Practical Hydrogen Systems: an Experimenter's Guide

by Phillip Hurley

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Designing Hydrogen Systems

An introduction to hydrogen systems

The term hydrogen system can denote many things, but for our purposes it designates a system that:

- Produces hydrogen by electrolysis,
- Processes hydrogen by catalytic recombination and simple liquid scrubbing,
- Compresses and stores it in gaseous form.

Anyone can produce hydrogen by mixing a few materials, but to go beyond a simple demonstration to a practical application involves the disciplines of chemistry, electrochemistry, physics, mechanics, electronics, and electrical applications. Building a hydrogen system requires basic skills in the areas of finding material resources, understanding material compatibility, and fabricating components.

This may sound formidable, but the good news is that anyone of average intelligence, who is thoughtful and methodical, can, with a few easily learned skills, fabricate a hydrogen system at reasonable cost if they approach the process as a learning experience with the goal of developing a better understanding of these systems.

If you are a plug and play person and will hurt yourself if anything is not UL approved, you will not do well in the hydrogen lab. Patience, caution and a level head are very important, to go along with the sense of adventure that comes from the excitement of being involved in a forward looking technology.

This book is not intended to be a course in chemistry, physics or electronics. All these disciplines are touched on here as they are needed for a basic understanding of design and operation of simple hydrogen systems. We do presume some familiarity with the disciplines involved. We do not cover every aspect or possibility of design. We do work with several simple experimental ideas and develop them to finished products that will give you some idea of what is involved.

Designing your hydrogen system

Many methods can be used for hydrogen production, processing and storage, and one's choices will be determined by a variety of factors. To design and experiment with hydrogen systems, you need a good understanding of the materials and methods you are going to be working with. You will need to decide what you want your end product to be and do; and then how your hydrogen system is going to do it.

Designing Hydrogen Systems

Defining your goal is usually fairly easy. Figuring out how you are going to get there is a bit more complex. It requires knowledge of components, what they do, how they do it and what type of environments they can operate in. This requires consideration of such things as pressure ratings of components; and how the materials the components are made of will react to the other materials and the conditions in the system. To avoid errors that will cause system failure or create a safety hazard, materials must be well matched and the processes of the system must be well understood.

Form follows function. First of all, you need an understanding of the primary substance you will be working with (hydrogen). Then, research the materials and components to design your subsystems; and let the system take its final shape from these.

Functions within a basic hydrogen system

A basic system involves:

- Hydrogen generation
- Hydrogen transport (within the system)
- Hydrogen processing
- Hydrogen storage
- System control
- System monitoring

All hydrogen generation and processing systems are also concerned with:

- System safety
- System efficiency – according to need or state of the art for your particular application
- Location and environment – is it to be stationary, portable or mobile, and what sort of environmental conditions will it operate in.

The system and its context

The quality (or state) of system safety and efficiency is determined by all the elements of the system and its environment converging. For instance, if your hydrogen unit will be in a submarine, different considerations come into play than if it will be in a factory setting. The environments are different, and certain space, safety and other factors are very important in one setting while they may not be relevant another. Designing a hydrogen system requires a holistic approach. You should always design a system with careful consideration of the conditions of its external environmental.

Effects of weather

For instance, a simple unit placed outdoors in a stationary or mobile setting is going to be affected by the weather. Factors such as temperature changes and the rate at which the temperature changes occur can have a marked effect on materials. Some plastics, for example, do well in cold weather and others do not.

Different component materials have different rates of expansion and contraction. If they are connected, temperature changes can cause leaks if the expansion and contraction rates are too different. Some materials such as PVC are prone to ultraviolet degradation. Phenomenon like fog, dew, rain, and snow can cause electrical shorts in process control units if their housing does not protect against moisture. Most commercial units are placed outdoors with some sort of shelter to temper their exposure to ambient weather conditions.

Of course, gross weather disturbances such as high winds, lightning, hurricanes, tornadoes and flooding as well as geological phenomena such as earthquakes need to be considered in areas susceptible to any of these.

Indoor systems

If the unit will be indoors in a more controlled environment, then other factors need to be considered such as ventilation. Ventilation can be addressed through the use of gas cabinets and ventilating fans.

