© 2017 IJEDR | Volume 5, Issue 1 | ISSN: 2321-9939

Review on Design of Centrifugal pump for supercritical Helium

Mitesh Daxini[1], A.K.Sahu[2], Dr. S. M. Mehta [3]
[1] Student, M.E., Cryogenic Engineering, L D College of Engineering, Ahmedabad, Gujarat, India.
[2] Scientist-Engineers SG, Institute for Plasma Research-Bhat, Gandhinagar, and Gujarat, India.
[3] Associate Professor, Mechanical Engineering Department, LDCE, Ahmedabad, Gujarat, India

***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).

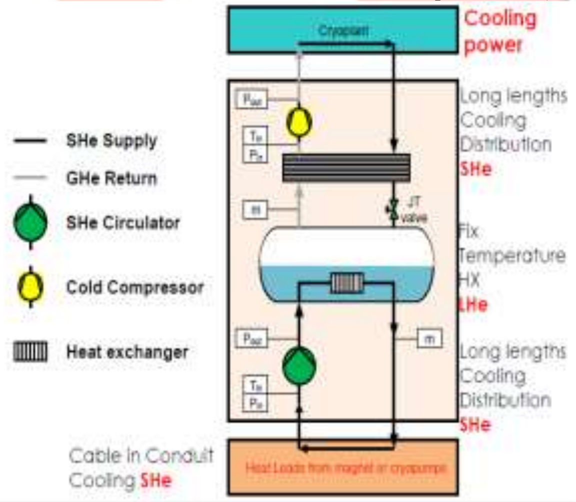

Fig.1 closed-loop circulation of supercritical helium (Courtesy: IPR)

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.

Temp.(K)	Tensile strength (MPa)	Yield strength (MPa)	Elongation (Percentage)	Reduction of area (Percentage)
297	309	291	16.5	50
-196	400	335	23	48

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).

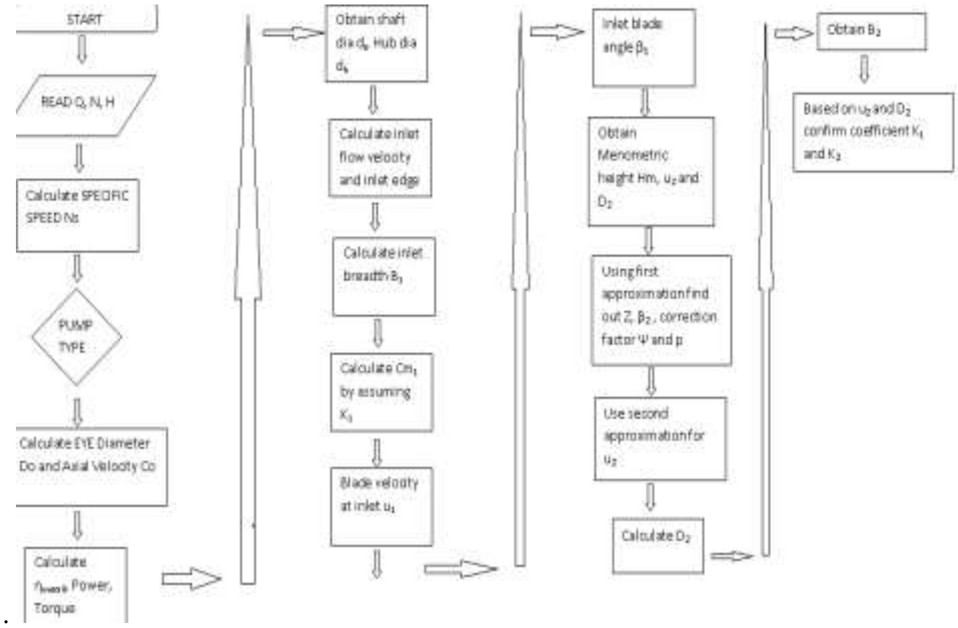

Figure 2 Design Methodology of centrifugal pump impeller

DESIGN SUMMARY

NO.	COMPONENET		DIMENSIONS	
	INPUT PARAMETERS			
1	DENSITY OF HELIUM	den	128.8	Kg/m3
2	MASS FLOWRATE	m	0.1	Kg
3	pressure diff	P	50000	N/m2
4	Rotational speed	N	6000	Rpm
5	head output	H	39.54	m
6	volume flow rate	Q	0.000776398	m3/s
	Pump specification			
7	specific speed	Ns	10.97	
8	Hydraulic efficiency	ηh	71.26	%
9	volumetric efficiency	ηv	32.615	%
10	mechanical efficiency	ηm	96	%
11	overall efficiency	η	22.313	%
12	output power	No	0.042	KW
13	input power	Ni	0.1867	KW
14	Shaft dia	ds	6	mm
15	Hub dia	dh	7.5	mm
16	EYE dia	Do	19.43759271	mm
17	diameter of inlet edge of impeller blade	D1	21.38135198	mm
18	inlet breadth B1	B1	8.241552	mm
19	inlet blade angle	β1	18.82395622	degree
20	dia of outer edge of impeller blade	D2	89.14143446	mm
21	outlet breadth	B2	3.86374	mm
22	outlet blade angle	β2	12.08078077	degree
23	No of blade	Z	4.328259131	nos
			5	
	velocities			
	flow velocities			
24		cm0	3.284874417	m/s
25		cm1	4.598824184	m/s
26		cm2	3.159392214	m/s
27		cm3	3.097443347	m/s
	blade velocities			
28		u1	11.1997558	m/s
29		u2	41.4550371	m/s

[1] 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.

