RESEARCH PAPER | Engineering | Volume - 5 | Issue - 1 | Jan Special Issue - 2015 | ISSN - 2249-555X

Qualitative Considerations for the Instrumentation & Control System Design for Cryogenic Turboexpander

KEYWORDS: Control loops,Cryogenic Turboexpander,Gas bearings,Sensors and Actuators, Instrumentation and Control system.

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ABSTRACT Cryogenics field involves temperature below 123 K which is much less than atmospheric temperature. In addition, many industrially important physical processes – from fulfilling the needs of National Thermonuclear Fusion programs, superconducting magnets to treatment of cutting tools and preservation of blood cells, require extreme low temperature. The low temperature required for liquefaction of common gases can be obtained by several processes. Liquefaction is the process of cooling or refrigerating a gas to a temperature below its critical temperature so that liquid can be formed at some suitable pressure which is below the critical pressure. Helium liquefier is used for the liquefaction process of helium gas. The Helium Refrigerator/Liquefier (HRL) needs turboexpander as expansion machines to produce cooling effect which is further used for the production of liquid helium. Turbo-expander, a high speed device that is supported on gas bearings, is the most critical component in helium refrigerator. A very minor fault in the operation and manufacturing or impurities in the helium gas can destroy the turboexpander. However, since the performance of expanders is dependent on a number of operating parameters and the relations between them are quite complex, the instrumentation and control system design for turbo-expander needs special attention. Proper sensors have to be selected for the accurate measurements of temperature, pressure, speed and flow rate. For different normal and off-normal operations, speeds will be different and hence the flow parameters for bearing gas flow should be controlled via control valves through a developed logic. Also a proper monitoring system has to be selected for observing the behavior of turbo expander in various operational scenarios. This paper involves the design of instrumentation and control system needed for the testing of cryogenic turbo-expander.

I. INTRODUCTION

Liquefaction of gases uses a compressor at atmospheric temperature in which the gas is first compressed to an elevated pressure. This highly compressed gas is then passed through counter-current heat-exchanger to a throttling valve (Joule-Thompson valve) or a Turboexpander. Upon expanding to a certain lower pressure below the critical pressure, cooling takes place and some fraction of gas is liquefied. The cool, low-pressure gas returns to the compressor inlet through a recycle stream to repeat the cycle. The counter-current heat exchanger warms the low-pressure gas prior to recompression, and simultaneously cools the high-pressure gas to the lowest temperature possible prior to expansion.

Turbo expander is a machine, which continuously converts kinetic energy into mechanical energy. This is done by expanding the high pressure gas from upstream to a lower pressure downstream through the expander. The high pressure gas causes the radial expander to rotate. Rotation is transmitted to the shaft, which is supported by a set of bearings. The energy transmitted to the shaft can be used to drive a compressor. Cryogenic turboexpander are significantly smaller in size compared to those for room temperature applications but rotation speed is high, about few lakhs of rpm and hence these have contactless gas bearings or magnetic bearings. For different normal and off-normal operations, speeds will be different. Deviation of mass flow rate or gas pressure from its optimum point reduces the efficiency of the turboexpander and hence parameters like Temperature, Pressure, Flow rate and Speed should be controlled through a developed logic.

II. PROCESS FLOW SCHEME OF HELIUM LIQUEFIER

Figure 1 shows the process flow diagram of the Helium liquefier. Main components of HRL are (i) Compressor station, (ii) Oil removal system, (iii) Purifier system (iv) Cold box with Main Control Dewar (MCD), which is vacuum insulated & thus takes care of the heat load on the components of Cold box. The Cold box consists of heat exchangers, turboexpander and Joule-Thomson (J-T) valve for the main process cycle.

Helium gas at 14bar pressure, from the compressor station & Oil removal system, is being purified and passed to the Cold box. Pure helium gas stream, which is the process stream, passes through the heat exchanger 1(HE-1) (He/He/N2) which then passes through the liquid Nitrogen precooled Heat exchanger 2(HE-2) where it attempts to get the temperature at around 80K.Now the stream passes through the next heat exchanger (HE-3) where it further reduces its temperature to so called around 35K.