Electrical influences

Electrical influences on the system that should be considered are electrostatic charge, and lightning effects, whether direct or indirect (such as induced charge from a nearby lightning strike). Electrostatic charge buildup can occur from blowing dust or snow, general wind conditions and a wide variety of other sources. Any metallic object (conductor) that can be electrified must be grounded so that any electrostatic charge that might build up is drawn safely to ground. If this is not done, and a charge is built up sufficiently, it can discharge to a nearby conductor – or to you – as a pathway to ground. This is similar to what happens when you get out of your car and you get an electric shock. Hydrogen systems need to be grounded with appropriate wire or metallic braid to prevent igniting the hydrogen if there is a leak. It is convenient to have a grounded plate you can touch before you

Grounded touchplate

approach the system. This will avoid having a static charge your body has accumulated discharge to the metallic components, which could cause ignition if there is any leak in the system.

These are just some of the basic considerations necessary to begin to design a system.

The Design Process

System diagrams and lists

Start the design process by making simple block diagrams of the main components of the system. Then, make a pictorial diagram indicating the exact parts you plan to use. Along with the diagram and list of parts, include the parameters of each part as it relates to your system, supplier and contact information, and the cost of each part.

Collect information resources

To develop your plan, you need to understand the components and their parts, and where to access them. You may wish to make a database of suppliers and their catalogs and reference materials. Most suppliers have online catalogs and/or paper catalogs that have plenty of information about how to use their products, including charts and tables that will help you select the products you need. You should also have trade books and other information that is pertinent to your choice of components so that you can design the system intelligently. Your database should include all cost, safety, compatibility, and performance information in order to build the system according to your experimental goal.

Once you have the information organized, you will be able to study material compatibility and identify details for your preferred system components.

Consider the internal and external environment, medium characteristics, compatibility of all the materials used in the process, and the conditions of operation when studying your choices for components. Then, put your goal through the filters that will separate fact from fiction. Those filters are consideration of the cost, safety, and performance of your designed system.

The budget for your hydrogen system

You can estimate the cost of the components from your component supplier database. This will give you a general idea about whether your budget is realistic for your experimental goal. If it is not, you will need to lower the costs of components and/or reevaluate (and perhaps change) your goal.

For example, if your experimental goal is to design and build a hydrogen system to fuel a fuel cell unit for home power backup, and you found that the cost of your plan does not fit your budget, you will either have to pare down the system, find less expensive or used components, or come up with some ingenious innovation to bring the cost into line.

Every part of the system must meet safety and performance criteria. Although it is not always the case, usually safety and performance of components is directly tied to cost. Most of the time, the more expensive a component is, the more safe it is. The same is true for performance. The more

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costly the component, usually the better it will perform. It should be mentioned here that while more expensive components have a tendency to perform better and be safer than less expensive components, that is not always the case, and at a certain level, that may not be an important criterion. For instance, although there is a big difference between the cost of a Porsche and the cost of a Honda, both of them perform certain basic functions equally well. The Honda will not give you all the performance characteristics of the Porsche, but if you don't normally use those high performance extras, the Honda will do just fine.

Tools and safety equipment should be included in the budget for the project. The same rules apply for tools as for the components for the system. Usually the less expensive tools and equipment are not as reliable as the more expensive choice, but depending on your needs, they may be more cost effective.

Do it yourself or out-source

Another important cost consideration is to assess your own skills and what portions of the project you should out-source. For instance, if you know how to weld the particular materials you will be working with, and have access to the equipment needed, you will probably do this particular fabrication yourself. If you don't know how to weld or have the equipment, you will probably out-source your welding jobs. Call various shops and evaluate their expertise for what you need done, and get the cost for the welding job. Price and quality of work can vary widely from shop to shop. It is sometimes wise to spend more and be assured of having a professional job done as this can save you time and money later. Even if you have these fabrication skills, you may decide to out-source certain tasks.

You can learn welding and machining, and purchase equipment, if you have the time and money to do so. This can involve a significant investment for milling machines and welding equipment, and there is a substantial learning curve. However, it is always handy to have some basic machining, welding, electrical, and electronics skills; and to have the equipment to do the more basic operations yourself, even if you leave the really critical jobs to more skilled hands.

Working with the Materials

Hydrogen history and characteristics

The alchemist Paracelsus (1493-1541) mixed metals with acids and became the first person to produce hydrogen.