[2] ACKNOWLEDGMENT

It is with deeply pride and pleasure to express my sincere gratitude to my guides Mr. A. K. Sahu and Prof. (DR.) S.M.MEHTA, for their encouragement and constant help. I am obliged to the Principal and Head of the Mechanical Engineering Department of L.D. College of Engineering Ahmadabad, for giving permission to do work at Institute for Plasma research (IPR), Gandhinagar, and making available various facilities of college and department. I am also thankful to The Chairman of IPR & BRFST, for providing me such a good opportunity to do project work at IPR. I am glad to express my thanks to the entire Staff of IPR, Bhat; & Faculty Members of Cryogenic Engineering Dept. of L. D. College of Engineering, Ahmadabad for giving me the necessary guidance in the project.

REFERENCES

BIBLIOGRAPHY

[1] K.M. Srinivasan ,"Rotodynamic Pumps(Centrifugal and Axial)",1st edition, New Age International(P) Limited, New delhi.
[2] O.moniz, P.Girdhar "Practical Centrifugal Pumps", 1st edition, Newnes, Australia.
[3] A.K. Mihaelo and V.V Malish, "Construction and calculation of high pressure centrifugal pumps", 1st Ed, Moscow publishing house.
[4] V.P. Vasandani, "Hydraulic machines theory and design", 10th edition, Khanna Publishing house, New Delhi.
[5] A.J.Stepano, "Centrifugal and axial flow pumps theory design and application", 2nd Ed, John wilay and sons, New York.
[6]G.K.Sahu,"Pumps (Theory Design and Application)", 1st edition, New Age International (P) Limited, New Delhi.
[7]R.K. Srivastav, "Pumps-A Complete Reference ", 1st edition, Galgotia Publications (P) Limited, New Delhi.
[8]R.K. Turton "Rotodynamic Pump Design", 2nd edition, Cambridge University Press, New York.
[9] Robert R Ross "Centrifugal pumps: design and application", 2nd edition, Gulf publication company, Houston, TX.

WEBSITES:
[10] https://www.cryogenicsociety.org/resources/defining_cryogenics/supercritical_fluids/
[11] http://www.ruhrpumpen.com/productos/VLT%20Cryogenic
[12] http://www.cryostar.com/web/cryogenic-pumps-stationary.php
[13] http://www.kiwipumps.com/cryogenic-pumps.html
http://encyclopedia.airliquide.com/Encyclopedia.asp?GasID=32#GeneralData

RESEARCH ARTICLES:
[14] D. A. Wigley, "Mechanical Properties of Materials at Low Temperatures", Cryogenics 1968
[15]J. E. Campbell, "Structural Alloys at Subzero Temperatures", Metals Hand book, American Society for Metals (ASM), Pg.20.24 to 20.34.
[16] N.P.Raval, M.K.Gupta, D.S.Sharma, V.L.Tanna, "Mechanical properties of structural alloys at cryogenic temperature" ICMPC-2012, pp. 547-551.
[17]"Centrifugal Pumps for Petroleum, Petrochemical and Natural Gas Industries", ANSI/API Standard 610 11th Edition, (November 2013).
[18] Robert D. McCarty "thermodynamic properties of helium 4 from 2 to 1500 K at pressure to 108 bar", Cryogenic Division, Institute of basic and standards, National Bureau of standard, Boulder, Colorado.
[19] Ragonath Singh, M Nataraj, "Design and Analysis of Pump using SWFS'', World journal of Modelling and simulation, vol 10, 2014, No. 2, pp. 152-160.
[20] R. Pengo , S. Junker , H. Kate "Liquid helium centrifugal pump characteristics from 80 g/s to 1200 g/s", Cryogenics 50 Page 812,(2010)
[21] D. Chopra, H. Babb, " Inexpensive liquid nitrogen pump", Rev. Sci. Instrum., Vol. 46, No.8, pp. 1126-1127, (1975).
[22] T.Ebisu, T. Watanabe, "Small pump for liquid nitrogen", Rev. Sci. Instrum. 59(4), Page 658-659, (1988).
[23] Gang Li, Shane Caldwell," A compact centrifugal pump'', cryogenics| volume 75|april 2016|35-37.
[24] Nipun Raval, D S Sharma, Manojkumar gupta, Vipul tanna," Design and Performance Prediction of Liquid Nitrogen Booster Pump for 80 Kelvin Thermal Shield Using CAE Tools "2nd International Conference on Multidisciplinary Research & Practice.