



TURBINE ROTOR WITH  
TILTING PAD HOUSING

## 11. CRYOTECHNOLOGY

### INTRODUCTION

Cryogenic refrigeration technology in the temperature range of 20 K to 2 K, is an essential input for other advanced technologies. BARC has set out a road map for acquiring core competence in this important area. Development of cryogenic systems concerns with technology generation for the cryogenic needs of DAE with a special reference to cryo-distillation of hydrogen isotopes and the Accelerator Driven Sub-critical System (ADS) project.

In a significant development effort, a fully indigenously designed helium based 20 K cryogenic refrigerator has been fabricated and tested. All the critical components, cryogenic turbo expander, heat exchangers, bearing, bellow sealed valves, transition joints, feed throughs also have been indigenously developed. The chapter shows the capability of BARC in mastering this advanced technology.

## 11.1 CRYOGENIC SYSTEM DEVELOPMENT

### ■ Helium Gas based Cryogenic Refrigerator (1kW at 20 K).

Cryogenic Technology Division has developed a cryogenic refrigerator for 1kW of refrigeration at 20 K with helium gas as the refrigerant and installed at Engineering Hall no. 8, BARC, Trombay. This refrigerator can be used for cryo-distillation of hydrogen isotopes and has undergone operational tests. The plant is based on reversed Brayton cycle with two stage turbine based expansion. The system, in effect, consists of a cold box housing components such as turboexpanders, brazed plate and fin heat exchangers, gas purifiers and piping with cryogenic extended stem valves together with temperature sensors, pressure transducers and vibration monitoring instrumentation for the turboexpanders.



A close-up of the prototype refrigeration system showing turboexpanders, extended stem valves, and external piping mounted on the top cover of the cold box



The prototype 1kW at 20K Cryogenic Refrigeration system developed and installed at BARC.

The operational tests revolve around measuring cool down time, lowest temperature reached, turbine speeds, vibration, and overall system reliability. Preliminary tests conducted have enabled us to reach a lowest temperature of 14.9 K without any refrigeration load. The cryogenic system has been tested with a refrigeration load of 200 W at 16.5 K. The turboexpanders reached an operational efficiency of about 60% during loading.

### ■ Test Set-up

A test set-up has been built to test the efficiency and vibration levels of turboexpanders, efficacy of vacuum system, cryogenic insulation, indigenous temperature sensors and overall system performance and reliability. These apart, air screw compressors modified for helium service are being used to provide first hand data regarding the viability of using such compressors in larger plants in future. Currently, the test set-up can accommodate a single turboexpander and a temperature of about 170 K is achieved. A second cold-box when incorporated with the facility would allow to simulate plant conditions in laboratory with a full two staged expansion.



Laboratory test set-up built to test the performance of turboexpanders, efficacy of vacuum system, cryogenic insulation, indigenous temperature sensors and overall system performance and reliability



Air compressors modified for helium service are being used for laboratory test set-up



Turboexpander mounted on the test bench

## 11.2 DEVELOPMENT OF CRITICAL COMPONENTS FOR CRYOGENIC SYSTEMS:

### ■ Cryogenic Turboexpanders

Turboexpanders, being the active cooling component of modern plants are considered the heart of the system. The mixed-flow turbines rotate extracting energy from the high pressure process stream thereby inducing the cooling. Cryogenic conditions necessitate the use of smaller gas passages in the turbines that translate into small size and correspondingly high speed for high operational efficiency. For our process, turbines of two different sizes (16 mm and 26 mm diameter) are planned to be employed. The smaller of the two designed to achieve a speed of around 2,40,000 r/min, have already been developed and tested in existing plants with satisfactory performance.



Miniature turbomachinery: expansion turbine and brake wheel

The turboexpander rotor consists of a vertical shaft with a turbine and a brake compressor wheel mounted at the two ends. The shaft consists of a collar, which together with flexibly supported spiral grooved plates, forms the axial/thrust bearing system. The cantilever arrangement of the grooved top thrust plate ensures higher flexibility at the outside diameter of the bearing to conform to the shaft collar shape during conical whirl. To prevent wear during occasional touches at high speeds, the bearing surfaces are provided with a hard coating. Precision photo-etching techniques required for fabrication of the grooves have been developed and standardised. The high speeds required for high



Turboexpander rotor with turbine (R) and brake (L) wheels mounted at the ends



Top (L) and bottom (R) thrust bearings showing inward pumping grooves



Brake wheel



Expansion turbine wheel



Tilting pads (radial bearing).



Turboexpander rotor with tilting pad bearing housing



Balancing machine developed in conjunction with Shenck Avery for vertical in-situ balancing of rotors

operational efficiency of the system presents typical problems of radial bearing instability. Tilting pad journal bearings consisting of three pads per bearing and possessing excellent stability characteristics constitute the journal bearing system. The entire bearing system is designed to provide enough damping to cross over critical speeds easily. The balancing problem of the high speed rotor was addressed with a specially developed vertical in-situ balancing machine as well as a small (capacity less than 2 kg) rigid bearing precision horizontal balancing machine.

#### ■ Heat Exchangers for Cryogenic Service.

High effectiveness (in excess of 0.95) brazed plate and fin heat exchangers are a necessity for modern high performance cryogenic plants. As the technology for these exchangers (fins, large brazing furnaces, transition joints, etc) is not available in India, Cryogenic Technology Division has undertaken development of these components. In a transition joint between aluminium and SS 304 pipes using diffusion bonding techniques have been fabricated at the Centre for Design and Manufacture, BARC. The joint withstood a full vacuum (Leak tight to  $10^{-10}$  mbar.l/s) and pressure holding of 30 bar. As a step towards the future development, high effectiveness (0.97 or higher) matrix type heat exchangers, which are used in small cryo coolers, have been designed.



Transition joint between aluminium and stainless steel pipes

#### ■ Accessories for Cryogenic Systems.

Most valves used in cryogenic processes need extended stem with thin wall to serve the following primary purposes:

- a) The valve handle is maintained at ambient temperature to protect the operator (whether operated manually, pneumatically, or by solenoid),
- b) The valve stem may be sealed at ambient temperatures instead of cryogenic temperatures, thereby eliminating a severe sealing problem and improving the reliability of the valve, and
- c) In order to prevent a loss of cold from process to environment. Special long stem bellows seal cryogenic valves have been developed for use in the proposed helium liquefier. Ceramic feed-through for wire connections (temperature sensors) inside the high-vacuum cold box, have also been developed indigenously.



Indigenously developed extended stem bellow seal cryogenic valve



Indigenously developed 5-pin ceramic feed-throughs

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