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Design and CFD analysis of axial flow viscous fluid pump

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ABSTRACT

Each year all over the globe, from infants to adults millions of patients are diagnosed with heart failure. Heart related diseases are increasing at a fast pace around the world but the limited number of donor's hearts are available. These results in the high demand for Mechanical Circulatory Support System (MCSS).There are two different options that may be an Artificial Heart or a ventricular assist device (VAD). This Thesis takes the advantages of axial flow pumps to design a VAD and to conduct a numerous case studies on the different shapes and sizes. The CFD based design study has been done to examine the outputs of the needy parameters primarily the mass flow rate, pressure rise for the scope of the independent parameter that is a rotating speed of VAD.

Keywords— *Ventricular assist devices, Axial flow pump, H-Q Curves*

1. INTRODUCTION

1.1 Axial Flow Pumps

An axial flow pump uses a screw propeller to accelerate the liquid axially. The outlet passages and guide vanes are placed to convert the velocity increase of the liquid into a pressure. As distinct from the centrifugal pump, the axial flow pump absorbs the maximum power at zero flow. The axial flow pumps are used where large quantities of water with a low head are required Ex: In condenser circulating. The efficiency is equivalent to the low lift centrifugal pump, and the higher speed FS possible enable a smaller driving motor to be used. The pump casing is of gunmetal for condenser cooling duties and cast iron for healing and trimming pumps. The impellers are of aluminum bronze, and guide vanes of gunmetal are arranged immediately after the impeller, the pump shaft being of stainless steel.

1.2 Applications

Axial flow pumps were used in applications requiring very high flow rates and low pressures. They are used to circulate fluids in VAD, Power plants, and evaporators as well as in flood dewatering and irrigation systems. Axial flow pumps are dynamic pumps, which mean they use fluid momentum and velocity to generate pump pressure. Specifically, these are centrifugal pumps, which help to generate this velocity by using an impeller to apply centrifugal force to the moving liquid.

1.3 Pumps in LVAD

Selecting the right kind of pump requires an understanding of the properties of the liquid in the addressed system. These properties include viscosity and consistency.

Axial pumps utilize the momentum as well as the velocity of the fluid flowing through the pump, caused by an impeller applying a centrifugal force to the liquid, to create pressure inside the pump. An axial pump is almost similar to a centrifugal pump in many ways, except the fluid flow is parallel to the impeller instead of radial to the shaft. This feature allows axial pumps to have a much higher efficiency than most other pumps; however, it also causes a pump to have a low head and discharge pressure. Axial pumps are sometimes termed as propeller pumps owing to their similarity to the propeller of a boat. The difference, however, is that these axial pumps are usually enclosed in a casing to transmit fluids from one specific location to another.

Axial pumps are used when we need to have high discharge and a low head. They are also used when you have a smaller exit and entrances, and in general, they have the smallest dimensions as far as pumps go. Axial pumps differ depending on the direct use, but they generally follow the same setup.

Axial flow pumps were designed to handle low viscosity fluids because they generate low head and high capacities.

A Ventricular Assist Device (VAD), which is a miniaturized axial flow blood pump from the point of view of the mechanism. It consists of an impeller, an inducer, and a diffuser. The main design objective of this VAD is to produce an axial pump with a streamlined, idealized, and no obstructing blood flow path. The magnetic bearing is adapted so that the impeller is completely magnetically levitated. The VAD operates under transient conditions because of the spinning movement of the impeller and the pulsatile inlet flow rate.

A Ventricular Assist Device (VAD) will aid the failing heart but doesn't replace it. Most recent models of VADs are implanted in the abdomen that is connected to tubes. Through these bloods is drawn from one of the heart's ventricles and pumped into the circulatory system. A temporary Ventricular Assist Device can support any of the ventricles, or two VADs can support both. Such devices are usually employed to assist the left heart, the side primarily affected in most types of heart failure. The second category of MCSS, a Total Artificial Heart (TAH), is similar in concept to two VADs but replaces the diseased heart.

1.4 Hydraulic requirement of Pump in LVAD

1.4.1 Hydraulic Requirements

- The pump should able to generate 60 to 120mm Hg pressure rise
- A volume flow rate of 6-12L/min
- Speed range: 5000 -10000rpm

1.4.2 Size Requirements

- Hub diameter of impeller: ≤ 18mm
- Blade Tip diameter of impeller: ≤20mm
- Clearance between the inner wall and blade top: 2-4mm
- Number of blades: 4
- Blade thickness: 0.5mm

Hydraulic necessities from the VADs are for the most part the pressure rise and flow rate. The patient-explicit necessities fluctuate as indicated by their heart condition. In general, VAD should have the option to create 60 to 120mmHg pressure rise, with flow of 2 to 12 lit/min. These flow and pressure rise necessity help in deciding the pump size.

