Abstract

The Tevatron liquefer is operated from a control room located on the second floor of the Liquefer Building at Fermilab. The entire plant is monitored and controlled by operators in the control room. The control system is electronic and consists of loop controllers, sequencers and digital readouts installed in an operations console with interactive process display.

Process readings from the plant are checked for out-of-limits values by the sequencers each 8.3 ms. The sequencers can display warning messages in color on the operations console to alert the plant operators to changes in the process. In the case of an alarm, one of the operators can correct the process from the control room by manually altering the loop controllers while monitoring the readouts of the process variables. The sequencers are capable of shutting down part or all of the process system if the combination of alarms is serious.

A spectrographic nitrogen detector has been designed and installed to continuously monitor contamination at the 1 ppm level in the helium process. Gas from the process stream is excited to produce photon emission. A grating monochrometer is used to select light of one wavelength. A photomultiplier measures the intensity level of the wavelength corresponding to nitrogen contamination. The high intensity of spectral lines from the helium process is ignored by this detection method. The system is a continuous monitor with a rapid response.

Introduction

The Central Helium Liquefer of the Fermilab Tevatron requires a system to control the process shown in Figure 1. Two compressors operate in parallel to compress helium to 12 atm, in three stages. The helium then enters the cold box where it is expanded using three turboexpanders and a final Joule-Thompson valve to produce liquid.

The operations console is shown in Figure 2. The upper portion of the console is a data panel 30 ft² in area which is used to display a lighted flow diagram in color. The operators' instrumentation includes loop controllers which show the operator the value of the process variable and the opening of the corresponding control valve. The control loops are implemented independently (i.e., they are upset) and the automatic loops have feedback response with P.I.D-action. Process variables not incorporated into control loops are also displayed at the console for the operator. Eighty analog process readings in the plant are checked for out-of-limits values. Texas Instruments 5701020 sequencers are used to perform ladder logic as described here and elsewhere.

Control Loops

Each compressor has three unloading valves which bypass the individual stages (a total of six loops). The compressors have control loops to regulate discharge pressure (two loops). The gas management system involves four control loops to supply make-up gas to each compressor and return excess inventory to storage.

The cooling system involves four on-off control loops to operate the fans in forced-air cooling towers. In addition, two control loops regulate the temperature of the cylinder cooling water.

The cold box requires three control loops on the inlet valves to the turbines. Each turbine also uses a control loop which acts as a brake. The Joule-Thompson valve is the output element of a control loop. The flow of liquid nitrogen used for precooling is controlled by another loop.

Sequencer

The sequencer consists of input and output modules shown in Figure 3 connected to a processor. In operation, the sequencer is capable of performing three functions. (1) It can scan a set of logic-level inputs called X. (2) It can produce a set of logic-level outputs called Y. (3) It can read and write a 512-bit word within the processor. This word is called the CR and its value is the internal state of the sequencer. Because of these three operating functions, the...
sequencer is an example of a model computing machine described at an early date. Perhaps this is not surprising; however, it is interesting that such a machine has found a practical application over forty years after being first identified.

The operation of the sequencer is governed by a program stored in 1024 words of 16-bit memory. This program cannot be modified by program execution and therefore the program is serially reusable if the CR is initialized on each pass. Although the number of internal states of this machine is very large \(2^{256} = 10^{77}\), the size of the sequencer's program effectively limits its computing power. This design makes the reliability of the sequencer software high. Operating experience over the last 12 months shows that the implementation of the machine in hardware is also high.

Spectrographic Nitrogen Detector

The development of this device was motivated by the need to keep impurities in the helium stream to the liquefier at a very low level. This is absolutely necessary to avoid damaging turbinions, plugging valves and lines, and impairing the efficiency of heat exchangers. The most troublesome contaminants in practice tend to be nitrogen and oxygen with nitrogen being the largest contributor and the most difficult to monitor at very low levels of the order of one part per million.

The method used to detect nitrogen is to observe the characteristic molecular spectrum emitted when the gas is optically excited in an electric arc. The difficult part is to maintain a stable excitation.

A stable excitation has been obtained by using an alternating electric field of a frequency of 100 kHz and a field strength of about 5000 V/cm across a pair of tungsten electrodes placed in the contaminated helium medium at atmospheric pressure. Normally this excitation will not break the gas stream initially or restore the arc if a quench occurs. A dc voltage is applied at the level of about 15000 V/cm which breaks the gap down. This "keep alive" current is limited to 150 \(\mu\)A by a series 10 K\(\Omega\) resistor. It is also observed that once the arc ignites, the dc current has no effect.

Once the arc is glowing, it is easy to distinguish even by direct observation that helium with 50 ppm nitrogen contamination produces a blue arc whereas pure helium produces a very pink arc. To make the system automatic and sensitive the arc is projected on the entrance slit of a grating monochromator with a single quartz doublet of focal length 35 mm. The monochromator is equipped with a photomultiplier detector.

After early testing and development the device has found useful and continuous operation in a working liquefier at Fermilab for the past year. It is currently on line at the 1500 W refrigerator being used to supply liquid helium for the superconducting magnet testing program. It has proved steady, reliable and was readily maintained and used by the refrigerator operating crew.
With the monochromator set at a wavelength of 392.4
A, a slit width of 200 microns, one can get a signal
of 10 mV/ppm of nitrogen (by volume). Under these
conditions the photomultiplier is set at 600 V supply
and the anode load is the chart recorder input impedance
of 2 MΩ.

The background of apparent nitrogen in our operat­
ing system is about ½ ppm and there is a stray light
signal equivalent to about ½ ppm. We normally run with
the chart recorder set to alarm at 10 ppm.

We plan, in the future, to attempt to apply this
device to other substances in the helium stream, such
as oil or neon. The principle should work for other
process gases as well.

The details of the spectrum are described else­
where. Figure 4 shows the general layout of equipment.
Figure 5 shows the RF amplifier which gives the stable
arc. Figure 6 shows a wavelength spectra of pure
helium and 4 ppm nitrogen. In operation the device is
left at the nitrogen peak.

At contamination levels above ~100 ppm the arc
begins to quench and the nitrogen signal diminishes.
In our installation this limits the use of the detector
above 100 ppm. Above this level we normally use a
commercial thermal conductivity device. It is possible
to extend the range of the device by compensating for
this effect by monitoring the total light output.

References

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