if scavenging is at a maximum, then the generator should be shut-down and the source of the contamination identified and corrected. Do not operate the generator for more than a few minutes with purity less than the low-low-alarm point (<80%).

5. Vacuum Treated Seal Oil Systems.

Systems with vacuum treated seal oil are not susceptible to contamination in the end cavities and therefore do not require scavenging from the drain enlargements. It is possible that the gas purity monitoring equipment will only sample gas from the generator casing. The desired set point of generator casing gas will be very high, approximately 95-98%, and will not be adjustable because there is no scavenging. The low-alarm point initiates operator investigation and the low-low-alarm point would trigger an automatic shut down or be used to advise the operator to manually shut down the generator.

If the vacuum treatment processing of the seal oil is being bypassed or is inoperative, then the operator will have to scavenge gas from the seal oil drain enlargements. 35 standard cubic fee (1 m^3) (about 1/6 of a bottle), (17.5 ft^3(0.5 m^3) TE and 17.5 ft^3(0.5 m^3) CE), of gas should be scavenged every hour.

6. Sources of Contamination

Possible sources of contamination of the end cavity gas are excessive seal oil flow, poor seal oil draining, insufficient scavenging, and excessive air in the seal oil supply.

The low purity in the casing may be due to a leaky CO_2 valve. CO_2 valves often corrode due to an interaction of CO_2 with humidity causing an acid to form, and so are susceptible to internal leaks.

Moisture in the gas analyzer probe may cause erroneous readings. An aluminum moisture indicator should be upstream of the gas analyzer probe, and will warn of moisture contamination.

Moisture is often removed from the gas sample by a molecular sieve filter. This special type of filter traps carbon dioxide and bleeds it out over a day or so. Therefore, if the carbon dioxide from the purge operation was inadvertently routed to the filter, then the reading will erroneously show low purity for about a day.

B. Generator Gas Temperature High

If the generator casing gas temperature is too high there is a possibility of damage to the winding insulation. The generator casing gas temperature alarm is part of the generator equipment, and not part of the hydrogen gas system. Typically the alarm point is 2°C (3.5°F) above normal operating gas temperature. After the alarm, cooling water flow should be increased, or other action taken immediately to lower the gas temperature. If the cause cannot be immediately corrected, the load on the generator should be reduced until the normal gas temperature is obtained.

C. Generator Gas Pressure High

The generator gas pressure is maintained by a control valve in the gas control valve assembly. If the control valve is found to be non-adjustable or otherwise malfunctioned, it can be isolated and repaired. The generator can continue to operate with hydrogen being periodically provided through the bypass valve around the control valve. Alternatively, if a two-stage pressure regulator is provided on the bottle manifold, that regulator can be adjusted and used to control generator gas pressure temporarily.

The primary concern with high generator gas pressure is that it will rise above the capability of the seal oil system. By system design, this situation is unlikely.

D. Generator Gas Pressure Low

A low generator gas pressure of only a few psi (several kPa, several hundredth's of a kg/cm^2) will cause several degrees Celsius of elevated temperature in the rotor windings. Therefore it is important to reestablish nominal generator gas pressure or else reduce load after a low generator gas pressure alarm.

The generator pressure low alarm should be set within 2 psi (13.8 kPa, 0.14 kg/cm^2) below nominal generator gas pressure.

The generator gas pressure is maintained by a control valve in the gas control valve assembly. If the control valve is found to be non-adjustable or otherwise malfunctioned, it can be isolated and repaired. The generator can continue to operate with hydrogen being periodically provided through the bypass valve around the control valve. Alternatively, if a two-stage pressure regulator is provided on the bottle manifold, that regulator can be adjusted and used to control generator gas pressure temporarily.

The other likely cause of a gradual lowering of generator gas pressure is low hydrogen supply pressure or an extremely leaky vent valve.

If the pressure is dropping rapidly, the cause is possibly a failed open relief valve, a shaft seal failure, a casing or pipe failure, or a failed open float trap valve in the seal oil drain system. In case there is a rupture of hydrogen containment, the generator should be shutdown immediately, and it should be determined that the area is free of H_2 or CO_2 hazards before an operator approaches or enters the equipment. Generators with autopurge feature will put CO_2 into the generator automatically. The concentrations of hydrogen in air, which are explosive, are between 5% and 75% hydrogen. During this emergency period, while the generator is still charged with hydrogen, the seal oil system should be operating, in spite of the fact it may be pumping oil into the generator. As the pressure drops below 15 psig of CO_2 air, if it is possible to do so, the float trap bypass valve should be opened. As the pressure of CO_2 or air drops below 2 psig, the seal oil system should be shut down.

E. Hydrogen Supply Pressure Low

An indication of low hydrogen supply pressure is provided so that the operator can be prompted to replace depleted hydrogen bottles and avoid the more critical event of a low generator gas pressure alarm.

F. Liquid Detection

Liquid inside the generator indicates that there is an oil or water leak, or else the seal oil drain is backed up.

Liquid oil and oil vapor (which easily condenses) create a sticky surface on the generator internal surfaces including the insulation. Dirt particles then have a tendency to cling to the insulation and may eventually damage it. Liquid water on the insulation will degrade the quality of the insulation.

A High Generator Liquid Detection Alarm may indicate a slow leak of liquid into the generator casing which should be investigated when convenient. A slow leak of oil is possible due to the interaction of seal oil with rotor rotation while on turning gear.

A fast leak is evident if there is a High-High Generator Liquid Detection Alarm. The fast leak should be immediately identified and corrected, or else the generator should be shut down prior to generator casing flooding.

A High Seal Oil Drain Enlargement Detection Alarm is provided so that the operator will know the reason for an impending High Generator Liquid Detection Alarm and can take proper corrective action.

1. **Investigation**

   After an alarm, the liquid detection device can be drained to determine if the liquid is water or oil.

2. **Water**

   There are two sources of water: the hydrogen coolers and the stator cooling water system (if the armature bars are direct water cooled).

   A recent abnormal requirement for make-up water for the stator cooling water system indicates a possible leak.

   To determine if a hydrogen cooler is leaking, valves on the underside of the generator may be intermittently closed and opened. Also the operator could shut off the flow of water to one cooler at a time if running at 80% of rated load capacity. If a cooler leak is severe, the defective cooler may be left out of service until repairs can be made. Generators are typically designed to operate at rated power factor at 80% rated load capacity with one hydrogen cooler out of service.