Hydrogen derives its name is from the Greek *hydro*, meaning water, and *genes*, meaning forming, thus “water forming.” Hydrogen was recognized as a distinct substance by Cavendish in 1776 and was later given the name hydrogen by Lavoisier who noticed that water was formed when hydrogen was burned.

Hydrogen is the most abundant element in the universe. Over 90% of all the atoms, and thus about three quarters of the mass of the universe, is hydrogen. This is one very simple reason why the planet is definitely going into a hydrogen economy.

Although present in the atmosphere, hydrogen is not exactly a “free floater,” as it is chemically very active. It combines readily with other elements, and so is locked into compounds. On this planet most hydrogen is in water and organic compounds which make up about 70% of the earth’s surface. In the atmosphere it is present at only about 1 ppm (part per million).

It is the lightest of all gases and disperses quickly if not confined. It is colorless, tasteless, odorless, and slightly soluble in water. Hydrogen can be liquefied at -423°F, and can take on a metallic state under certain conditions. At about 120.7 kilajoules per gram, it has the highest energy content of any known fuel. Its atomic number is 1, its atomic symbol is H, and its atomic weight is 1.0079.

Apart from the isotopes of hydrogen (protium, deuterium, and tritium), hydrogen occurs under normal conditions in two forms or kinds of molecules. These two forms are known as ortho- and para-hydrogen. They differ from one another by the spins of their electrons and nuclei. Hydrogen can be produced by steam reforming, electrolysis, ammonia dissociation, and partial oxidation. It can be stored for later use, as a gas, a liquid or in compounds such as hydrides. It is highly flammable and explosive, and can be easily ignited through static electric discharge; or by a catalyst such as platinum without any other source of ignition, in the presence of air or oxygen.

Hydrogen safety

Proper precautions and safety measures recommended in the hydrogen MSDS (Material Safety Data Sheet) should be followed as well as other ruling jurisdiction safety rules and guidelines when handling hydrogen. Please follow this link to **MSDS recommendations** on the internet, and study the MSDS carefully!

Oxygen

The name oxygen is derived from the Greek *oxys*, sharp, acid; and *genes*, meaning forming, thus "acid former." Priestley is generally credited with discovering it. Oxygen's atomic number is 8, its symbol is O, and its atomic weight is 15.9994. It is slightly soluble in water and becomes a liquid at -297°F. It has nine isotopes. Oxygen is about 21% of the earth's atmosphere by volume, and over 49% of the earth's crust. It is colorless, odorless, and tasteless. It reacts with all elements except inert gases, and it forms compounds called oxides. Although oxygen is not flammable, it vigorously supports the combustion of materials that are flammable. It is used in many industries for a variety of purposes. It can be produced by electrolysis, by heating potassium chlorate with a manganese dioxide, or by fractional distillation of liquid air. It is nontoxic, and as a gas poses no hazards except for its vigorous support of the combustion of flammable materials.

Oxygen and safety

Because of its support of combustion, it is important to keep oxygen separated from hydrogen, both in the production of this gas in the electrolyzer, and at any other stage of gas processing and storage. It is also important to store oxygen away from oils and greases and other hydrocarbons. Large volume storage of oxygen should be at least 20' from hydrogen tanks, or separated

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by a barrier at least 5' high and rated for fire resistance of at least a half hour. For connections, green color coded Teflon tape is compatible with oxygen; and LOX-8, Super LOX-8, or Oxytite are recommended pipe dopes.

The significance of MAWP becomes clear when the MOP (maximum operating pressure) of the system is considered. In designing a system you decide what pressure the system will operate at. This is the MOP. The MOP needs to be 10% to 25% (or more) below the MAWP or the pressure of the lowest rated component in the system.

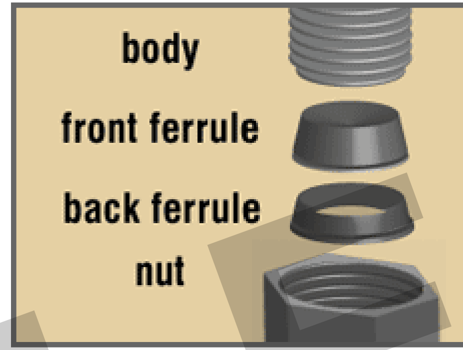
In determining the MAWP, we are looking at components such as fittings, piping and vessels; however, how components are fitted is also a concern in this equation. For instance, a vessel with a flange that is screwed on would have a different pressure rating than a vessel with a flange that is welded on.