1.5 Axial Flow Pump Advantages

- The main advantages of an axial flow pump are that it has relatively high discharge (flow rate) at a relatively low head.
- It can also be easily adjusted to run at peak efficiency at low flow/high-pressure and high flow/low pressure by changing the pitch on the propeller.
- The turning effect of the fluid is not too severe in an axial pump, and the length of the impeller blades is also short. This leads to higher stage efficiencies.

1.6 Disadvantages

- Not suitable for suction lift
- Low head and discharge pressures
- These disadvantages are also helpful for the design of the Ventricular Assist Device (VAD) as the VAD needs low head and discharge pressures.

2. DESIGN OF AXIAL FLOW PUMP

2.1 Design Details

Steps followed to make the 3D modal:

- Select the front plane and draw a circle of diameter 14.8mm using sketch (sketch 1) command.
- Select the sketch1 and extrude it to 54.97mm by using Extrude Boss/base tool in features command.
- Now spiral is created by using Helix and spiral tool from curves command. During this base circle of the cylinder is selected, which is on the front plane.
- Following are the additional options for the Helix that are used:
- Helix is defined by Height and Revolution.
- Parameters: Variable pitch
- Starting angle: 90dgs, Counter clockwise
- Now, draw another sketch in the right plane cross-section profile of the blade (rectangle, i.e., sketch2). It should be touching the starting point of a helix.
- Height: 3.7mm,
- Thickness: .5mm
- Now, by using Swept boss/base feature, we can create the come profile of the blade
- Profile: Sketch2 ; Path: Helix
- Finally, by circular pattern command, we will create remaining three blades.
- Parameters: circle edge of the cylinder; Angle: 360; Number: 4; Equal spacing; Bodies: Swept1

2.2 Computer Aided Design (CAD) of an axial flow pump

Case 1: A Draft model to study the impact of all the elements like Inlet Angle, Length, Revolutions, and No of Blades.

