PROCESS CONTROL SYSTEM FOR THE TEVATRON LIQUEFIER

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Abstract

The Tevatron liquefier is operated from a control room located on the second floor of the Liquefier 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 Liquefier 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 ft^2 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 coupled only by process upset) and the automatic loops have feedback response with PID-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 5TI1020 sequencers are used to perform ladder logic as described here and elsewhere.[1]

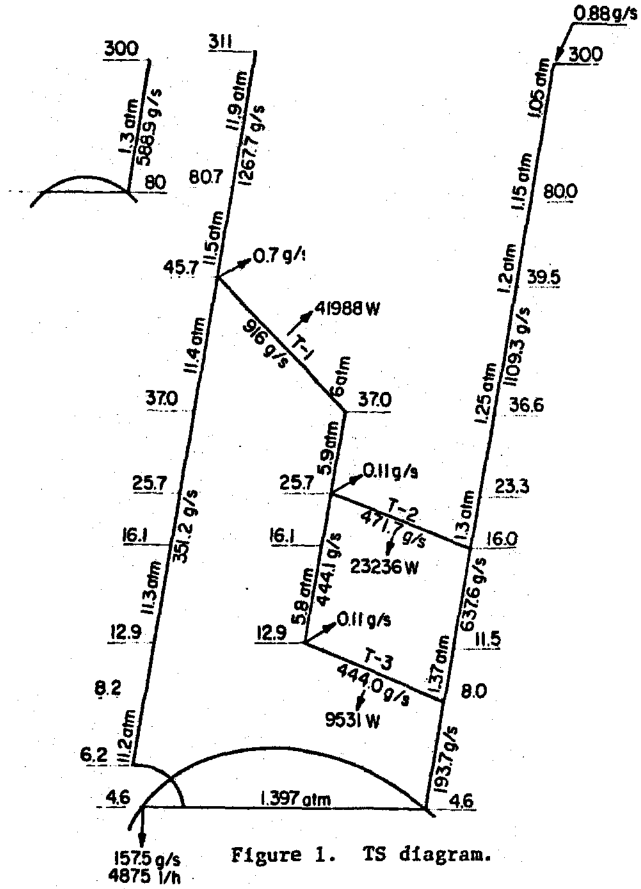

Figure 1. TS diagram.

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

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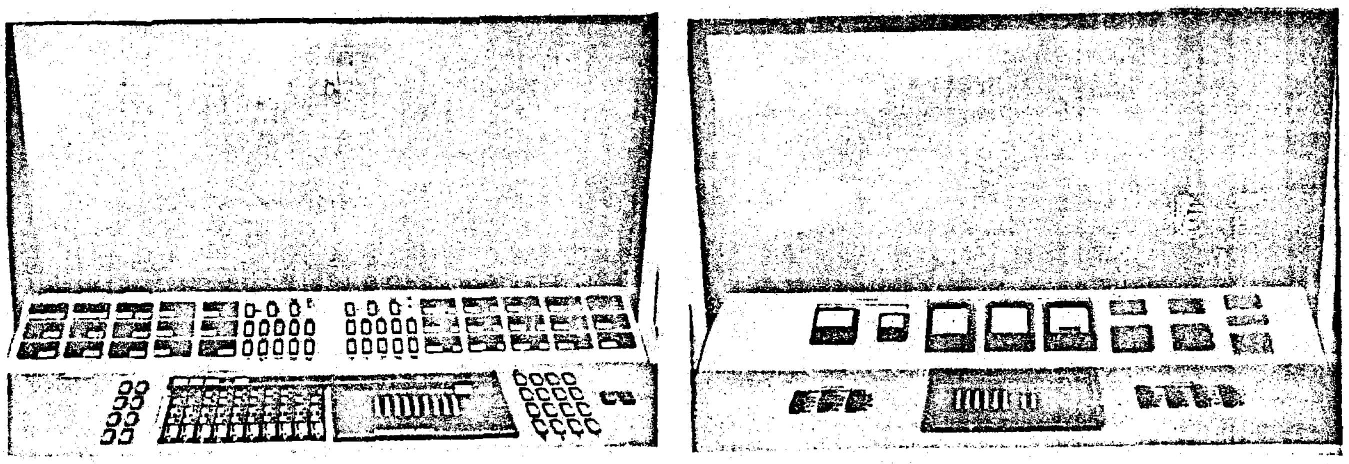

Figure 2. Operations console for the helium compressors and cold box.

sequencer is an example of a model computing machine described at an early date.[2] 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.

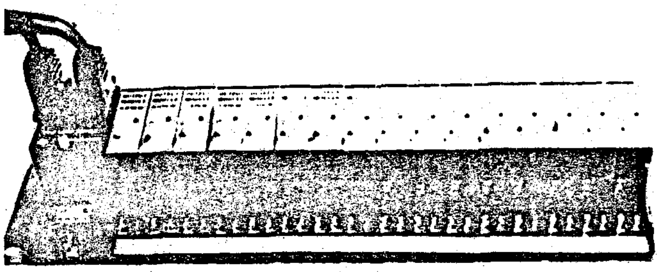

Figure 3. Sequencer input and output modules.

