Design and Performance Prediction of Liquid Nitrogen Booster Pump for 80 Kelvin Thermal Shield Using CAE Tools

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Abstract— **Centrifugal pump is widely used turbomachinery for circulation of fluid. It is essential to check its performance characteristics. Usually its performance is measured on pump test rig. It is time consuming and different test is required for different capacity pump and for different fluids. Here pump is designed for 15 m head and 90 m^3/h capacity using Ansys Bladegen tool. Also CFD analysis done on designed pump using CFX tool of Ansys. Pressure and velocity distribution profile from inlet to outlet of impeller of pump is obtained in CFX. The stress induced on the impeller blade due to fluid pressure is also obtained using structural analysis in Ansys. The results obtained give the estimate whether proposed design will give desired output or not. So here quick turbomachinery design using standard software is presented.**

Keywords:**Centrifugal pump design, CFD analysis, Ansys BladeGen, Ansys CFX, Structural analysis of blade**.

I. INTRODUCTION

In Steady state superconducting tokomak (SST-1) superconducting magnets are to be operated at 4.5K, so to avoid its direct exposure of room temperature thermal shield of Liquid Nitrogen around it at 80K temperature is provided. Liquid Nitrogen (LN2) Booster System as shown in figure 1 is proposed to flow LN2 with inlet and outlet condition of thermal shield as 7bar atmospheric pressure at 80K and 5.5 bar atmospheric pressure at 90K respectively. To flow LN2 in closed circuit under steady state in single phase, centrifugal pump is required which should be cryo compatible and can produce pressure rise of 3.5 bar and flow rate of 50 Liters/Minutet atmospheric pressure.

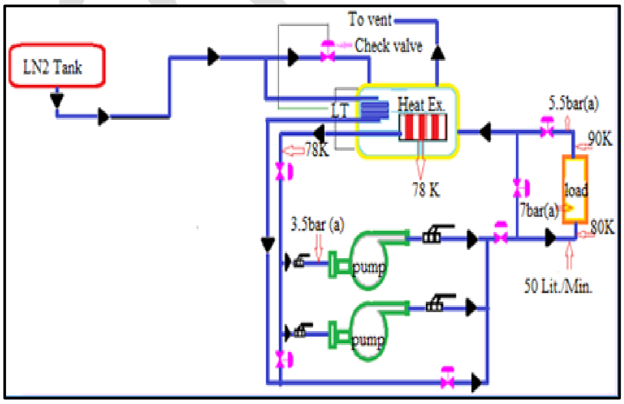


Fig.1 Liquid Nitrogen Boosting System

II. DESIGN METHODOLOGY OF IMPELLER FOR CENTRIFUGAL BOOSTER PUMP

In conventional material like carbon steel ductile to brittle transition takes place at cryogenic temperature which is the main cause of catastrophic failure at cryogenic temperature. API 610 provides guideline for material for pump at cryogenic temperature. Aluminum alloy has shown tremendous potential for cryogenic application. Aluminum alloy Al-6061 retains goodmechanical properties as well as good fabrication properties at cryogenic temperature. So Al-6061 is selected as impeller material. Using formula available design is done for impeller analytically. Further dimensions are also obtained from Ansys Bladegen tool. Figure 2 shows chart of methodology adopted for impeller design. Also impeller dimensions are obtained using CFturbo software.