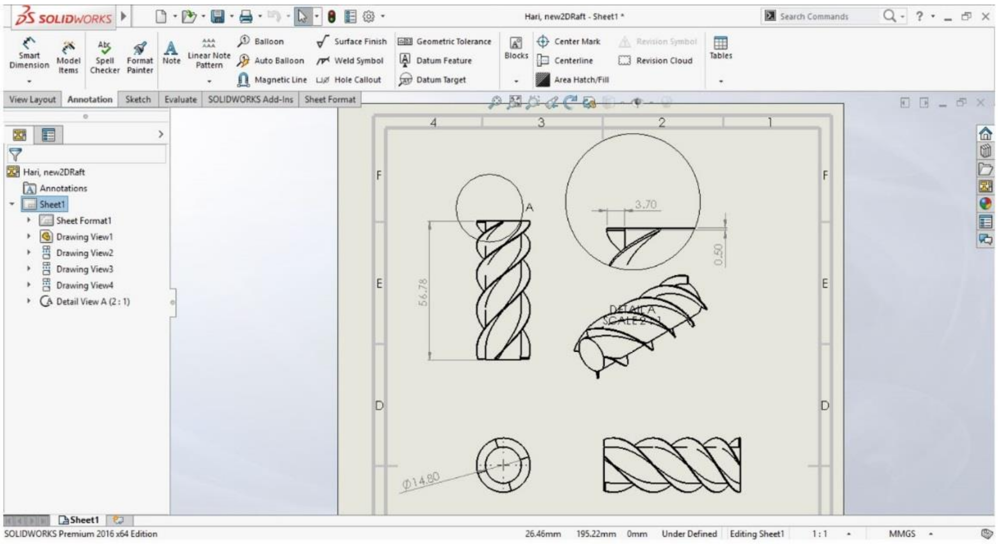

Fig. 1: CAD of an axial flow pump

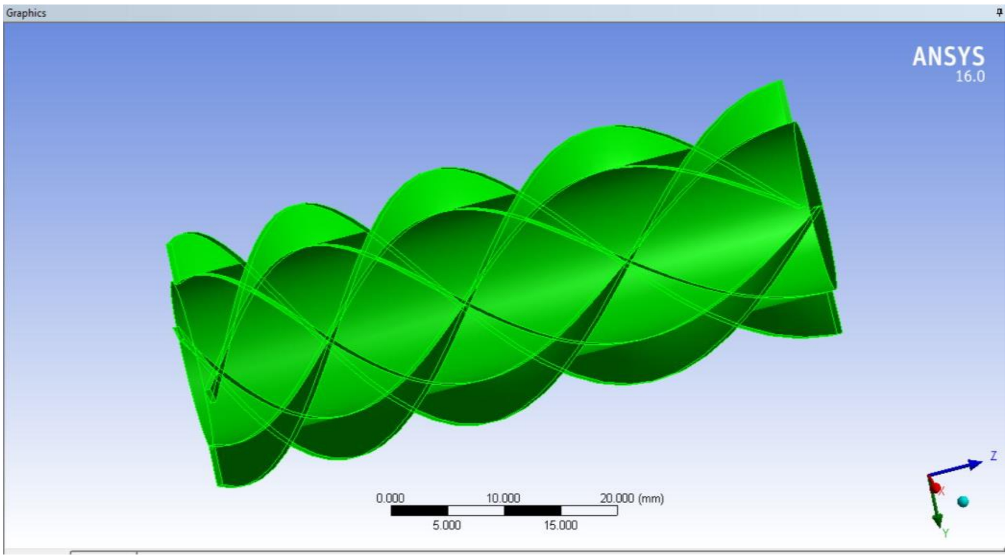

Fig. 2: CAD model for Draft model

2.3 Converting CAD geometry for CFD Analysis

An axial pump impeller is a rigid object that creates the pressure variance over the pump by rotating in the fluid region. For the investigation of the stream conduct over the impeller, this liquid locale ought to be made utilizing the strong work geometry of an impeller. With the ultimate objective of this project and concentrate economically accessible ―ANSYS programming has been used. Ansys stage underpins the smooth progression of information among different sections using numerical tools and meshing. Different impeller geometries developed by solid work modeling are imported to ANSYS software as one of the geometries, as shown below.

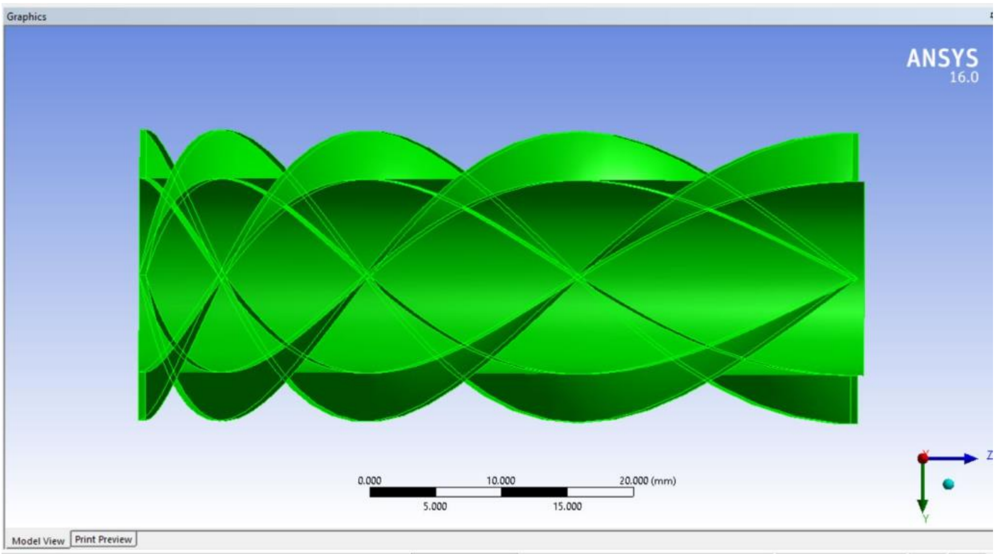

Fig. 3: Imported geometry from solid work modeling to ANSYS

3. CFD ANALYSIS OF AXIAL FLOW PUMP

The Axial flow design of VAD is a repetitive technique that requires investigating different geometries and shapes of an impeller; in addition it includes the confirmation of impeller shapes for their reasonableness to be utilized as VAD. CFD displays simulations results with the end goal of the proposal. This section is restricted to the specific structure that was chosen for mock trial assessment of VAD.

In this section, it gives simulation results of a VAD working as a blood flow pump that integrates the results based on CFD using every parametric investigation. This was done to analyze the effect of working speed on the characteristic structure parameters. The Pump performance as a continuous flow blood pump is computed by using the results of optimization. Results of the CFD simulations for pressure at steady-state are discussed to picture the inward flow details.

The CFD based Design study has been done to examine the reaction of the needy parameters primarily the mass flow rate, pressure rise for the scope of the independent parameter that is a rotating speed of VAD. The structure grid is created for the scope of VAD rotating speed-shifting from 5000 to 10,000 RPM, flow rate differing from 3L/min - 9L/min, and pressure rise of 5mmHg to 120mmHg. Now by face selection, create the named section of the geometry by taking at most care while selecting every corner and edges of the geometry.
Creating cylinder geometry around the impeller and developing Booleans with respect to the impeller geometry acts as a rotating frame and wall pipe (casing) as shown in below figure. Mesh has been generated for the whole flow domain by generating 1, 58,711 elements as shown in the figure.