   The hydrogen gas dryer, if provided, does not have the capability to dry the generator if there is a generator internal water leak.

3. **Oil**

   Oil may enter the generator from the shaft seals or else from flooding of the hydrogen detraining tank.

   Do not shut down the seal oil supply until after H_2 has been purged out of the generator with CO_2.

   Oil may be flowing quickly into the detector during the purging process.

   During the generator gas purge process, draining seal oil may have a tendency to back up in the drain system if the generator pressure becomes abnormally low. A bypass valve is typically provided so that an operator can increase the drain flow rate.

   Oil from the shaft seal area may be due to a leaky flange, or an extremely large seal oil flow, or another problem. It can be isolated to be either the turbine end or the collector end by intermittently closing the drain valves located near the end shield on either side of the underside of the generator.

   Shaft seals may become unseated if there is a temporary reversal of pressure on the gas side seal ring. This may occur during a transfer from one seal oil supply pump to another, either due to a time lag between pump stop and start or due to a time lag in the pressure control valve response. An unseated seal may cause an extremely large oil flow which might not drain through the generator's internal drains to the seal oil drain enlargement. This event is more typical when the shaft is not turning. Field experience has shown that the seals often re-seat after several minutes when the shaft is rotated at turning gear speed.

VIII. MAINTENANCE

A. Leak Testing

After a joint has been adjusted or otherwise loosened or tightened, such as after a component is replaced, the joint must be pressure tested to ensure it will not leak hydrogen. Testing may be performed with air or CO_2, typically at approximately 20 psig (14 kPag, 0.14 kg/cm^2).

Leaks can be identified by applying a soapy solution to the joints and welds. A typical solution would be liquid soap, glycerin, and water. Bubbling will indicate leakage.

B. Regular Maintenance

An operator should be available in the control room to receive alarms at all times.

Each mechanism in the gas control system should be inspected periodically to ensure it is functioning properly.

1. Daily Inspections

Once a day the operator should review the transmitter signals from the gas system and compare them with standard values. The standard values will be established from previous operation experience. Also the transmitter signals should be compared with the previous days' readings to identify any trends. The gas control system transmitter signals are:

Generator Gas Pressure

Generator Gas Purity

Core Monitor (not provided with all generators)

Hygrometers (not provided with all generators)

Once a day the operator should walk around the gas system equipment to look for anything abnormal. The gas control system features to be inspected daily are:

All valves should be in the proper position

Check the sight glass in the gas dryer (if a gas dryer is provided and it has a sight glass) Compare the reading on all the pressure gauges with standard values Hydrogen control cabinet settings and indicators should be normal

Core monitor and pyrolysate collector should be operating normally (if provided) Check the sight glass in both liquid detectors and the seal oil drain system float trap Drain condensate or other liquid out of the main vent line

2. Inspections Every Six Months

Calibrate or otherwise perform maintenance on the hydrogen control panel as required. Perform a Core Monitor system test. (Core monitor is not provided with all generators.) Check the calibration and operation of all the alarm devices and contacts.

3. Inspections to be Done After Every Scheduled Purge with Carbon Dioxide

Check all drip legs and other drains for liquid accumulation.

If the generator is purged with air, close isolation valves in piping at the generator and elsewhere to prevent humid atmospheric air from entering the piping.

4. Generator Maintenance Outage

Test all the relief valves for a possible leakage into the vent lines.

All gauges should be calibrated every three years minimum.

C. Special Maintenance

1. Gas System Components Designed for Maintenance Activity

Tag all valves, switches, or other devices which are important to be in a particular state during the maintenance duration.

Do not disable the CO_2 supply system at anytime for maintenance. CO_2 must be continuously available for an emergency purge.

Read the warnings concerning hydrogen which are at the beginning of this document. The following gas system fluid processing components have been designed for maintenance while the generator is operating normally:

Hydrogen supply pressure sensing devices

Generator gas pressure sensing devices

Pressure Regulating Valve

Pressure Relief Valves

Liquid Level Detectors

Core Monitor (not provided with all generators)

Gas Dryer (if a gas dryer is provided)

Hygrometer Probes (if provided)

Hydrogen control cabinet (short duration only)

Because there are no compressed air sources permitted to be connected to the generator, it is unlikely that a fast air contamination of the generator gas can occur. Therefore, the hydrogen control cabinet can be isolated for a short duration for simple maintenance activity (for example, changing the filter cartridge).

D. If the Hydrogen Control Cabinet is Flooded with Oil or Water

If the generator is flooded with oil or water, then there is the possibility that the hydrogen panel may also have flooded.

After a flooding accident, all the tubing and components of the hydrogen panel should be cleaned and dried. Oil flooding will require cleaning with alcohol or similar solvent (not methanol CH3OH because it deteriorates elastometric seals). This will require some disassembly at tubing and NPT joints. The filter-dryer cartridges will have to be replaced. The silica-gel will have to be replaced if it was contaminated with oil. The cell blocks will have to be removed and flushed with alcohol to remove oil from inside the thermister chamber.

The cleaning should extend at least back to the last drip leg in the piping. For additional information please consult the hydrogen control panel's O & M manual.

E. Materials and Design Conditions

The gas system piping and components are made of ASTM A105/A106 carbon steel, AISI 304/304L316/316L stainless steel, or bronze.

The design pressure of the piping and assemblies is 150 psig (1,034 kPag, 10.55 kg/cm^2). Bottle manifolds are designed to a higher pressure.

IX. OPERATION AND DESIGN REQUIREMENTS FOR THE H_2 AND CO_2 GAS SUPPLIES

The gas system equipment supplied with the generator does not include the H_2 and CO_2 gas storage equipment nor the piping to connect the gas storage equipment to the gas system gas control valves.

The following section gives instructions on the design of the gas storage equipment and piping. It also provides instructions to operators on how to use equipment which is designed to these requirements.

A. Requirements on Gas Used in the Generator

The sources of gas should be able to provide the gas control valves to the following requirements:

1. Carbon Dioxide

Phase: Vapor Phase - this includes the emergency event of a loss of AC power

Purity: Commercially available purity grade

Flow rate: 120 scfm (3.4 sm^3/min) for a 2,800 ft^3(80 m^3) generator. Changes proportionally with generator volume

Pressure: Approximately 2 psig (13.8 kPag, 0.14 kg/cm^2) as determined by the generator internal pressure.

Temperature: Low temperatures are acceptable.