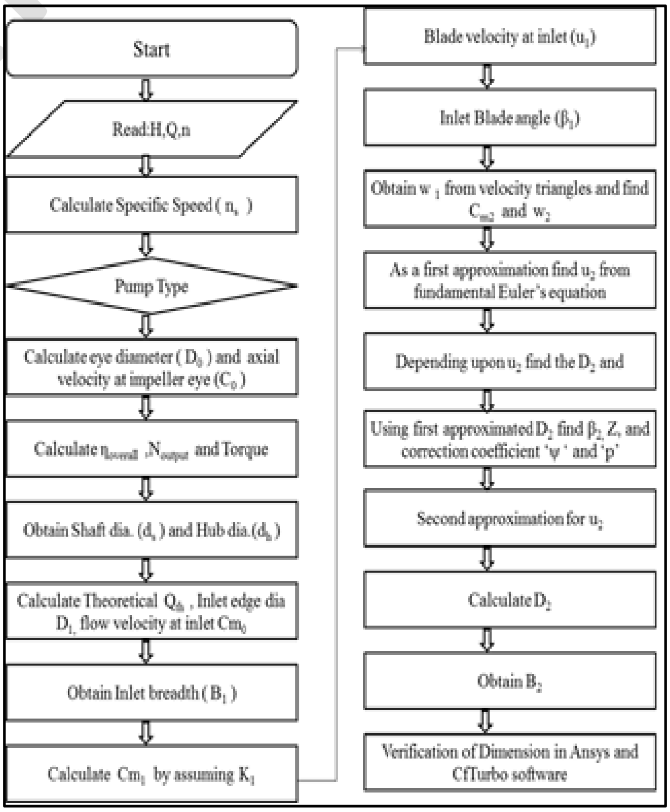
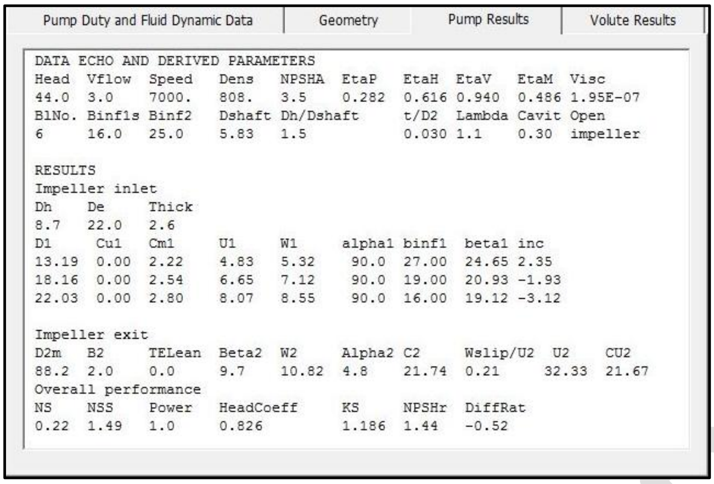


Fig. 2 Methodology for Impeller Design

III. Impeller Dimensions Obtained Using Commercial Softwares

Ansys Blademodeler is the design tool of Ansys CFX which is widely used for calculation of inlet as well as outlet dimensions of the impeller and also useful for volute design. CfTurbo is another tool which is purely dedicated to turbo machinery design and its performance prediction. The inputs given to these softwares are head (H) = 44 m, speed (N) = 7000 R.P.M, flow rate (3 m^3/s), kinematic viscosity = (1.95e-7 m^2/s), density (ρ) = 808 kg/m^3.

Figure 3 illustrates outcome from Bladegen tool of Ansys.



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Pump Duty and Fluid Dynamic Data | Geometry | Pump Results | Volute Results

DATA ECHO AND DERIVED PARAMETERS
Head   Vflow  Speed   Dens   NPSHA  EtaP   EtaH  EtaV   EtaM  Visc
44.0   3.0    7000.   808.   3.5    0.282  0.616 0.940  0.486 1.95E-07
BlNo.  Binf1s Binf2   Dshaft Dh/Dshaft     t/D2  Lambda Cavit Open
6      16.0   25.0    5.83   1.5           0.030 1.1    0.30  impeller

RESULTS
Impeller inlet
Dh     De     Thick
8.7    22.0   2.6
D1      Cu1   Cm1     U1     W1     alpha1 binf1  beta1 inc
13.19   0.00  2.22    4.83   5.32    90.0  27.00  24.65 2.35
18.16   0.00  2.54    6.65   7.12    90.0  19.00  20.93 -1.93
22.03   0.00  2.80    8.07   8.55    90.0  16.00  19.12 -3.12

Impeller exit
D2m    B2     TELean  Beta2  W2     Alpha2 C2     Wslip/U2  U2    CU2
88.2   2.0    0.0     9.7    10.82  4.8    21.74  0.21     32.33  21.67
Overall performance
NS     NSS    Power   HeadCoeff     KS     NPSHr  DiffRat
0.22   1.49   1.0     0.826         1.186  1.44   -0.52
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Fig. 3 Outcome from Bladegen tool

IV. Correction of Number of Blades and Impeller Diameter in CfTurbo

Minimum number of blades by calculation is 6. But while doing simulation in CfTurbo software it is found that due to overload on impeller blades bent as shown in Figure 4. It is required to increase impeller diameter and number of blades to decrease overload on the blades. Initially impeller diameter increased from 78mm to 84mm and number of blades from 6 to 8, despite of these changes blades shows little bit bending. Finally after much iteration diameter is taken as 88mm and number of blades as 10. For these change blades profile is symmetric without overloading as shown in Figure 5.