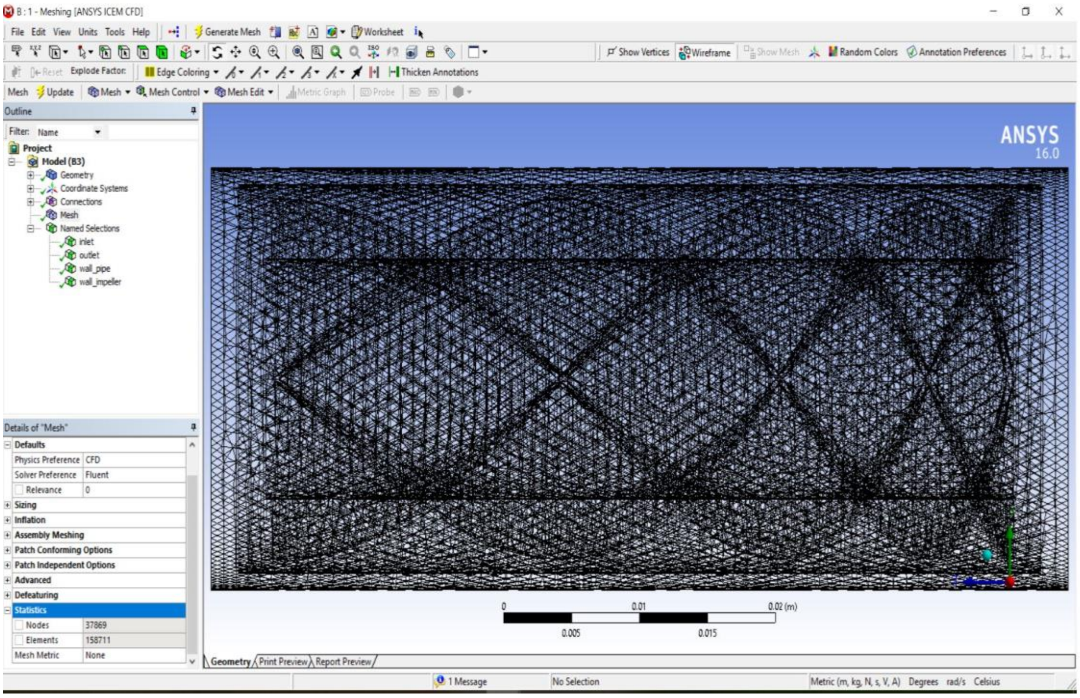

Fig. 4: Mesh Generation

3.1 Convergence

To run a successful CFD simulation for a composite profile like axial flow left ventricular assist device, it is fundamental to look into the various behaviors of the numerical processes. The concept of residual value is to showcase the irregularity and mistakes happening in each and every node of the grid. Convergence is achieved only when the resulting residual value fulfills the predetermined reach of tolerance. A reduction of the residual value by order of three in magnitude throughout the iteration procedure demonstrates the less qualitative convergence. There are different purposes behind the convergence failing, for example, poor mesh, nonphysical boundary conditions, and selection of inappropriate models.

3.2 Blood Properties

Blood is not a pure Newtonian fluid, if we use this non-Newtonian fluid for simulation, it will make the simulation procedure into a very complicated one. Numerous scientists and international researchers likewise treat it like this.

- Blood viscosity is considered normally 3 ~ 4 (10-3) Pa.s But, here we take 0.0035 Pa.s.
- Normal adult blood flow rate of heart is 6L/min (0.106kg/s),
- Normal blood pressure is 80 ~ 120mmHg.
- Blood density is 1060kg/m3.

Mass flow rate is considered as the inlet boundary condition which is 0.106kg/s. Set Pressure at outlet as an exit boundary condition as 100mmHg (13332Pa). Consider a steady-state condition, by using standard turbulence model ε−k, to use wall condition as solid wall without any slip.

3.3 H-Q curves

For optimization design, H-Q curves play a significant job to choose which structure geometry has fit the hydraulic requirements. H-Q curves say for what discharge what will be the pressure head. In this way, to create H-Q curves of three unique geometries, we should change speed (for example 5000 to 10000 RPM) and stream rate (for example 3L/min to 9L/min.) in the setup section of ANSYS software. After the solution is converged, the pressure difference can be acquired from the CFD-POST. In the wake of getting the pressure difference for each flow rate and speed plot the curve as Q on x-axis and H on y-axis respectively.

The obtained pressure difference values and H-Q curves for each case are appeared in underneath figures.