Gas Quantity: There should be enough carbon dioxide available for an operator to purge the generator of hydrogen during an emergency. Bottles should be stored near the manifold

The flow rate and pressure requirements can be satisfied by the use of an orifice when designed to the design requirements given later.

2. Hydrogen

Purity: 99.9% or better.

Humidity: maximum of 0.1 gram of water per cubic meter of gas (0.00007 lbm/ft^3) (Gas should be desiccant dried).

Flow Rate: 50 scfm (1.4 sm^3/min) during purging for a 2,800 ft^3(80 m^3) generator. Substantially higher flow rates up to 500 scfm (15 m^3/min) are permitted during the generator fill operation.

Pressure: 125 +/- 25 psig (862 +/- 172 kPag, 8.79 +/- 1.76 kg/cm^2) during purging and normal operation. During the generator fill operation the gas control valves have no flow restriction smaller than a 1 inch (25.4 mm) diameter pipe, so pressure will be between 2 psig (13.8 kPag, 0.14 kg/cm^2) and full generator gas pressure as determined by generator internal pressure.

Temperature: Low temperatures as experienced during the discharge of bottles are acceptable.

3. Air

Humidity: Air should be desiccant dried.

Cleanliness: Air should be filtered. No oil vapor is permitted.

Flow Rate: No upper limit on flow rate. Maximum flow rate based on the pipe size restriction is expected to be 150 scfm (4.2 m^3/min)

Pressure: Approximately 2 psig (13.8 kPag, 0.14 kg/cm^2) as determined by generator pressure. The gas valve piping has no flow restriction smaller than 1 inch (25.44 mm) diameter pipe.

Temperature: Should be between -20°F and 120°F (-28.9°C to 48.9°C).

Gas Quantity: Several generator volumes of gas will be necessary to purge the generator.

B. Characteristics of Compressed Gas

It is important that the operator become familiar with the behavior of compressed hydrogen and carbon dioxide.

1. Compressed Gas is Dangerous

Be cautious when using compressed gas. Be alert to kinked flexible pigtails, especially at the fittings, and to over-stressed metal tubing-type pigtails. Replace damaged pigtails immediately. Be cautious of high pressure gauges by minimizing the amount of time an operator stands in front of them. Read all warnings provided by the gas supplier.

C. Gas Bottles and Regulators

1. Regulators

Connecting Bottles

Prior to attaching a bottle, the dirt and dust in the valve outlet and in the pigtail fitting should be completely removed. Dirt in a pressure regulator will cause it to leak internally when it should have a tight shut off.

Slowly Open Valve

Bottle pressure should be applied to a pressure regulator by slowly opening the bottle's hand valve. This avoids damage to the regulator or a gauge by a pressure shock.

Replace Leaky Valve Seats

If the pressure downstream of the pressure regulator increases when there is no flow, then the pressure regulator valve seat may leak. The seat should be replaced if it leaks. If the pressure at the gas control valve assembly is at the pressure relief valve setting, then the seat of the pressure regulator is likely leaking.

Low Flow Delivery Pressure

Single stage regulators (which have more flow capacity than two stage regulators) have their delivery pressure set point established at a high flow rate. During low or no flow, the delivery pressure set point is much higher. Therefore, if the gas system is designed so that a tight shut-off is necessary (i.e., the manifold globe valves are open in a “ready” mode), then the low or no flow delivery pressure should be deliberately set below the gas system relief valve setting. Otherwise, the gas from the bottles will seep out the relief valve and not be available when needed.

2. H_2 Bottles

Hydrogen Bottle Size

239 standard cubic feet (6.77 m^3) per bottle (about 200 ft^3(5.7 m^3) is usable because the pressure drops off during discharge). At 70°F (21°C) the pressure is 2400 psig (16.5 MPa, 169 kg/cm^2).

Minimize Number of Active H_2 Bottles

For safety reasons, as few bottles of hydrogen as possible should be used during any one time during normal operation.

Do Not “Crack” Hydrogen Bottles

Unlike non-flammable gasses, it is not recommended to “crack” hydrogen bottles prior to connecting them to a regulator of manifold since “self-ignition” of the released hydrogen is likely to occur.

3. CO_2 Bottles

Use Gaseous CO_2 Only

Only bottles which discharge the vapor phase of carbon dioxide should be used. Bottles which have a siphon tube so that they discharge liquid, or bottles with the discharge port on the bottom so that they discharge liquid, are not to be used with the generator. Liquid carbon dioxide is extremely cold and may adversely affect the welds in the piping. Also, it will easily form solid carbon dioxide after dropping in pressure in a flow restriction and potentially block the piping.

Carbon Dioxide Bottle Size

50 lbm (50 pounds mass, 22.7 kg) of gas per bottle. At 70°F (21.1°C) the pressure is 850 psig (5.86 MPa, 59.8 kg/cm^2) and the contents is about 45 lbm (20.4 kg) liquid and 5 lbm (2.3 kg) gas. At 110°F (43.3°C) a full CO_2 bottle will have 1800 psig (12.4 MPa, 127 kg/cm^2) of pressure, at 140°F (60°C), 2600 psig (17.9 MPa, 183 kg/cm^2). The pressure inside a carbon dioxide bottle decreases during discharge because the evaporating liquid cools the bottle contents, thus lowering the vapor pressure.

Usable CO_2 - Freezing

A 50 lbm (22.7 kg) bottle has 435 standard cubic feet (12.3 m^3) of gas. However, the CO_2 may freeze during the bottle discharge. A potion of the contents in a CO_2 bottle will be liquid for bottle pressures between approximately 60 psig (414 kPag, 4.22 kg/cm^2) and 1,050 psig (7.24 MPa, 73.9 kg/cm^2). During a bottle discharge the fluid contents at 60 psig (414 kPa, 4.22 kg/cm^2) will be approximately -56°C (-68.7°F). As gas continues to be depleted from the bottle, the liquid will transform into a solid.

Bottles initially at 30°F (-1°C) will discharge only 63% of their contents; bottles initially at 110°F (43.3°C) will discharge only 85% of their contents. The relationship between available percentage and initial temperature is approximately linear (a mid point is 73% at 70°F (21°C). Bottles which are disconnected from the manifold will not continue to discharge their gas to the generator as they warm up. Therefore, in systems with all the CO_2 bottles connected to bottle manifold connections, the bottle freezing phenomena has less of an effect.