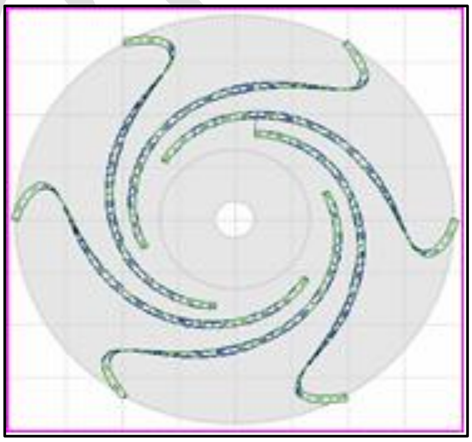

Fig. 4 Bending of blades due to overload on it

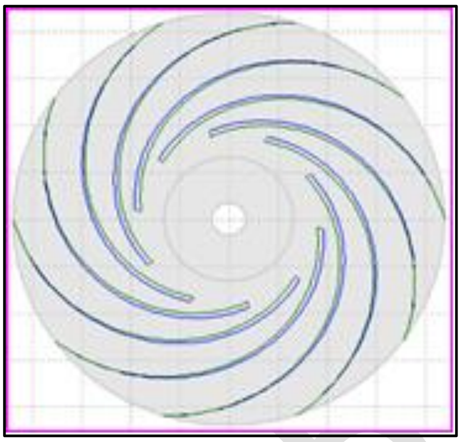

Fig. 5Blade Profile without overloading

Dimensions obtained by analytical method using existing literature available are compared with dimensions obtained using different CAE code. As it can be seen from Figure 6 they are in close approximation with each other.

	Analytical	Ansys BladeModeler	CfTurbo
Specific speed (n_s)	11.8	11.5	11.8
Type of Pump	Radial Centrifu-gal	Radial Centrifugal	Radial Centrifugal
Overall efficiency η	33%	30%	31.42%
Shaft diameter (d_s)	6 mm	6 mm	6 mm
Hub diameter (d_h)	8.5 mm	8.5 mm	8.5 mm
Eye diameter, (D0)	22	22	22
Inlet diameter (D1)	24	23	25
Inlet breadth , (B1)	5.4	5.2	5.4
Blade velocity (u1)	8.9 m/sec	8.07 m/sec	7.8 m/sec
Blade angle (β1)	23 (Degree)	23 (Degree)	23 (Degree)
Diameter (D2)	88 mm	88 mm	88 mm
Breadth (B2)	2 mm	2 mm	3 mm
Blade velocity (u2)	31 m/sec	32.33 m/sec	32 m/sec
Blade angle (β2)	19	19	19
No of blades (Z)	6 (minimum)	10	10

Fig. 6 Dimensions obtained by Analytical,AnsysBladeModeler and CfTurbo

V. Pump Performance Prediction in CfTurbo Software

It is essential to predict pump performance to confirm whether proposed design will meet required output or not. Here CfTurbo is used to estimate pump performance at design point i.e. flow rate of 3 m^3/hour (50 liter / minute), rotational speed of 7000 R.P.M. and diameter 88 mm. It is essential to get pressure difference of 3.5bar from inlet to outlet of the impeller to get head of 44m. It is evident from Figure 7 pressure difference for the design point will be nearly equal to 3.5 Bar. Now head developed by the pump is the function of the pressure difference between pump inlets to pump outlet. Pump should produce head of 44 meter as discussed earlier. From figure 8 it is observed that pump will exactly produce head of 44 m for design point. Figure 9 shows the electric power required. Usually for low density fluid power output is low, so for liquid nitrogen, for same condition required more power than water centrifugal pump. This is the prime reason why efficiency of these pumps is less than conventional water pump. From figure 9 itis observed that overall efficiency of the pump for proposed design will be around 32%.

