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Computational Fluid Flow Analysis: A Perspective Review

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Abstract- - Turboexpander are used in all areas of the gas and oil industries to produce cryogenic refrigeration. A turboexpander, on other hand, is a pressure let-down device that produces cryogenic temperature while simultaneously recovering energy from a plant stream in form of shaft power that can be used to drive other machinery such as compressor. Though nature has provided an abundant supply of gaseous raw materials in the atmosphere (oxygen, nitrogen) and beneath the earth's crust (natural gas, helium), we need to harness and store them for meaningful use. In fact, the volume of consumption of these basic materials is considered to be an index of technological advancement of a society. For largescale storage, transportation and for low temperature applications liquefaction of the gases is necessary. The only viable source of nitrogen, oxygen and argon is the atmosphere. For producing atmospheric gases like nitrogen, oxygen and argon in large scale, low temperature distillation provides the most economical route. The low temperature required for liquefaction of common gases can be obtained by several processes. While air separation plants, helium and hydrogen liquefiers based on the high pressure Linde and Heylandt cycles were common during the first half of the 20th century, cryogenic process plants in recent years are almost exclusively based on the low-pressure cycles. They use an expansion turbine to generate refrigeration.

1. INTRODUCTION

The turboexpander essentially consists of a turbine wheel and a brake compressor mounted on a single shaft, supported by the required number of journal and thrust bearings. These basic components are held in place by an appropriate housing, which also contains the fluid inlet and exit ducts. The basic components are turbine wheel, brake compressor, shaft, nozzle, bearing, diffuser, seals, etc.

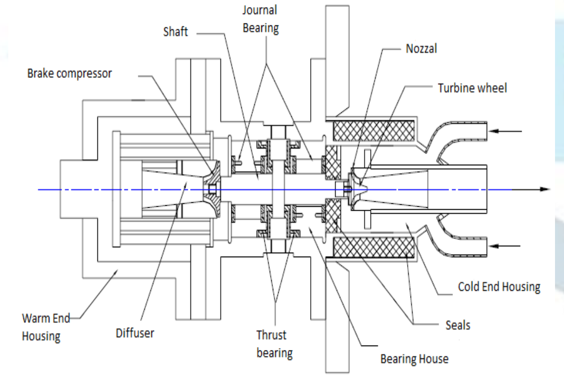

Figure 1: Division of Cryogenic Turboexpander

Most of the rotors for small and medium sized plants are vertically oriented for easy installation and maintenance. It consists of a shaft with the turbine wheel fitted at one end and the brake compressor at the other. The high-pressure process gas enters the turbine through piping to the cold end housing and, from there, into the nozzle ring. The fluid accelerates through the converging passages of the nozzles. Pressure energy is transformed into kinetic energy, so that reduction in static temperature takes place. The high velocity gas B streams impinge on the rotor blades, imparting force to the rotor and creating torque. The B nozzles and the rotor blades are so aligned as to eliminate sudden changes in flow direction and consequent loss of energy. The turbine wheel is of radial or mixed flow geometry, i.e. the flow enters the wheel radially and exits axially. The blade passage has a profile of a three dimensional converging duct, changing from purely radial to an axial-tangential direction. Work is extracted as the process gas undergoes expansion with corresponding drop in static temperature.

2. LITERATURE REVIEW

Gifford and Longsworth [2019] developed a relationship for the cold end temperature with zero heat pumping rate in terms of length ratio, hot end temperature and the ratio of specific heats of gas with the help of surface heat pumping (SHP) mechanism.

Colangelo et al [2019] developed a simplified heat transfer model for the performance analysis of basic pulse tube refrigerators. This model takes into account the heat and mass transfer processes in the regenerator and pulse tube. They assumed that the convective heat transfer between the gas and pulse tube wall or regenerator matrix during flow periods is a controlling mechanism.

Gifford and Kyanka [2018] returned to the problem of reversible pulse tube and attempted to compare with that of a valved pulse tube, although it would seem that the experimental comparison was based on limited data. The pressure ratio used in this work was 4.2:1 and a low temperature limit of 165 K was achieved. It was concluded that other factors being equal and the refrigeration capacity of a reversible pulse tube is inferior to that of the valved type.

Narayankhedhkar and Mane [2017] did theoretical and experimental investigations on pulse tube refrigerator. The method for the derivation of cold end temperature with zero heat pumping rates was introduced. Lowest cold end temperature obtained with air as the working fluid was 214.5 K, with a frequency of 50 Hz. Experimental investigations indicated that there exists an optimum speed and hot end length, and this speed decreases with increase in the total length of pulse tube. They verified Longsworth's conclusion about the variation of heat pumping rate with pulse tube length by experiments up to a total length of 550 mm and with air as the working fluid.

Mikulin et al. [2016] The main achievement when and his co-workers published their innovative modification of the basic pulse tube refrigerator. They showed that the efficiency of pulse tube refrigerator could be increased by fastening a reservoir to the warm end of the pulse tube, through an orifice instead of being closed. Using air as the working fluid, they achieved a low temperature of nearly 105 K and the net refrigeration capacity at 120 K was ~10 W.

Richardson et al [2016] updated Longworth analysis for BPT refrigerators by considering the maximum value of the gas charging period and he reached the prediction of an optimum pulse rate, which was verified qualitatively by experiments. However this study was mostly experimental and no system modelling performance analysis was done.

Zhou et al [2015] made an experimental investigation to compare the performance of coiled pulse tubes with those of straight ones having similar cross sections, length and operating conditions. The performance degradation of coiled pulse tube had also been reported when ratio of the axial radius to the radius of the cross section is reduced.

Matsubara et al [2014] In one experiment they replaced the orifice with a moving plug (also at room temperature) and lowered the temperature from 78 K to 73 K. Normally, a mechanical compressor is used to drive the pulse tube, but Matsubara tried a thermally activated pulse tube, where a hot displacer is used to move gas between a heated volume and a room temperature volume to generate a pressure oscillation. The thermally actuated pulse tube refrigerator has been operated at the temperature of about 200 K.

Richardson et al [2013] reviewed the development of valved PTR and explained clearly the heat pumping mechanism inside it. He experimentally optimized the valved pulse tube, which involves the two variables of throttle setting and buffer volume. The schematic of valved PTR is shown in Fig.2.8. It can be seen from the figure that, the valved pulse tube differs from that of the simple design in having a buffer volume linked to the warm end heat exchanger. A throttle valve or a fixed orifice controls the flow of gas between the pulse tube and buffer volume. With the valve fully closed, the device functions as a BPT refrigerator.

3. CONCLUSION

Meridional plots are showing the variation of pressure and relative Mach number from inlet to outlet. Here we can see that pressure and relative match number are continuously decreasing due to transfer of fluid energy to impeller. As a result, the gas exits the impeller with low pressure and velocity. We see that at trailing edge color of streamline is turning to blue, which shows decrease in fluid velocity.

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