Analytical and Experimental Studies on Cryogenic Turboexpander

Parthasarathi Ghosh

Abstract

The expansion turbine constitutes the most critical component of a large number of cryogenic process plants – air separation units, helium and hydrogen liquefiers, and low temperature refrigerators. In spite of having a moderately large cryogenic industry, and decades of experience in building high and medium pressure air separation plants, India lacks an indigenous technology in production of expansion turbines. To address to this problem, a modest attempt has been made at IIT Kharagpur to understand, standardise and document the design, fabrication and testing procedure of cryogenic turboexpanders. This thesis, constituting a part of the nascent cryogenic turboexpander research programme at IIT, focuses mainly on the design of the turbine system, with particular emphasis on the aerodynamic and structural design of the turbine.

There is an extensive literature on the subject of turboexpander design and analysis. Starting with the pioneering work of Kapitza, many workers have contributed to the growth of the unique technology. The analytical works of Balje, Hasselgruber, and Whitfield and Baines, and the reports on prototype development by Sixsmith, Kun, Ino and Yang et al are particularly noteworthy. A detailed review of the development process, as well as all relevant technical issues, has been presented in the thesis.

A cryogenic turboexpander essentially consists of a small set of distinct components :

- turbine wheel	- nozzle ring	- diffuser
- brake compressor	- shaft	- journal bearings
- thrust bearings	- housing	- plumbing & instrumentation

A streamlined design procedure, based on published works, has been developed and documented for all the components. The thesis contains full details of the design process, from conception of the basic topology to preparation of production drawings and solid models. Based on this methodology we have designed and constructed a prototype turbine having the following specifications. The specifications correspond to the capacity of the air compressor available in our laboratory.

Working fluid	:	Air / Nitrogen
Inlet total pressure	:	6 bar
Inlet total temperature	:	120 K
Discharge pressure	:	1.5 bar
Fluid flow rate	:	190 sm^3/hour

The unit has been constructed using the facilities available in the Institute, taking assistance of the local industry when necessary.

The bearings constitute the most critical components of the system. Because of the high rotational speed (1,40,000 r/min), it is not practical to use conventional antifriction or oil lubricated bearings. Gas lubricated bearings, using the process gas itself as lubricant, offer the most practical solution. Although both aerostatic and aerodynamic bearings have been successfully used by other workers, we have chosen aerostatic bearings for their higher load capacity and lower manufacturing precision. We have selected rubber stabilised journal bearings and inherently compensated orifice type thrust bearings, which provide good rotodynamic stability.

An experimental set up has been built to study the performance of the turbine. The thesis presents the construction of the test rig, including the air / nitrogen handling system, bearing gas system, and instrumentation for measurement of temperature, pressure, rotational speed and vibration. The vibration and speed are measured with a proximity sensor, its output being fed to a spectrum analyser and a storage oscilloscope. The prototype turbine was successfully run at 80,000 r/min.

Because the structural strength of most materials improves at low temperature, there is a general impression that cryogenic turbines are inherently safe. But in reality, because of the high rotational speed, components like the thrust collar on the shaft and the brake compressor operate close to their failure stress. The thesis presents a detailed finite element based stress and displacement analysis made with the FEM package ALGOR. The results reveal the critical areas of stress and displacement.

The performance of a turbine system is expressed as a relationship among mass flow rate, pressure ratio and rotational speed. This relation is governed by the conversion of pressure to kinetic energy and dissipation through a set of loss mechanisms. Based on the method suggested by Whitfield and Baines, we have developed a one-dimensional meanline procedure for estimating various losses and predicting the off design performance of an expansion turbine.