Review on Design of Centrifugal pump for supercritical Helium

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Abstract - the application of superconducting magnets at liquid helium temperature needs circulation of supercritical helium (SHe) to remove heat loads of magnet system and maintain the magnet at low temperature. Design of this pump involves, vacuum, low temperature and high density SHe. All these involvements make the design of pump different than that for conventional pumps used at room temperature. The flow rate of working medium through this impeller will be about 100 g/s at pressure ~ 5 bars. At the downstream of the pump, there will be a LHe (liquid helium) chamber in which the heat loads of the pump will be removed.

Keywords - Super critical helium, Centrifugal Pump, Super conducting magnet.

I. INTRODUCTION

Superconducting electromagnets which is surrounded by the cryostat at 300K at (SST-1) has to be cooled at 4.5 K by using the supercritical helium. To reduce the heat load on the superconducting magnets, 80K thermal shield is planned using LN2 at 80K to protect the Superconducting magnets from direct view of 300K cryostat. The application of superconducting magnets in SST-1 (steady state superconducting tokamak) is operating at liquid helium temperature. To achieve LHe temperature, needs circulation of supercritical helium (SHe) to remove heat loads of magnet system and maintain the low temperature.

In fig1.1 close loop circulation of super critical helium is shown. The liquid helium changes its phase from liquid to gas and flows in two phase flow condition. This condition is very difficult to handle and give problem of mass flow distribution measurement, Vapour lock, uneven temperature distribution etc. System as shown in Fig.1.1 will use centrifugal pump is going to be installed which is able to Circulate helium in liquid form (single phase).

Fig.1 closed-loop circulation of supercritical helium (Courtesy: IPR)

I. Super Critical Helium:
   a. A supercritical fluid is defined as a substance whose temperature and pressure exceed those of its critical point.
   b. The critical point for helium has a critical temperature of 5.2 K and a critical pressure of 227.46 KPa.
   c. The physical meaning of a supercritical fluid is that as long as a fluid is in the supercritical region, it will not undergo a phase transition between liquid and gas and no meniscus separating liquid and gas will be observed.

II. Pump:
   a. A pump is a device used to move liquids from lower pressure to higher pressure, and overcomes this difference in pressure by adding energy to the system.
   b. Depending on the operating condition Srinivsan [1] has classified pump as (1) Positive displacement pump and (2) Rotodynamic pump.

III. Centrifugal pump:
   a. As explained by Moniz and Girdhar [2] a centrifugal pump is a Rotodynamic pump that uses a rotating impeller to increase the velocity of a fluid.
b. A centrifugal pump works by the conversion of the rotational kinetic energy, typically from an electric motor or turbine, to an increased static fluid pressure. This action is described by Bernoulli’s principle.

IV. Classification of centrifugal pump:
   a. On the basis of the head
      i. Low lift: Impeller is surrounded by volute there are no guide vanes.
      ii. Medium lift: They are generally provided with guide vanes.
      iii. High lift: They are multistage pumps because single stage cannot easily build up such a high pressure.
   b. On the Basis of the type of casing:
      i. Volute casing
      ii. Diffusion pump
      iii. Volute with vortex chamber
   c. On the basis of the number of stages
      i. Single Stage
      ii. Multi stage
   d. On the basis of the flow through impeller
      i. Radial: Ordinarily all the Centrifugal pumps manufacture with radial Flow impeller.
      ii. Mixed: Outlet is combination of Radial and axial. This is used for large quantity of liquid to low height.

V. Components of centrifugal pump:
   1. Impeller: The impeller of the centrifugal pump converts the mechanical rotation to the velocity of the liquid. The impeller acts as the spinning wheel in the pump.
   2. Casing: At the impeller outlet, the velocity of the liquid can be as high as 30-40 m/s. This velocity has to be reduced within a range of 3-7 m/s in the discharge pipe. Velocity reduction is carried out in the pump casing by recuperators. The kinetic energy in the liquid at the outlet is converted to pressure energy by the recuperators.
   3. Shaft: The prime mover drives the impeller and displaces the fluid in the impeller and pump casing through the shaft.
   4. Bearings: Depending on the position of impeller different bearings like axial thrust, ball bearing etc, are used.
   5. Wearing rings are required to bear axial thrust.
   6. Seals are required to minimize recirculation losses.

VI. Material selection criteria for centrifugal pump:
   a. According to wigley,” Mechanical properties of material at low temp”, cryogenics, 1968[14]: Most FCC (face centre cubic) material retain good ductility at subzero temp. Aluminium can be strengthened by alloying and heat treatment while still retaining good ductility along with adequate toughness at subzero temperatures. Yield strength and tensile strength of structural alloys increase as the exposure temperature is decreased. The effect of low-temperature exposure on the ductility and toughness of these alloys depends on alloy composition. Values of Young’s modulus generally increase, and values of Poisson’s ratio generally decrease, as the testing temperature for the above alloys is decreased.
   b. As standard API (American Petroleum Institute) 610 suggested for cryogenic temp [17] AISI 300 series stainless steel like 304,316 and Al-alloys like 2219, 5083, 6061 are widely used materials for cryogenic application.
   c. According to E Chambell,”Structure alloys at subzero temp”, metals handbook, American society for metals (ASM), [15]: Al-6061 has ultimate yield strength of 400 MPa, and it retains good ductility at cryogenic temperature. It is also cheaper than stainless steel AISI 300 series.
   d. As suggested in review paper of Raval, Gupta, Sharma, Tanna ,” Mechanical properties of structure alloys at cryogenics temp”, ICMPC-2012,[16]:Here Al-6061 is considered for the construction of the impeller and casing of the pump.

<table>
<thead>
<tr>
<th>Temp.(K)</th>
<th>Tensile strength (MPa)</th>
<th>Yield strength (MPa)</th>
<th>Elongation (Percentage)</th>
<th>Reduction of area (Percentage)</th>
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<tr>
<td>297</td>
<td>309</td>
<td>294</td>
<td>16.5</td>
<td>50</td>
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<tr>
<td>-196</td>
<td>400</td>
<td>355</td>
<td>23</td>
<td>48</td>
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</tbody>
</table>

Table 1.1: Mechanical properties of Al 6061 at room temp and at LN2 temp

II. DESIGN METHODOLOGY & DESIGN SUMMERY

A design of pump includes various components like impeller, volute, shaft, bearings, seals etc. Before starting design it is required to decide, what type of pump (radial, mixed or axial) need to be designed for given parameters. Specific speed ns decide the type of the pump. Specific speed is the function of Speed (N), Head (H) and low rate (Q).
CONCLUSIONS

The current work deals with the design of centrifugal pump for circulation of supercritical helium. Here helium used is in supercritical stage so it will remain in single phase during the whole operation. Operating condition for pump is ~5 K temp and ~5 bar pressure. Here material used for impeller is Al 6061, and for design of shaft we have used En 8 material. Here for head ~40 m, rotational speed ~6000 rpm is used. And we are getting ~11 specific speeds in SI unit.

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