Bottles which are partially depleted will return to the full bottle pressure of 850 psig (5.86 MPa, 59.8 kg/cm^2) at 70°F (21°C) after they warm up if they have about 30% or more CO_2 still inside.

D. Carbon Dioxide in Pipes and Valves

During the purge step of admitting CO_2 to the generator, the carbon dioxide should go through two stages of pressure drop. The first is through a pressure regulator, the second is through an orifice.

The two could be combined into one orifice, but flow rate would then vary considerably with bottle pressure.

1. CO_2 Feed Piping Should Have a Region Where Solid CO_2 Can Form

Carbon dioxide will form solid precipitation as it goes through a flow restriction (such as a valve or orifice) if the pressure on the discharge of the restriction is below approximately 60 psig (414 kPa, 4.22 kg/cm^2) and the gas is cold, such as during the second half of a bottle discharge. Therefore the piping should be designed to accommodate a build-up of solid carbon dioxide and operating procedures should be set up to periodically vaporize it by admitting warm CO_2 or heat from another source.

The orifice which regulates carbon dioxide flow rate should be designed so that the precipitation accumulates in a large diameter pipe. The large diameter pipe provides surface for heat transfer from the ambient environment and will greatly extend the time before the solid carbon dioxide accumulation restricts flow rate. Precipitation should not be directed into a globe valve or small diameter pipe elbow. A well designed system will accommodate solid CO_2 accumulation without forming a blockage if the operators simultaneously open all the CO_2 bottles which are connected to manifolds.

If there is a pressure regulator on the bottle manifold, then it should be designed to have a discharge pressure substantially higher than 60 psig (414 kPag, 4.22 kg/cm^2), such as 100 psig (690 kPag, 7.0 kg/cm^2) or 125 psig (862 kPag, 8.79 kg/cm^2). In addition, it should have a flow rate capacity (in scfm's) greater than the flow rate expected through the orifice. If it does not have a high enough flow rate capacity, then it will not pass enough flow to maintain the 100 psig (690 kPag, 7.0 kg/cm^2) or 125 psig (862 kPa-g, 8.79 kg/cm^2), and there will be a possibility of solid CO_2 accumulating in the small bore piping immediately downstream of the pressure regulator. More than one bottle manifold pressure regulator can feed the orifice which regulates carbon dioxide flow rate. See regulator sizing instructions below.

2. Vaporizing Solid CO_2 Blockage

If the operator experiences blockage due to solid carbon dioxide build-up in the piping, there are several methods of vaporizing it.

1. More Bottles Simultaneously to Avoid Rapid Boiling of CO_2

   Bottles which discharge too quickly will have rapid boiling inside the bottle. The rapid boiling causes foam and splatter which will transport liquid to the top of the bottle. If it is suspected that some liquid is being discharged from the bottle, then more bottles should be discharged simultaneously. By having more bottles discharge simultaneously, each will discharge more slowly, and the boiling will not be so rapid.

2. Less Bottles Simultaneously to Periodically Vaporize Solid CO_2 Build-Up

   If blockage is due to solid carbon dioxide forming after a flow restriction, then less bottles should be discharged simultaneously. For example, if the blockage occurs during the last few minutes of five bottles being discharged, then there will be less blockage after four bottles are discharged. When the next four bottles are initially discharged, the relatively warm carbon dioxide will vaporize the solid carbon dioxide which had accumulated.

3. Heating Pipes with Water

   Water can be dripped onto pipes and valves to provide heat to vaporize solid carbon dioxide.

3. CO_2 Heaters May Not Operate in an Emergency

Even if the carbon dioxide is being electrically heated, the system and operating procedures should be designed to accommodate solid carbon dioxide precipitation and the operators should be familiar with effects of solid carbon dioxide. The heater may not be available during an emergency situation if the AC electrical power is lost.

4. Optimal CO_2 Storage and Piping Design

The best carbon dioxide supply system is one where there are enough carbon dioxide bottles connected for fully purging the generator. The advantages are that the operator will not be busy removing and installing bottles in the event of an emergency purge, and the full contents of the bottles are available because bottles which have had solid CO_2 form will eventually warm up and discharge their remaining gas. It would also be advantages if the piping is designed so that all the bottles can be opened simultaneously without the possibility of solid carbon dioxide accumulating to the extent that it blocks the pipe to the generator.

E. Sizing the Carbon Dioxide Flow Orifice

The CO_2 orifice should be sized to provide the optimum flow rate of CO_2 into the generator during the purge process. A flow rate which is too high will waste CO_2 because CO_2 will mix with H_2. A flow rate which is too low will cause the process to outlast the DC seal oil pump battery life, assuming the purge is being done because of an emergency after AC power is lost.

Optimum flow rate is 120 scfm (4.2 m^3/min.) for a 2,800 ft^3 (80m^3) generator interior. The optimum flow rate is approximately proportional to generator volume. The orifice will have an upstream pressure between 100 psig (690 kPag, 7.0 kg/cm^2) and 150 psig (1,034 kPag, 10.55 kg/cm^2) and a downstream pressure between 2 psig (13.8 kPag, 0.14 kg/cm^2) and 5 psig (34.5kPag, 0.35 kg/cm^2). Therefore flow through the orifice is choked (Mach Number = 1), greatly simplifying the calculation.

Use the flow function relationship for choked flow, which is:

mass flow = area * (total pressure / sqrt (total temperature)) * X

X = sqrt (k / R) * sqrt [(2 / (k+1)] L [(k+1) / (k-1)]

Where R=35.04lbf*ft/lbm*R(0.1889kJ/kgK)for CO_2

and k=1.29for CO_2

Given average upstream conditions of 125 psig (862 kPag, 8.72 kg/cm^2) and -10°F (-23.3°C) and a desired mass flow rate of 120 scfm (4.2sm^3/min), the effective area of the orifice is 0.0536 in^2 (35.0 mm^2). The discharge coefficient, Cd, for large pressureratios such as this situation is 0.85 per "The Dynamic sand Thermodynamics of Compressible Fluid Flow" by Ascher H. Shapiro (page100).

Actual Area =Effective Area/Cd

The actual area of 0.063 in^2 (42.5 mm^2), the physical diameter of the flow restriction should be between 0.283 (7.2mm). A standard manufacturing tolerance can be applied to the orifice diameter.

The calculation method is given so that generators with gas volumes substantially different from 2,800 ft^3 (80 m^3) can have their orifices custom sized. Note that area is proportional to flow and inversely proportional to pressure.