Settings for safety release valves

All pressurized systems need safety release valves. The safety release pressure that is set should not be at MAWP or above MAWP but below MAWP and above MOP. Two of the types of safety release valves are pop safety valves, and what are simply termed relief valves. Take a look at a supplier's catalog such as McMaster-Carr's,

Adjustable relief valves

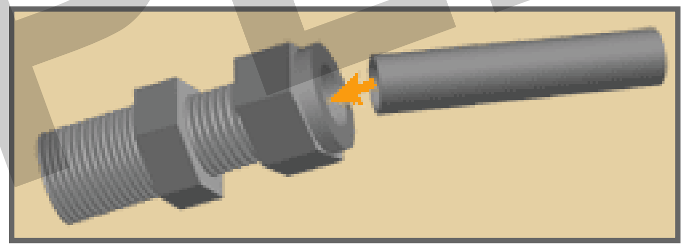
Component Overview

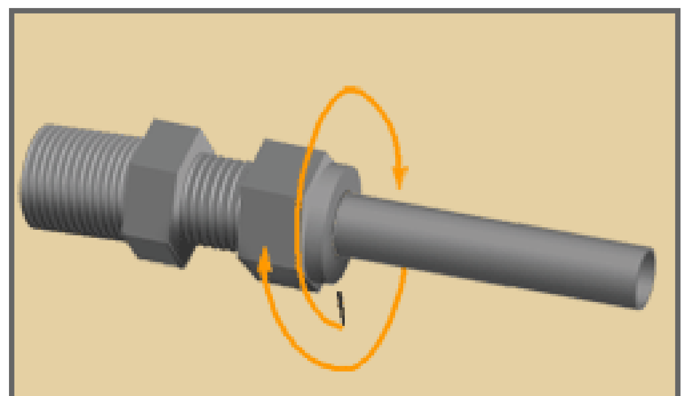


Ferrule placement
in compression fittings

The available configurations for these fittings are basically T, cross, straight; with options for either all tube ends, or tube to NPT. The tube connecting ends consist of a nut with two sleeves (ferrules) that slip over the tubing. The sleeves are compressed and locked into the tubing by tightening the nut to create a sealed connection. For this type, do not use any thread compound or tape on the tube end connection threaded nut. You can use tape on the NPT side, however.

Some other fittings are used, as listed, and some of these are brass, but they are sufficiently downstream from the KOH to not be significant concern for a short term duration experimental project.





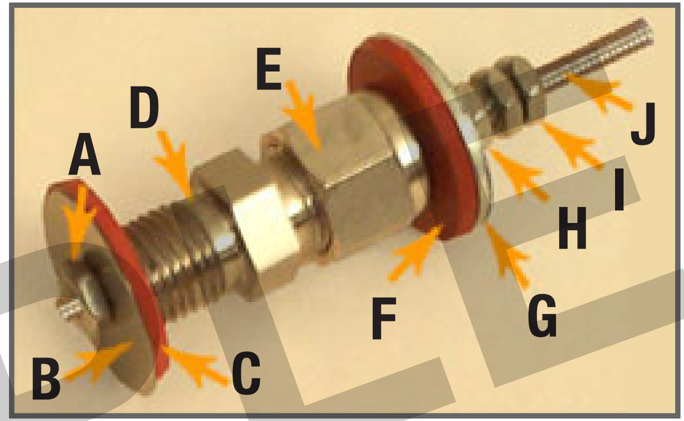
Placing and securing
fittings to a tube

Accuracies range from plus or minus 5% over full scale to plus or minus 0.1% over full scale. Of course, the more accurate a gauge is over full scale, the more expensive it is. For some applications, it is not necessary to have high accuracy.

Grades of accuracy for pressure gauges

4A	0.1% accurate full scale (the most accurate)
3A	0.25% accurate full scale
2A	0.5% accurate full scale
1A	1% accurate full scale
A	1% accurate mid scale and plus or minus 2% accuracy over the first and last quarters of the scale.
B	plus or minus 2% accurate mid scale and 3% in the first and last quarter of the scale
D	generally plus or minus 5% accuracy over full scale.