Case 1:

3 l/min = 0.053 kg/s

RPM	Exit Gauge Pressure (Pa)	Inlet Gauge Pressure (Pa)	dp in Pa	dp in mm-Hg
5000	13332	198527	-185195	-1389.076
6000	13332	197884	-184552	-1384.253
7000	13331.9	197350	-184018.1	-1380.249
8000	13331.8	196929	-183597.2	-1377.092
9000	13331.7	196660	-183328.3	-1375.075
10000	13331.6	196396	-183064.4	-1373.095

4 l/min = 0.07066 kg/s

RPM	Exit Gauge Pressure (Pa)	Inlet Gauge Pressure (Pa)	dp in Pa	dp in mm-Hg
5000	13330.2	274754	-261423.8	-1960.839
6000	13329.3	274103	-260773.7	-1955.963
7000	13328.3	273701	-259982.4	-1952.955
8000	13327.6	273310	-259982.4	-1950.028
9000	13327	273022	-259695	-1947.872
10000	13326.5	272846	-259519.5	-1946.556

5 l/min = 0.08833 kg/s

RPM	Exit Gauge Pressure (Pa)	Inlet Gauge Pressure (Pa)	dp in Pa	dp in mm-Hg
5000	13325.1	272390	-259064.9	-1943.146
6000	13320.7	358765	-345444.3	-2591.045
7000	13318.1	358193	-344874.9	-2586.774
8000	13316.4	357703	-344386.6	-2583.111
9000	13315	357334	-344019	-2580.354
10000	13313.8	357052	-343738.2	-2578.248

6l/min=0.106kg/s

RPM	Exit Gauge Pressure (Pa)	Inlet Gauge Pressure (Pa)	dp in Pa	dp in mm-Hg
5000	13302.2	450012	-436709.8	-3275.592
6000	13297.6	449473	-436175.4	-3271.584
7000	13294.9	448832	-435537.1	-3266.796
8000	13293.5	448427	-435133.5	-3263.769
9000	13292.5	448069	-434776.5	-3261.091
10000	13292.1	447822	-434529.9	-3259.242

7 l/min = 0.12366 kg/s

RPM	Exit Gauge Pressure (Pa)	Inlet Gauge Pressure (Pa)	dp in Pa	dp in mm-Hg
5000	13268.5	547880	-534611.5	-4009.916
6000	13266.1	546789	-533522.9	-4001.750
7000	13265.5	545871	-532605.5	-3994.869
8000	13265.5	545586	-532320.5	-3992.732
9000	13265.4	545352	-532086.6	-3990.977
10000	13265.5	545098	-531832.5	3989.071

8 l/min = 0.14133 kg/s

RPM	Exit Gauge Pressure (Pa)	Inlet Gauge Pressure (Pa)	dp in Pa	dp in mm-Hg
5000	13252	653213	-639961	-4800.102
6000	13246.9	652542	-639295.1	-4795.107
7000	13244.4	651797	-638552.6	-4789.538
8000	13242.6	651383	-638140.4	-4786.446
9000	13241.7	650847	-637605.3	-4782.433
10000	13241.2	650532	-637290.8	-4780.074

9l/min=0.159kg/s

RPM	Exit Gauge Pressure (Pa)	Inlet Gauge Pressure (Pa)	dp in Pa	dp in mm-Hg
5000	13215.8	763991	-750775.2	-5631.277
6000	13210.6	763185	-749974.4	-5625.270
7000	13208.6	762393	-749184.4	-5619.345
8000	13207.7	761871	-748663.5	-5615.436
9000	13207.5	761407	-748199.5	-5611.957
10000	13207.5	761036	-747828.5	-5609.175