As the process stream has cooled down to such temperature, it is then passed through the Turbine A where the expansion takes place and the temperature further gets reduced. This reduced temperature is further passed through further stages of Heat exchanger and Turbine B to get the temperature reduced to around 7K at the final stage of Turbine C.

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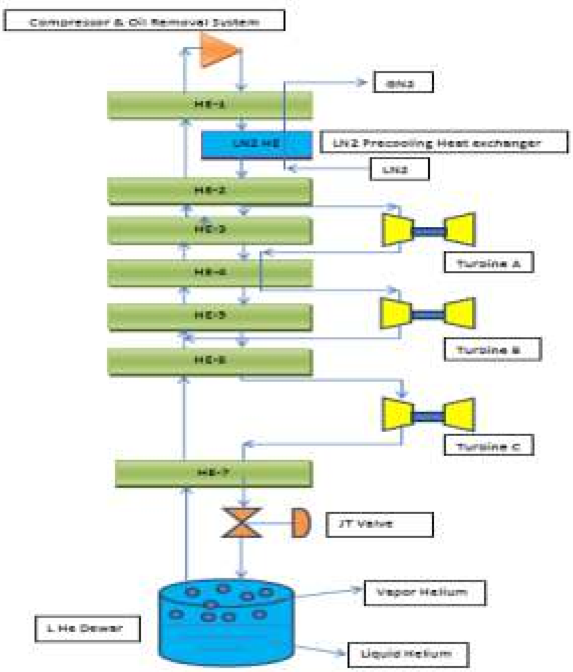

Fig. 1. Typical process flow diagram of HRL

The Further reduction in temperature can be easily and cost effectively obtained with the help of J-T valve which finally delivers the (LHe) Liquid helium (4.5K) to the Main control Dewar.

III. CRITICAL ISSUES IN CRYOGENIC TURBOEXPANDER

The exceptionally high rotating speed of cryogenic turboexpander induces vibration, which leads to the instability and thus the deterioration in the performance of the turboexpander. Due to this high speed of rotation, effect of flow dynamics for associated pipe and valves on turbine speed are necessary. If the turboexpander should tend to over speed, then some control action needs to be taken to avoid any damage to the turboexpander [3] [4].

Another issue is to take care that the gas bearing pressure is maintained properly ,because as the turboexpander rotates with high speed , so to minimize the friction, sufficient pressure must be exist between gas bearings and shaft before starting of the turboexpander [5].

Also if the mass flow rate or the gas pressure deviates from its best optimum point then the efficiency of the turboexpander gets affected badly. Also the surge control system for the compressor should be taken care of, with attention towards the anti-surge controller operation.

If such critical issues are taken care of while designing the instrumentation and control system then major factors resulting in the plant shutdown or equipment failure can be neglected.

Thus proper consideration and attention should be given to the observed critical issues in cryogenic turboexpander. This critical condition leads to the need of proper Instrumentation and Control system that could help to main the efficiency of the Turbo-expander and thus the HRL.

IV. LOCATION OF SENSORS AND ACTUATORS FOR CONTROLLING CRYOGENIC TURBOEXPANDER

TABLE I
SENSOR LOCATION AND FUNCTIONS

Sensor	Location	Function
Pressure	Turbo-expander cartridge	To measure the pressure of high pressure gas inlet to the turbo-expander
Pressure	Compressor outlet	To measure the pressure of helium gas from compressor outlet
Pressure	Between expander & compressor on Casing	To measure the pressure of helium gas passes to the compressor
Pressure	At the Gas Bearing inlet & outlet	To measure the Bearing gas pressure which plays a major role in controlling the speed of turbo-expander
Temperature Flow rate	At inlet of Turbo-expander	To measure the temperature and Flow rate of the gas entering the turbo-expander
Temperature	Break cooler	To measure the temperature of helium gas that comes from compressor
Temperature	Cartridge	To measure the temperature of bearing gas
Shaft	Contactless	To measure speed of the Turbo-expander

V. SENSOR SELECTION FOR CRYOGENIC TURBO EXPANDER

Selection of proper sensors is the basic need for any control. Turbo-expander needs temperature, pressure, flow rate and speed as the parameters to be controlled.