F. The Hydrogen Flow Orifice

Because hydrogen does not form solid precipitation inside the pipe, the orifice may be in the vicinity of valves. Therefore it is included in the gas control valve assembly, and does not have to be provided by others.

G. Sizing the Manifold Pressure Regulator Valves

The pressure regulator valves have to be sized large enough to pass enough flow so that the downstream orifice is the most restrictive component of the circuit, and therefore is the device which controls the flow rate. This is especially critical for the CO_2 circuit. If the CO_2 manifold pressure regulator valve is too restrictive, then the pressure immediately downstream of the regulator will be below 60 psig (414 kPag, 4.22 kg/cm^2) and solid CO_2 precipitation would form in the thin pipe after the bottled CO_2 becomes cold.

A typical manifold regulator is the Victor SR-703-ME-996 (0780–0805). The Victor catalog provides 2 data points for air with 125 psig (862 kPa-g, 8.79 kg/cm^2) delivery pressure: 50 scfm at 200 psig (1.4 sm^3/min at 1.380 MPa, 14.07 kg/cm^2) and 183 scfm at 2,000 psig (5.1 sm^3/min at 13.8 MPa,140.7 kg/cm^2). The conversion factors from the catalog are 0.81 for CO_2 and 3.79 for H_2. Therefore, for CO_2, the flow rates are 40 scfm at 200 psig (1.1 sm^3/min at 1.380 MPa, 14.07 kg/cm^2) and 150 scfm at 2,000 psig (4.2 sm^3/min at 13.8 MPa, 140.7 kg/cm^2).

Given 40 scfm at 200 psig (1.1 sm^3/min at 1.380 MPa, 14.07 kg/cm^2), there would have to be three (3) of this style regulator for 120 scfm (3.4 sm^3/min). Below 200 psig (1.380 MPa, 14.07 kg/cm^2), some solid CO_2 precipitation may form near the regulator. If only two (2) regulators are used, solid CO_2 precipitation may form with bottle discharge pressures up closer to 400 psig (2.76 MPa, 28.15 kg/cm^2).

If there is one pressure regulator for each bottle manifold, then the operator should open bottles from each of the manifolds simultaneously, so that all the regulators are in use simultaneously.

H. Calculating the Quantity of CO_2 Bottles Required to Purge a Generator

It is important to have enough gas immediately available for a carbon dioxide purge of the generator of hydrogen. A typical CO_2 bottle, when fully charged, has 50 pounds (22.7 kg) of carbon dioxide. When expanded and heated to ambient inside the generator, the typical bottle has 435 cubic feet (12.3 m^3) of gas. Of this gas, a fraction, x, is available prior to the bottle being removed from the manifold. If the bottle is not removed, x=1. The fraction, x, may be less than 1 because of CO_2 which freezes in the bottom of the bottle.

Because some mixing of gas will occur during purging, twice the generator worth of bottled CO_2 is required to purge out hydrogen.

bottles of CO_2 = 2* generator volume / (x * volume of gas in a bottle)

Example: Therefore, for a generator of 2,800 ft^3(80 m^3) and bottles originally at 32°F (0°C) for which x=0.64, 2*2800 / (0.64*435) = 21 number of bottles of CO_2 are required to be available in the event of an emergency purge.

I. Calculating the Quantity of H_2Bottles to Purge and Fill the Generator

The typical H_2 bottle has about 200 ft^3 (5.7 m^3) of usable hydrogen when warmed to ambient temperature inside the generator. Because some mixing of gas will occur during purging, twice the generator worth of bottled H_2 is required.

bottles for purging = 2 * generator volume / volume of gas in a bottle

Additional bottles of hydrogen are required to pressurize the generator. Conservatively, this quantity is:

bottles for filling = n * generator volume / volume of gas in a bottle

where n is chosen from the following chart:

n	final generator pressure (psig)	(kPag)	(kg/cm^2)
1	15	100	1
2	30	200	2
3	45	300	3
4	60	400	4
5	75	500	5

The total number of hydrogen bottles which should be available prior to putting hydrogen into the generator is:

bottles of H_2 = # bottles for purging + # bottles for filling

Example: To purge and pressurize a generator of 2,800 ft^3 (80 m^3) to 60 psig (about 400 kPa or 4 kg/cm^2), there should be 2 * 2,800/200 + 4 * 2,800/200 = 84 number of bottles available.