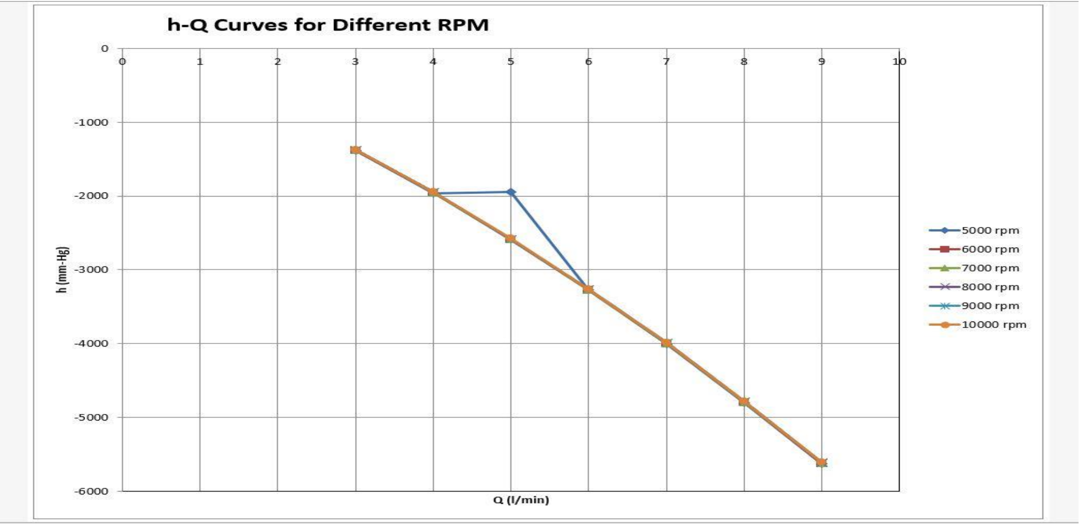

Fig. 5: H-Q curves for case-1 geometry

4. RESULTS AND DISCUSSION

4.1 Optimized Case: (Case2)

Length has been increased, and No of revolutions has been increased slightly, but the blade ends before reaching the outlet.

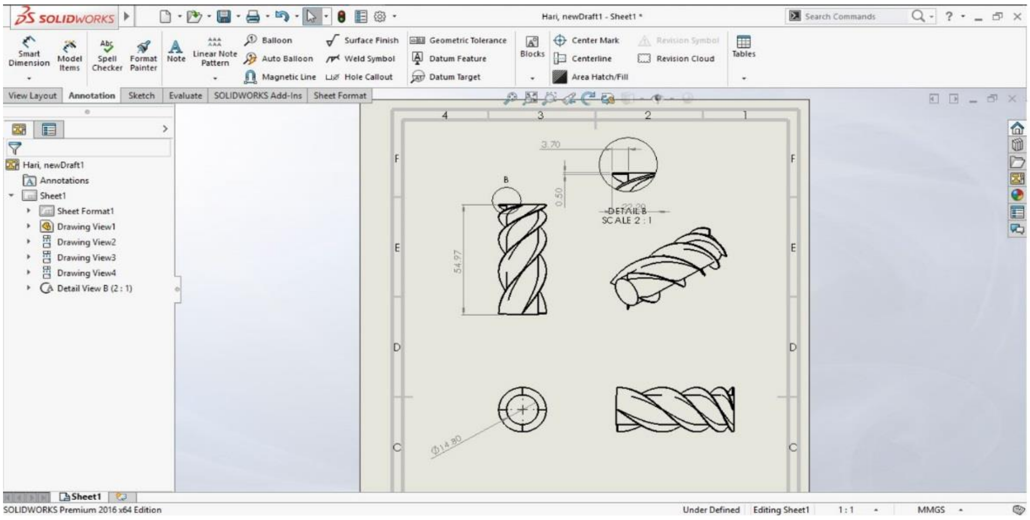

Fig. 6: CAD of an axial flow pump

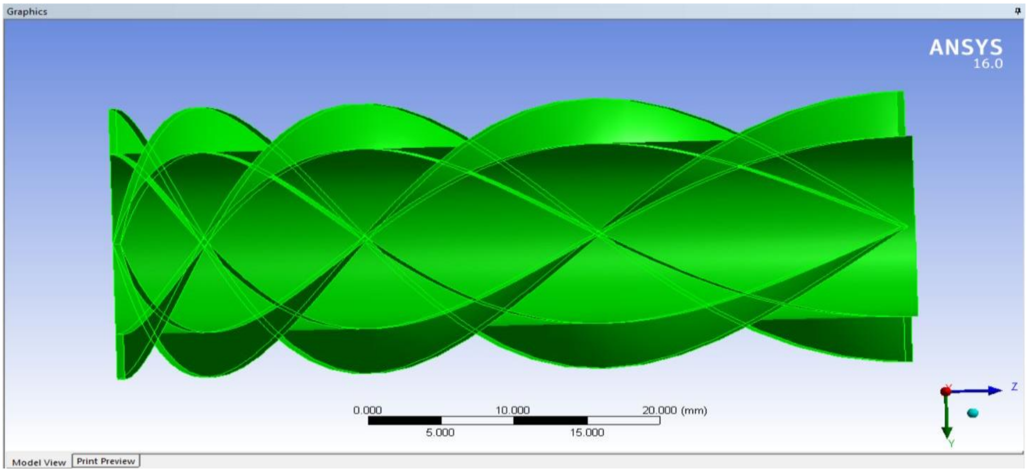

Fig. 7: Optimized design

4.2 Case-2: Pressure Difference values of optimized design

3l/min=0.053kg/s

RPM	Exit Gauge Pressure (Pa)	Inlet Gauge Pressure (Pa)	dp in Pa	dp in mm-Hg
5000	13259.7	9301.47	3958.23	29.689
6000	13234.7	5693.4	7541.3	56.564
7000	13192.8	3371.07	9821.73	73.669
8000	13144.4	872.603	12271.79	92.046
9000	13089.2	-2262.43	15351.63	115.146
10000	13027.7	-6106.74	19134.44	143.520