Understanding gauge accuracy designations is important, as errors can be introduced into your experimental work if you do not take into account the accuracy of the reading. Accuracy is important, for instance, for setting



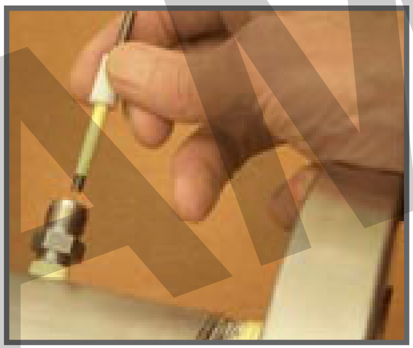
The positive electrode feed-through

A	**Nut**
B	**Nickel washer**
C	**Rubber washer**
D	**Fitting body**
E	**Fitting nut**
F	**Rubber washer**
G	**Stainless steel washer**
H	**Pair of nuts**
I	**Pair of nuts for connector**
J	**Threaded rod**

- Back off the Teflon insert by unscrewing it ⅝".
- Apply thread seal to the bare ⅝" of the rod you have just exposed
- Screw the Teflon insert back on over the part of the rod you applied the thread seal to. Do not use too much thread seal – a little will suffice.

Positive electrode installation

- Coat two ¼" NPT x ⅜" Yor-Lok fittings on the ¼" NPT side with thread seal, and tape with Teflon. Screw these into the positive electrode port holes and tighten.

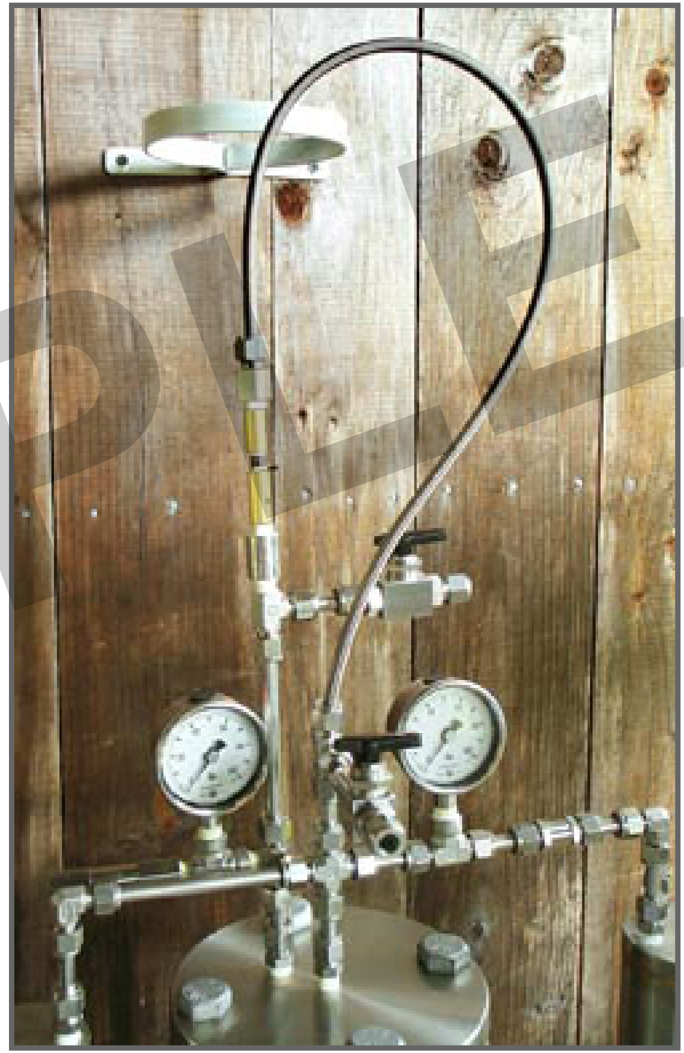


- Place the taped rod with the Teflon insert into the fitting, put on the ferrules and nut, and then tighten.
- Insert and position the Teflon liner back into the nipple. The threaded rod will now protrude through the holes in the liner when it is positioned correctly.

How the valve works

The equalization valve addresses the pressure disparity with a miniature hydraulic cylinder and a few machined parts. The miniature hydraulic cylinder is the heart of the valve. It responds to both gases to determine the amount of gas released from the oxygen side, based upon the pressure of both gases in relation to each other. The cylinder opens and closes an outlet port for the oxygen.