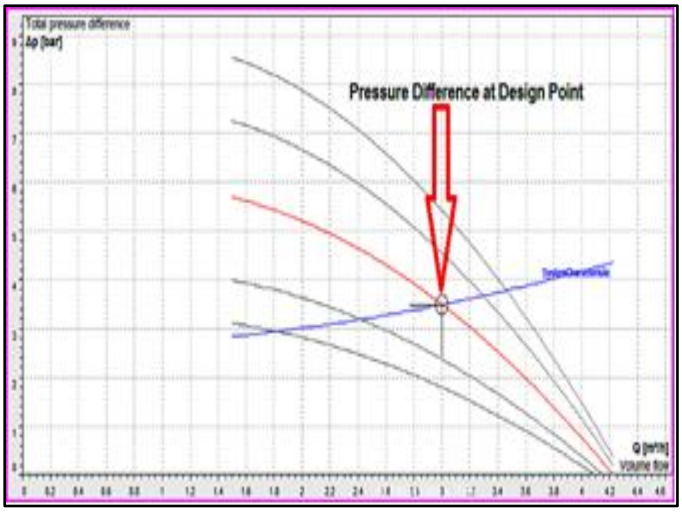

Fig. 7 Flow vs Pressure difference

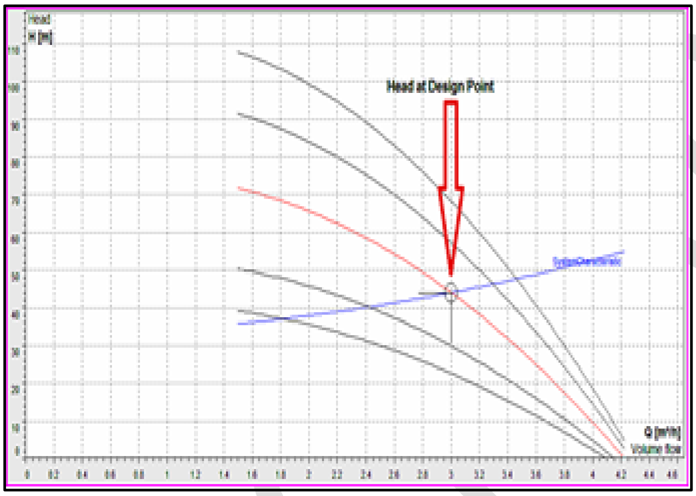

Fig. 8 Flow vs Head

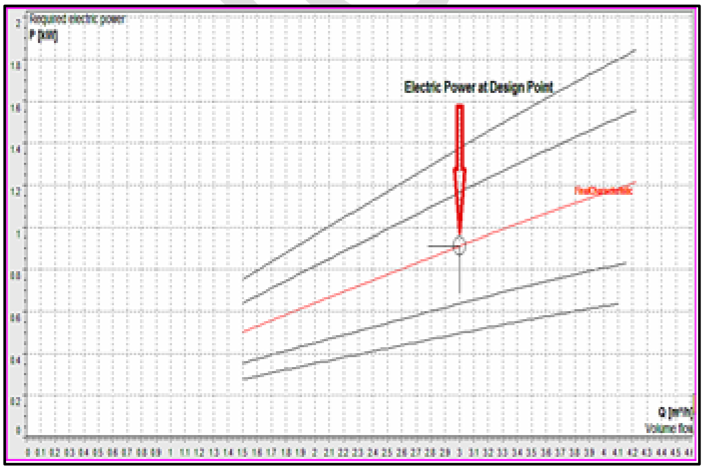

Fig. 9 Flow vs Electric Power at design

Fig. 10 Flow vs Efficiency

VI. CONCLUSION

Here design for required parameter is done i.e. for 44m head and to gate flow rate of 50 liters/minute to circulate LN2 in 80K thermal shield at SST1 at IPR. After carefully selecting material for cryogenic application, design is carried out for centrifugal pump impeller with analytical method from existing formula available. Design is also carried out using standard softwares like ANSYS and CfTurbo. Analytical results and results from softwares are in close approximation with each other. Number of blades and impeller diameter is modified for better loading condition in CfTurbo. Performance prediction in Cfturbo software illustrate that designed pump will give desired output. Thus by this methodology pump for any fluid can be developed.

REFERENCES

[1]. A.J.Stepanof , Centrifugal and axial flow pumps theory design and application , 2nd ed, John wilay and sons, New York.
[2]. Mihaeloff A.K and Malish, V.V (1971), Construction and calculation of high pressure centrifugal pumps,1st ed, Moscow publishing house ,.
[3]. Turton R.K, Rotodynamic Pump Design ,2nded, Cambridge University Press, New York.
[4]. Lomakin, A.A.,(1966) Centrifugal and Axial flow pumps,1st ed, Moscow Publishing House
[5]. Tuzson, J. Centrifugal Pump Design., 2nd ed ,John Wiley and Sons Inc.,New York.
[6]. Evans, J. , A brief Introduction to centrifugal pump[Online]. Avilable: http:// www.pacificliquid.com.
[7]. Chaurette,] J., Tutorial on centrifugal pump system [Online]. Avilable: http:// www.lightmypump.com.
[8]. Platt, M.J, Cook, C." (2002) Thermo Mechanical Turbo pump Design and Analysistools", 2nd Modeling simulation subcommittee,destin,florida..
[9]. Anagnostopoulos , J.S.(2009) " A fast numerical method for flow analysis and blade design in centrifugal pump impellers", Computers Fluids 38
[10]. Jafarzadeh ,] B. ,Hajari , A., Alishahi , M.M., Akbari, (2011)"The flow simulation of a low-specific-speed high-speed centrifugal pump", Applied Mathematical Modelling 35.
[11]. ANSYS CFX-Manual (2006), Published by, ANSYS CFX, Release 11.0, ANSYS, Inc

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