4 l/min = 0.07066 kg/s

RPM	Exit Gauge Pressure (Pa)	Inlet Gauge Pressure (Pa)	dp in Pa	dp in mm-Hg
5000	13271	9936.48	3334.52	25.010
6000	13244.2	6092.06	7152.14	53.645
7000	13205.2	3470.73	9734.47	73.014
8000	13161.2	610.946	12550.25	94.134
9000	13110.9	-2697.93	15808.83	118.575
10000	13052.7	-6456.88	19509.58	146.33

5 l/min = 0.08833 kg/s

RPM	Exit Gauge Pressure (Pa)	Inlet Gauge Pressure (Pa)	dp in Pa	dp in mm-Hg
5000	13274.2	10285.5	2988.7	22.417
6000	13246.2	6552.24	6693.96	50.208
7000	13206.8	3826.84	9379.96	70.355
8000	13164.7	848.132	12316.568	92.381
9000	13114.9	-2438.91	15553.81	116.663
10000	13057.3	-5936.57	18993.87	142.465

6l/min=0.106kg/s

RPM	Exit Gauge Pressure (Pa)	Inlet Gauge Pressure (Pa)	dp in Pa	dp in mm-Hg
5000	13276.4	10569.8	2706.6	20.301
6000	13250	6999.76	6250.24	46.880
7000	13211.1	3959.78	9251.32	69.390
8000	13167.7	1464.2	11703.5	87.783
9000	13116.7	-1164.53	14281.23	107.118
10000	13062.8	-5284.97	18347.77	137.619

7 l/min = 0.12366 kg/s

RPM	Exit Gauge Pressure (Pa)	Inlet Gauge Pressure (Pa)	dp in Pa	dp in mm-Hg
5000	13277.7	10935.9	2341.8	17.564
6000	13252	7458.52	5793.48	43.454
7000	13214.2	4347.59	8866.61	66.505
8000	13173.4	1396.91	11776.49	88.330
9000	13122.4	-762.534	13884.93	104.145
10000	13068.3	-4718.18	17786.48	133.409

8 l/min = 0.14133 kg/s

RPM	Exit Gauge Pressure (Pa)	Inlet Gauge Pressure (Pa)	dp in Pa	dp in mm-Hg
5000	13280.5	11234.2	2046.3	15.348
6000	13254.5	7754.3	5500.2	41.254
7000	13213.1	4756.47	8456.63	63.429
8000	13172.5	1729.09	11443.41	85.832
9000	13123.5	-1311.01	14434.51	108.267
10000	13068.1	-4365.53	17433.63	130.762

9l/min=0.159kg/s

RPM	Exit Gauge Pressure (Pa)	Inlet Gauge Pressure (Pa)	dp in Pa	dp in mm-Hg
5000	13282.9	11449.6	1833.3	13.750
6000	13252.3	8154.83	5096.47	38.226
7000	13217.1	4927.58	8289.52	61.176
8000	13175.3	1997.47	11177.83	83.840
9000	13127.9	-950.195	14078.09	105.594
10000	13074.7	-4093.56	17168.26	128.77