When the pressure on the oxygen side rises higher than the hydrogen pressure, the oxygen gas pushes in one direction against the cylinder, which is being pushed in



Storage Tank and Peripherals

There are many types of tanks that can be used. The best for this type of system is a stainless steel 316 tank. The size of the tank will depend on your storage needs. For initial experimental purposes a small tank is recommended. As discussed earlier, using a smaller tank makes the system's fill cycle shorter and faster, which saves a lot of time when running tests.

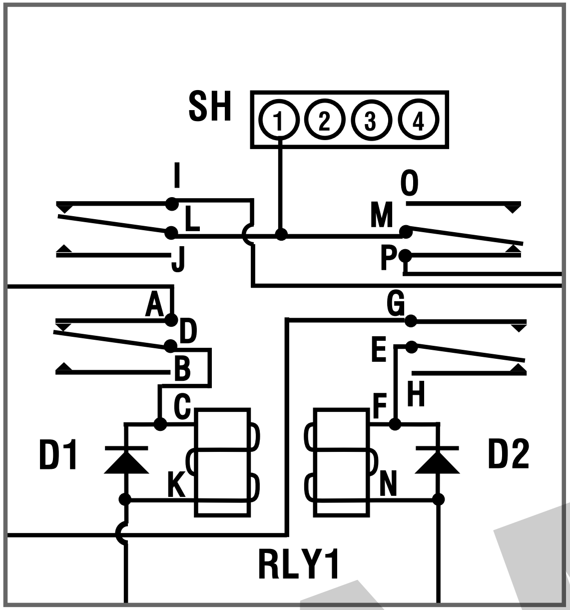
Pressure switch

There are three wire connections to be made on the pressure switch. Notice that the switch has three colored coded wires:

- Blue – "High" wire
- Red – "Low" wire
- Black – "Common" connection

- Insert 1½" length of ⅜" tube into tube end of this fitting.
- Attach the tube end of a Yor-Lok ¼" female x ⅜" tube fitting to the ⅜" tube and tighten.
- The ¼" NPT female end of this fitting is then attached to the flexible metal hose with swivel male fitting after you thread seal and tape. The hose part number is in the storage tank connections section on page 225.