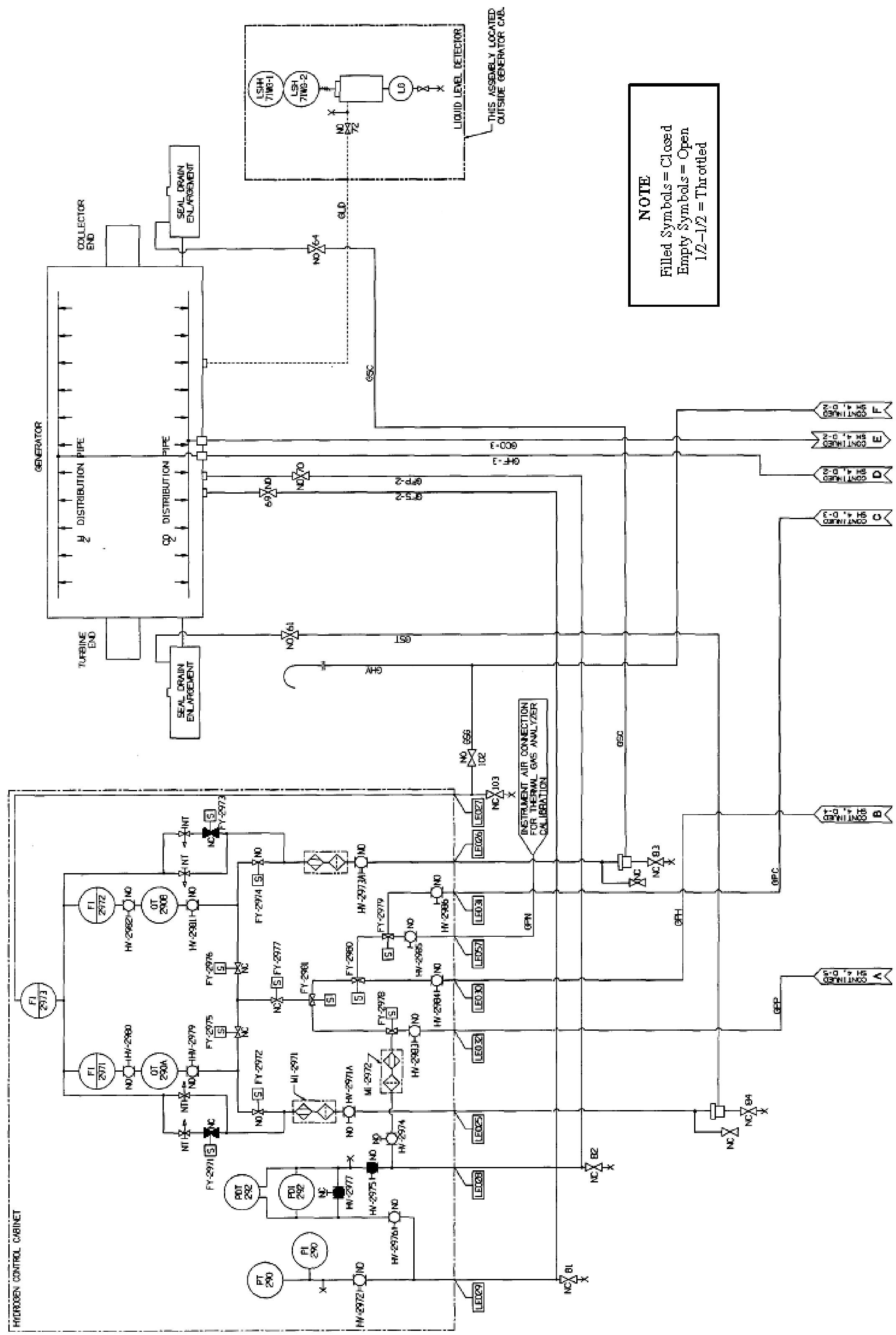

Figure 7. Process #1 Fill and Test with Air

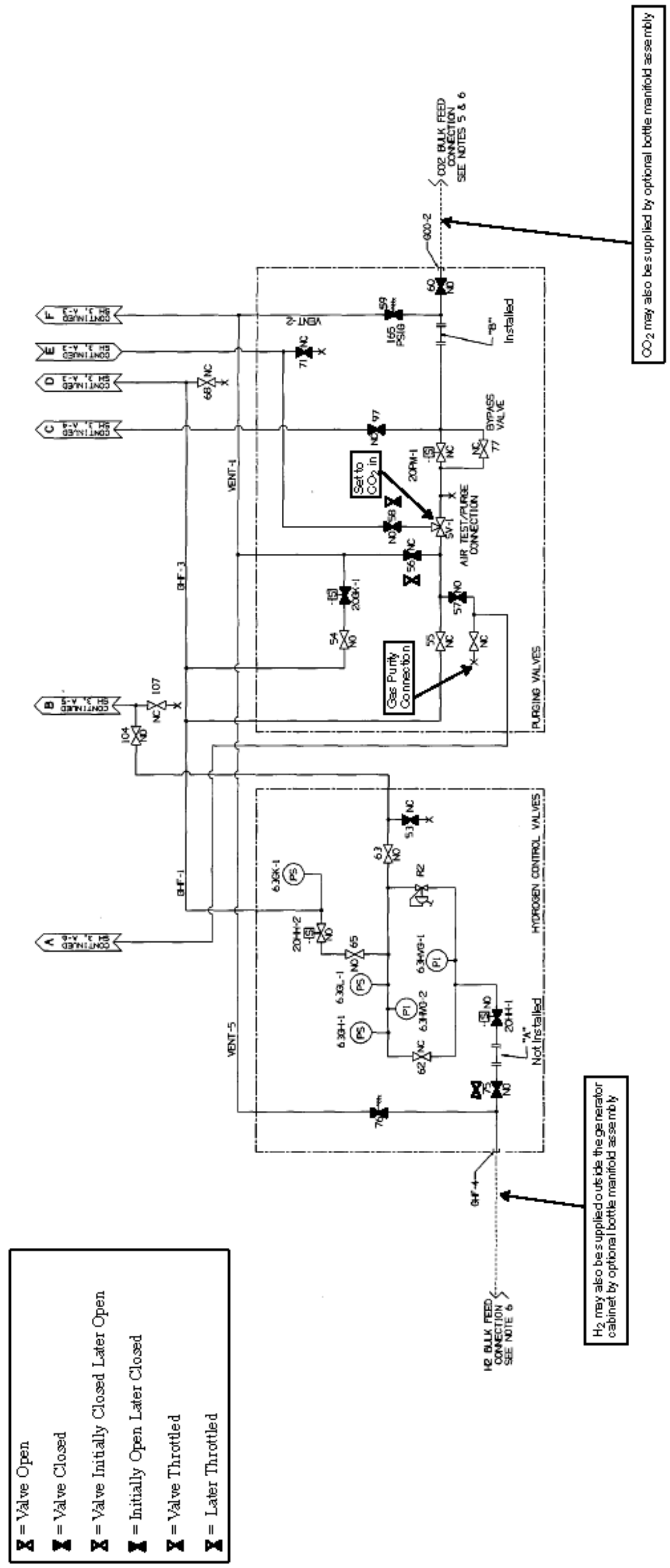

Figure 8. Process #1 Fill and Test with Air

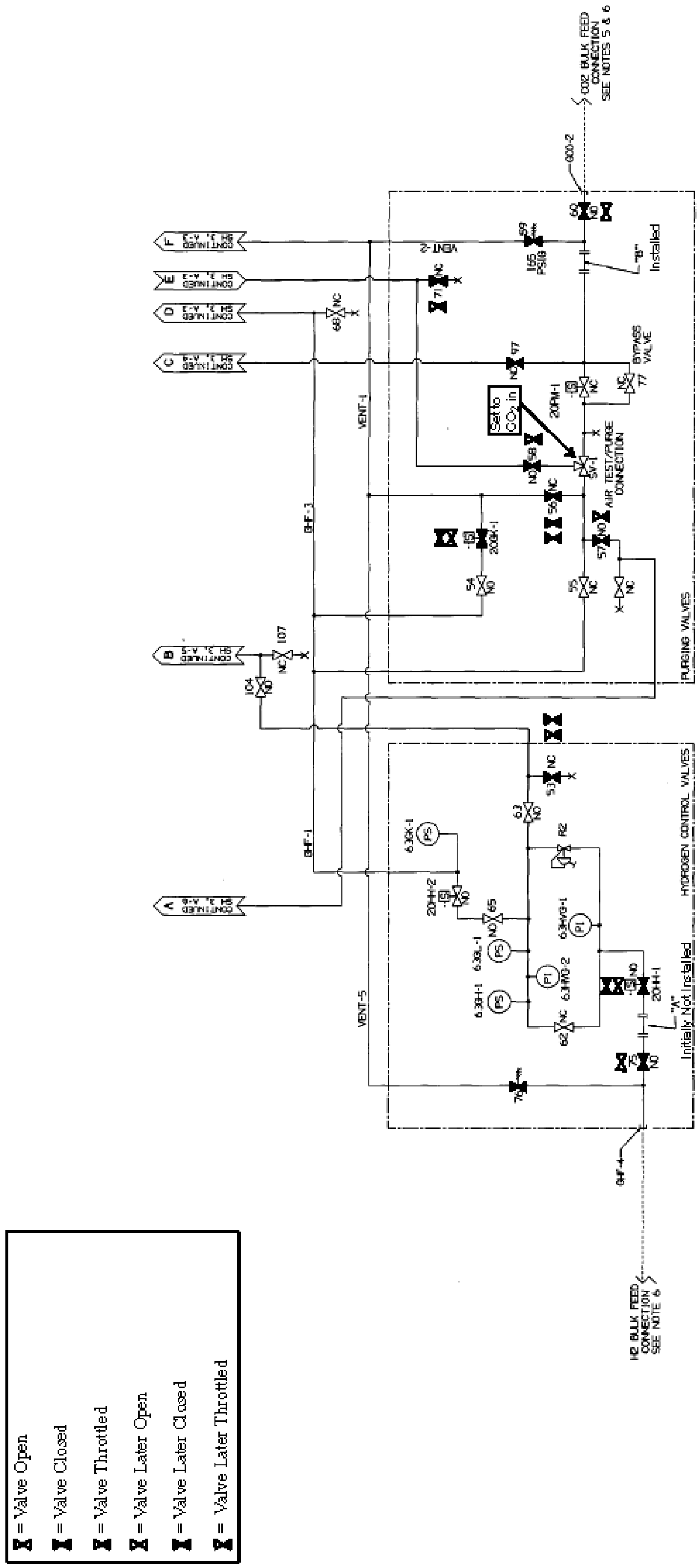