As we are dealing with cryogenic environment, proper care should be taken while selecting sensors and actuators. If the accuracy and range covered by the selected sensors are best enough, then it will help a lot from the controlling point of view [5][6].

TABLE II
SENSOR SPECIFICATIONS

Sensor	Type	Accuracy	Range
Temperature	Silicon diode	+-0.2K	<80K
Pressure	Piezo resistive	+-0.1 bar	0-20 bar
Flow Rate	Venturimeter	+-2g/s	20-100g/s
Speed	Optical		0-3lakh rpm

VI. CONTROL LOOPS FOR CRYOGENIC TURBO EXPANDER

As the cooling effect required for the HRL is produced by the most critical component, turboexpander, the control loops and the required logic has to be properly implemented with utmost care. The efficiency of the whole plant depends on the proper control operation of its components. Minor fault may result in trip of turboexpander which lead to major shutdown of the plant and economic failure. Thus, here I provide the PID controller loops that need to be implemented for successful operation of cryogenic Turboexpander. They are:

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1. Bearing pressure control system
2. Speed control system
3. Surge control system
4. Compressor pressure and Temperature control system
5. Expander's upstream and downstream pressure control system
6. Flow rate control system

VII. CONTROL SYSTEM ARCHITECTURE FOR CRYOGENIC TURBOEXPANDER

The system should be designed to operate in the harsh environment without losing its performance. The right tools Integrated together can provide immediate feedback to operators for action, or maintenance for planning and analysis. As the Turboexpander is the most critical component for a Helium liquefier plant, each component must be selected considering fast action, appropriate range, continuous run and fail-safe operation.

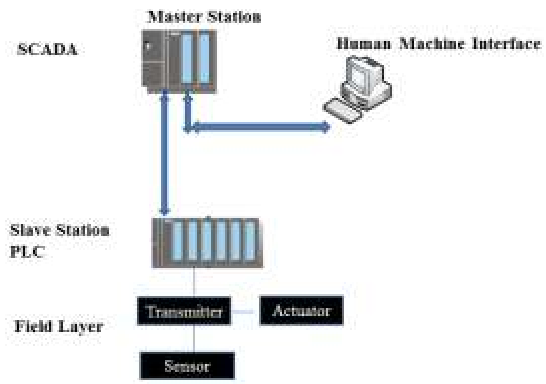

Fig. 2. Control system architecture for Cryogenic Turboexpander

To have control and monitoring of the operating conditions, a control system architecture needs to be defined in the most favorable manner. An overview of the control system architecture for cryogenic turboexpander is shown above.
It consists of the basic three layers:
1. Field Layer: It is having the process sensors, actuators and transmitters.
2. Control Layer: The information received from the field layer through sensors is collected and the required process controlling tasks are performed at this layer.
3. Supervision Layer: Monitoring and command facilities (Adjusting the process parameters, controlling, real time and historical trending, alarms and events) by the operators can be obtained by Supervision Control And Data Acquisition system(SCADA).

Thus, establishing proper communication leads to the distributed control and centralized monitoring of the cryogenic turboexpander.

VIII. CONCLUSION

The importance of Cryogenic turboexpander in the Helium Liquefier is studied. Critical issues that seek attention towards the need for the development of Instrumentation and control system for turboexpander are clearly discussed. A systematic approach for the selection of Sensors, with desired accuracy, range and installation in turboexpander is obtained. The PID controller loops for effective control operation of the turboexpander are suggested. Useful information and important guidelines for the development of control system for the Cryogenic turboexpander are sufficient to make this paper as a helping hand for the beginners.

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