Relay Schematics

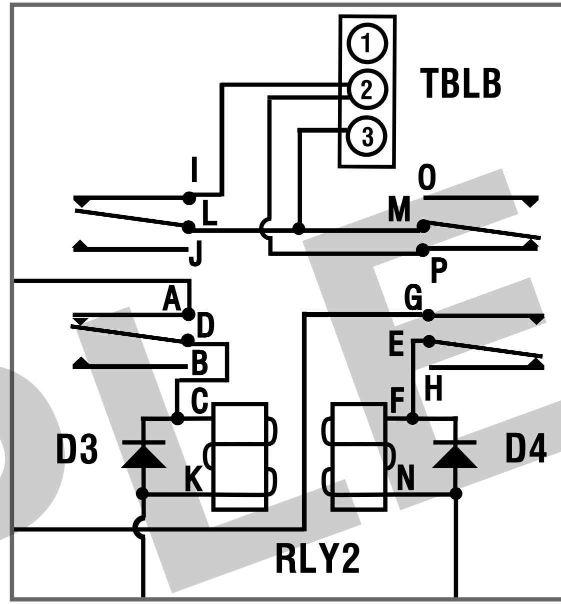


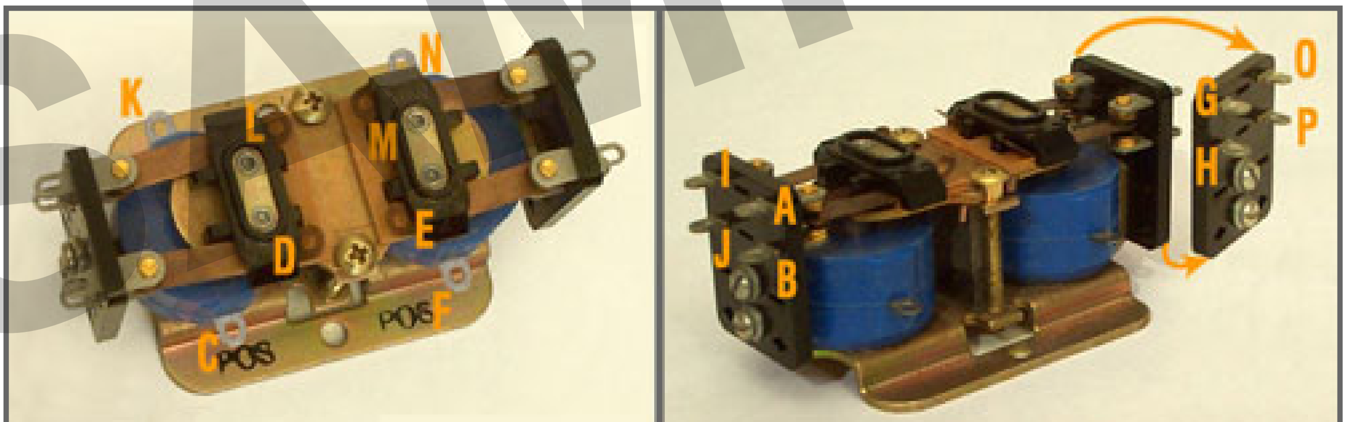
SH - Shunt

TBL - Terminal block connector

D - Diode

RLY - Relay



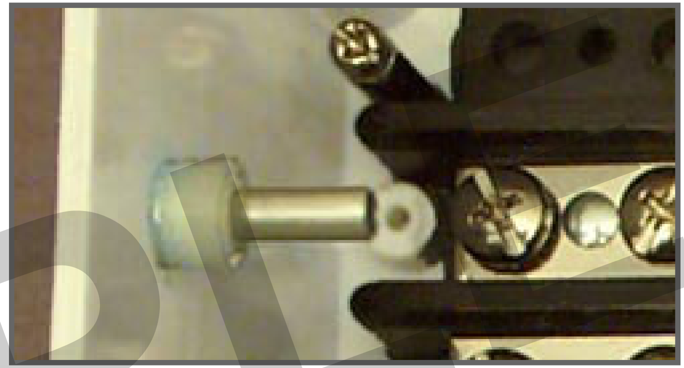


Pressure sensor

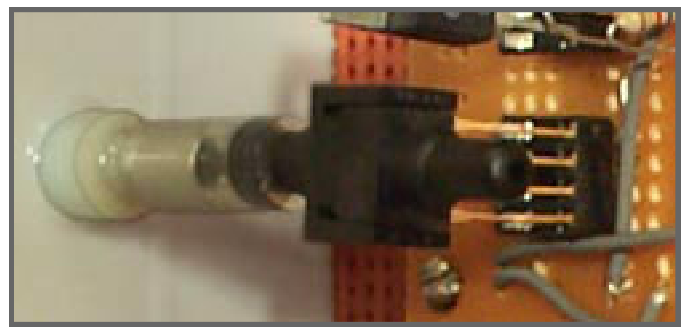
There is one more pressure port – the inlet for the pressure sensor for the box. This consists of a small drilled hole in the box. Ours is located on the side of the box (port 5), but it can be anywhere convenient for attaching the pressure sensor hose.

The pressure sensor is connected to its port via a plastic tube. Two standoffs are used to create a port attachment for the tube coming from the pressure sensor.

We used an aluminum standoff that slips tightly into the tube, and another plastic standoff that the aluminum standoff can be placed



Process control box pressure sensor port (above), and with pressure sensor installed (below)



4. With the regulator secured to the cylinder, make sure the outlet valve is closed by turning the adjusting handle to the full counterclockwise position on the regulator. The regulator outlet valve must always be closed before the next step, which is opening the cylinder valve.

Close regulator outlet valve

Open the cylinder valve

5. To open the cylinder valve, place both hands on the cylinder wheel and turn on slowly, allowing the pressure to gradually rise in the regulator. When the high pressure gauge shows maximum pressure (about 2200 psig), open the cylinder valve wheel fully.

Nitrogen purging sequence

1. Put regulator with attached outlet hose on cylinder and tighten CGA connection.

Basic system inspection

When you receive your unit be sure to inspect the surfaces for damage. Surface damage can affect operation. For instance, one unit we received had a dent in the door that prevented it from closing completely. The door was connected to a switch so that the unit would not turn on unless the door was closed. The door had to be hammered back into shape to correct the situation.

Read the manual before you first open up the fuel cell unit and start poking around. There may be special instructions for accessing certain parts of the unit. Also note if the unit is dirty or not. If it is, vacuum and wipe down the unit as well as possible. Many units have air ducts, filters and fan blades that should be inspected and cleaned on a regular basis.

Fuel cell cartridges visible below control panel

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