Figure 9. Process #2 Purge Air, Fill with CO_2

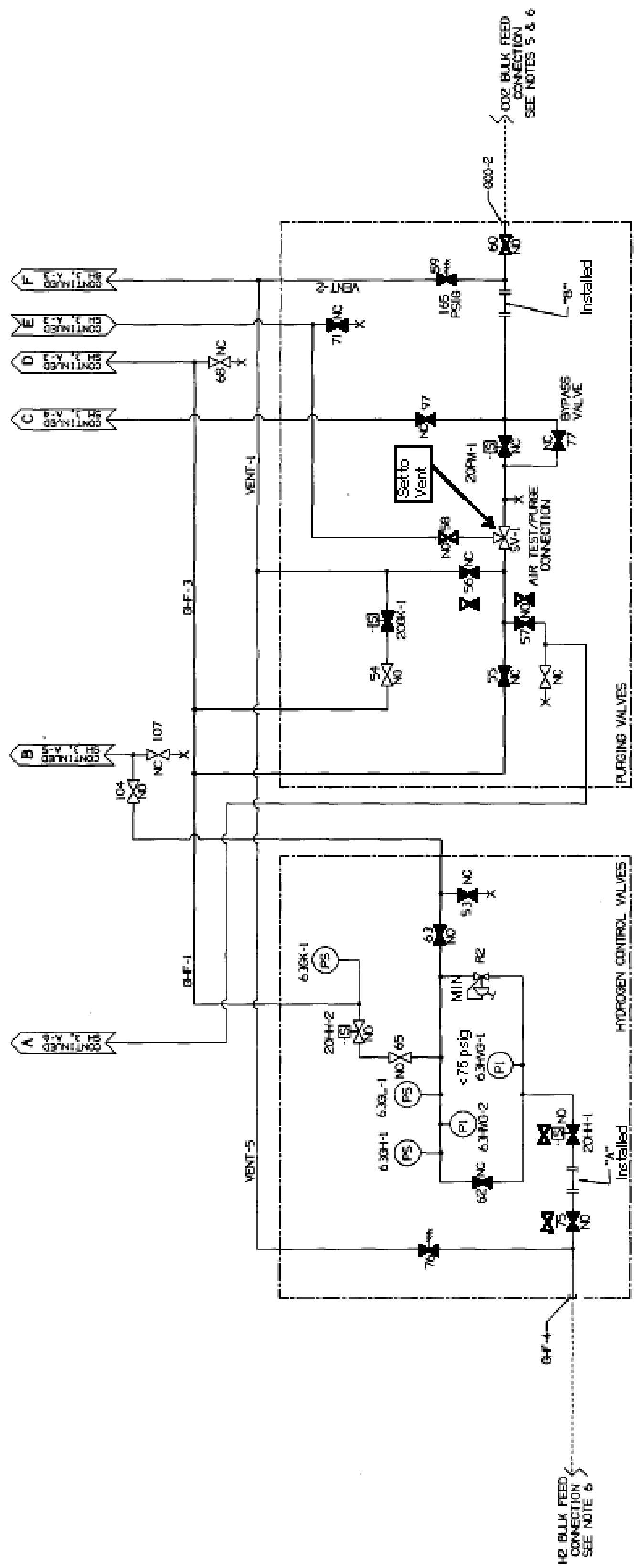

Figure 10. Process #3 Replace CO_2 with H_2

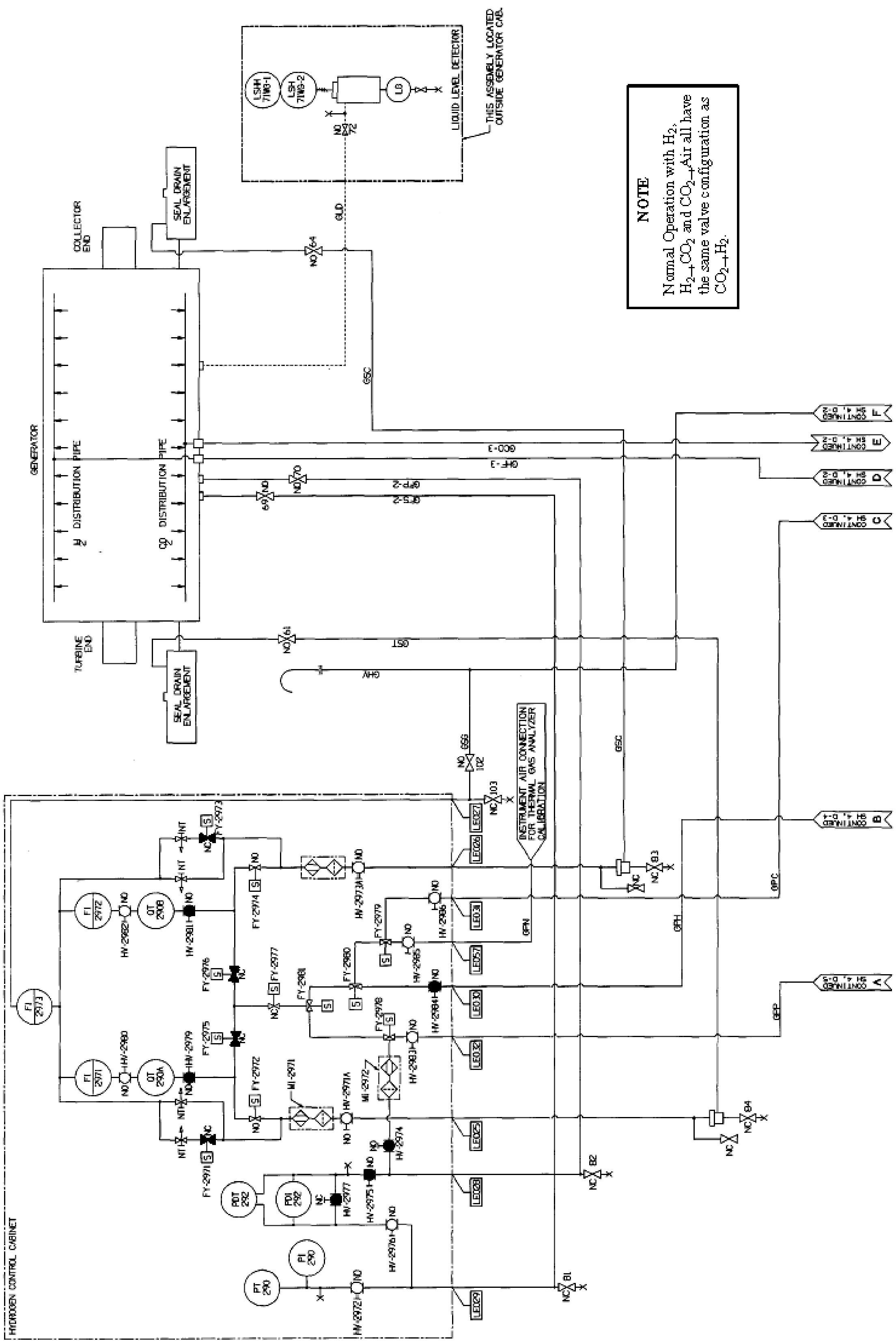