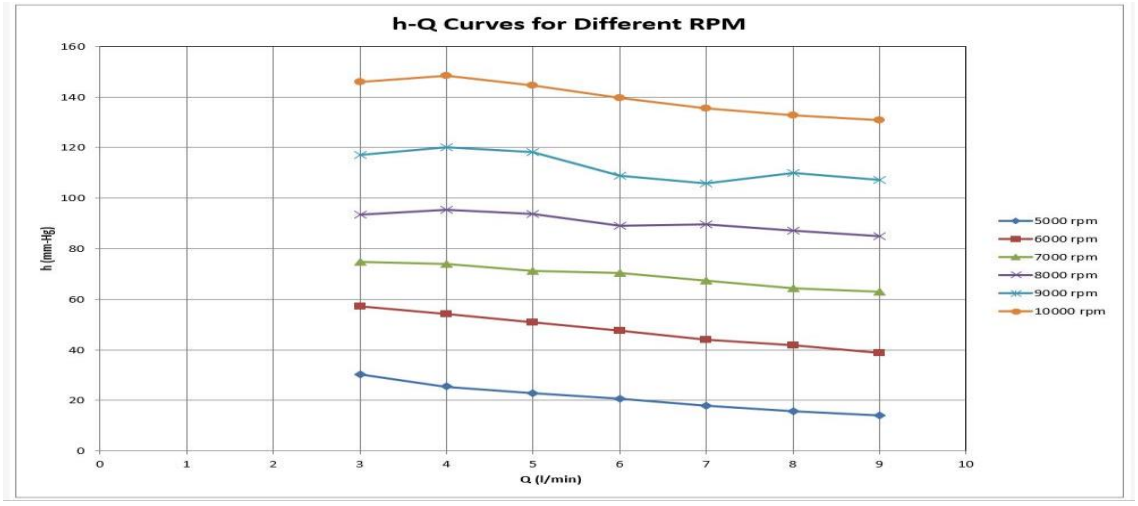

Fig. 8: H-Q curves for case-2 geometry

Table 1: Optimized Values

Name	Parameter
Number of blades	4
Length of the chord	54.97mm
Import Angle of Impeller blade	13°
Export Angle of impeller blade	76°
Airfoil Angle	38°
Diameter of cylindrical hub	14.80 mm
Diameter of Outer Blades	18.50 mm

There are a few other values that we considered in the design of the impeller. The thickness of impeller blades is taken as 0.5mm, and Clearance that has been considered unilaterally between the wall and outer edge is taken as 0.3 mm.

Pressure contour of optimized design

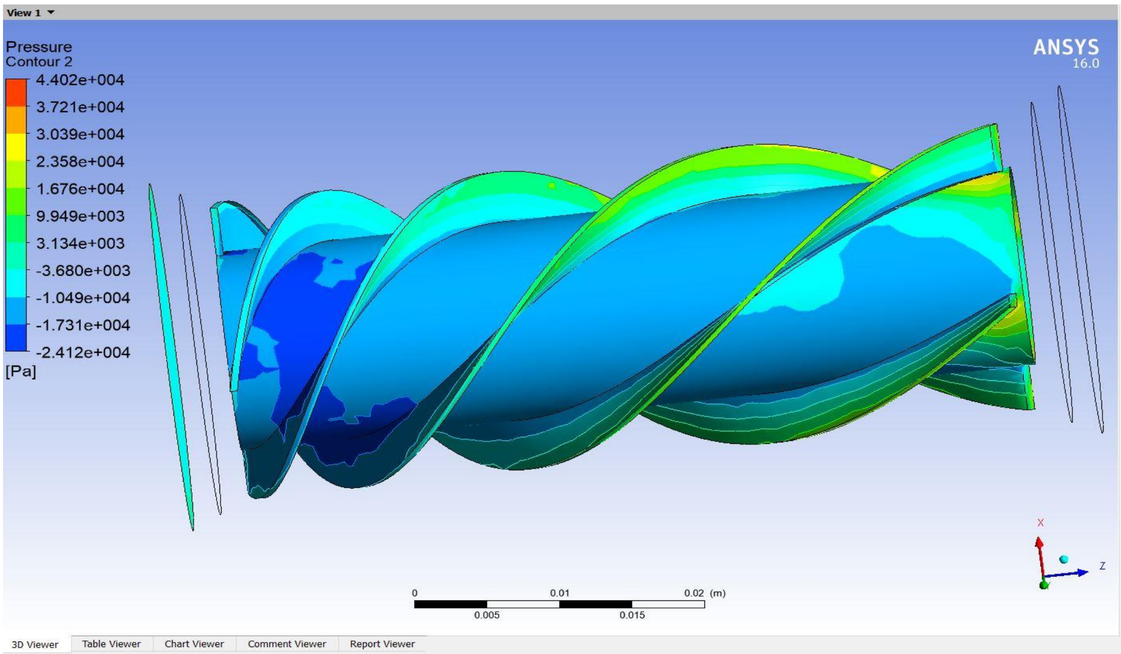

Fig. 9: Pressure Contour of optimized design

5. CONCLUSION

This postulation shows the plan and advancement of axial flow ventricular assist device (VAD). The evaluation assessment utilizing CFD of a VAD indicates a satisfactory design to expand upon and optimized VAD. The CFD consequences of VAD as an axial pump have demonstrated the best approach to build up a controlled flow that can fulfill the hydraulic prerequisite. The scope of working condition picked for this examination is expected to cover the scope of condition that the VAD will involvement during clinical use when working with the native heart. VAD can support the scope of pressure and flow rate prerequisite with levels by working it at varying limit speed. Henceforth, the old-style structure hypothesis of an axial flow pump can be utilized to design axial flow pump that can produce a controlled stream. As an underlying structure step, the working parameters were improved for the consistent flow and pressure rise, the VAD can help patients as a nonstop flow pump.

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