The sequencer is responsible for indicating alarm conditions on the operations console and for forming the permissive to the compressor main motors. In case the interlock logic is not satisfied, the sequencer is capable of preventing the startup of a compressor or causing an emergency shutdown. The sequencer prevents compressor operation under the following conditions: (1) excessive vibrations at any of the detectors mounted on each of the compressor cylinder heads, at three points on the compressor frame and on the motor towers of the fin-fan coolers; (2) low frame oil pressure; (3) high frame oil temperature; (4) low cylinder oil pressure; (5) high temperature of helium discharge at any cylinder; (6) high discharge pressure; (7) low water flow; (8) high water temperature; (9) low instrument air pressure. A second sequencer prevents operation of the cold box in case of any of these failures: (1) motor overload or other shutdown of turbine oil pumps; (2) loss of turbine oil pressure; (3) high turbine oil temperature; (4) incorrect valve line-up for turbine operation; (5) turbine overspeed; (6) failure of speed indicator circuit; (7) low temperature at the exit of the last turbine; (8) loss of insulating vacuum; (9) low flow of water through the vacuum pump.

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 turbines, 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 down 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 μA by a series 10 MΩ resistor. It is also observed that once the ac 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 3924 Å, 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 operating 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 elsewhere.[3] 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.

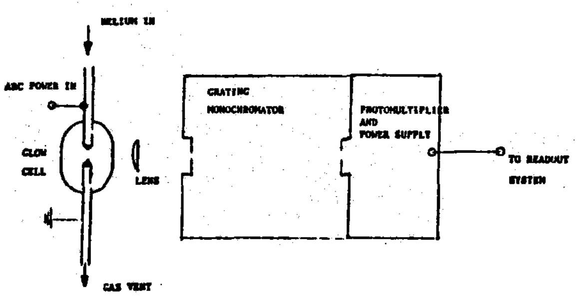

Figure.4. General set-up of spectrographic nitrogen detector.

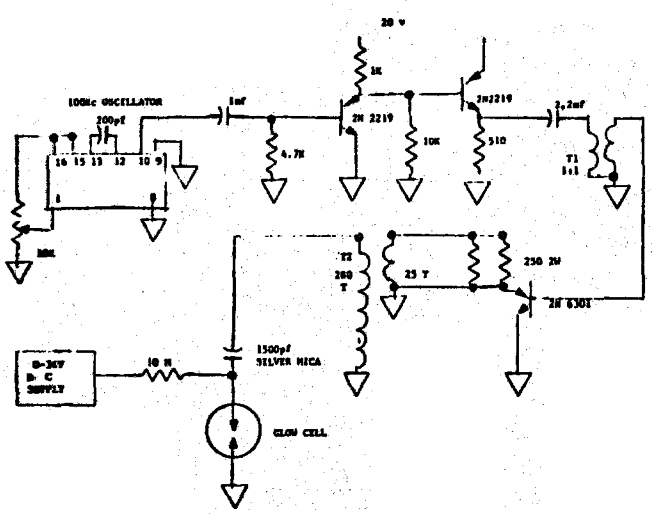

Figure 5. Circuit to supply power to the arc.

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.

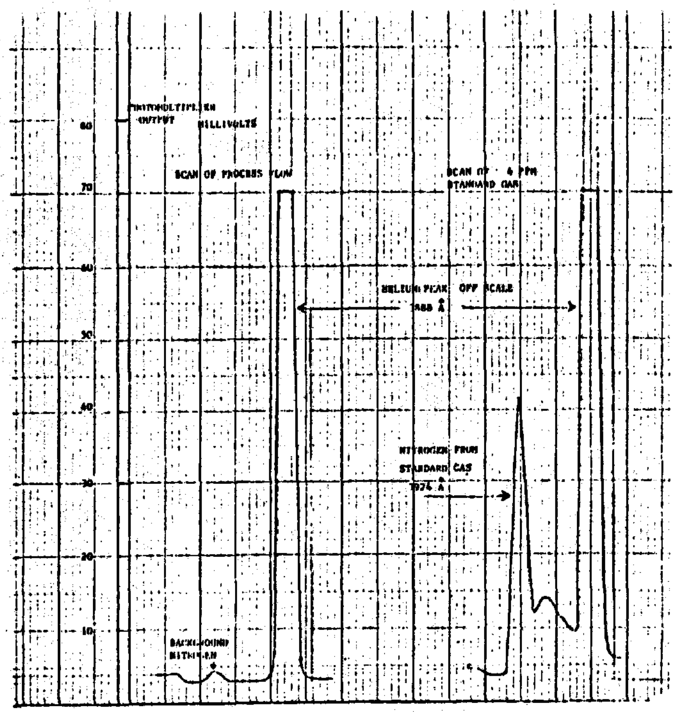

Figure 6. Chart recorder scan.
y = light output,
x = wavelength.

References

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[2]A.M.Turing, "On Computable Numbers, with an Application to the Entscheidungsproblem", Proceedings of the London Mathematical Society, 42, 230-265, 1936.

[3]R.J.Walker, "Spectrographic Nitrogen Detector", Fermilab Internal Report TM-742, August 1977.