Figure 11. Process #3 Purge CO_2 and fill with H_2

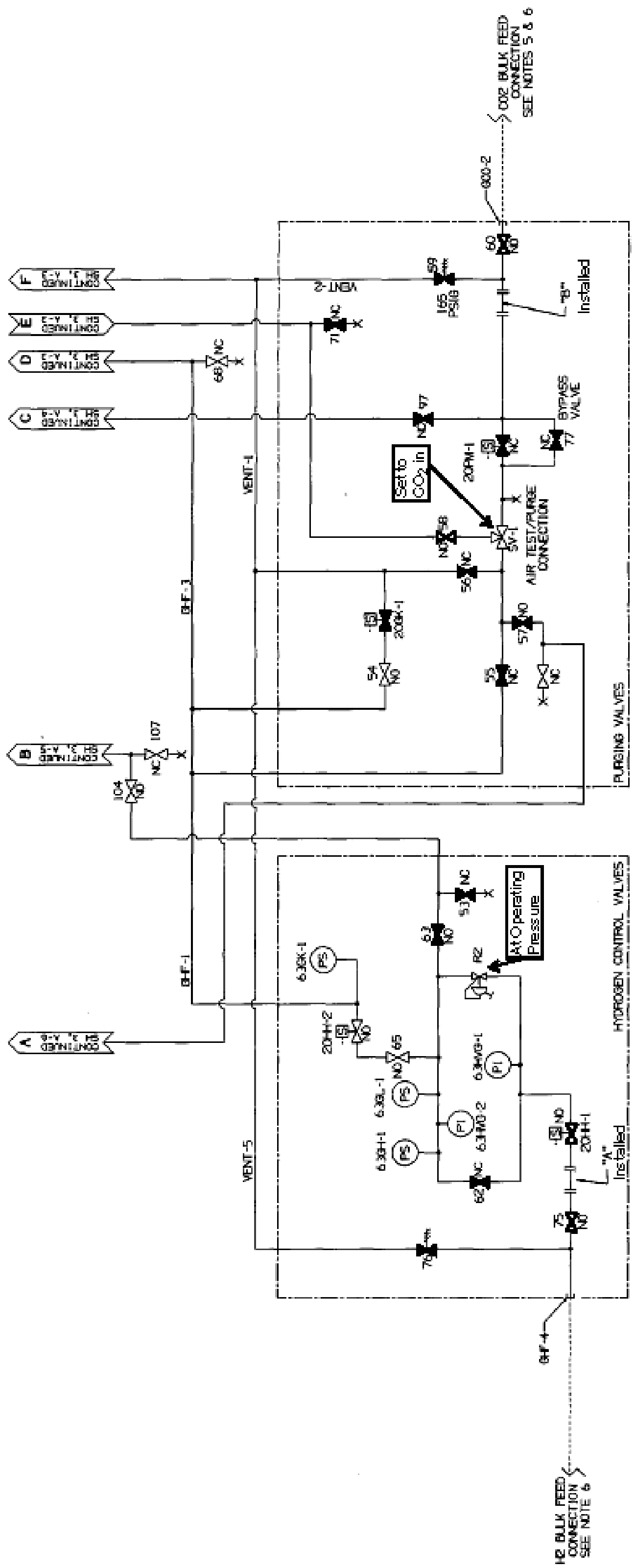

Figure 12. Process #4 Normal Operation with H_2

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