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Design Optimization of Internal Axial Flow Ventricle Assist Device (VAD) using CFD Model

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Abstract: Every year everywhere throughout the world, Millions of patients from new-born children to grown-ups are determined to have heart disappointment. A less number of donor hearts accessible for these patients brings about a gigantic interest of mechanical circulatory support system, as a ventricular assist device (VAD). As of now mechanical help is generally encouraging option in contrast to heart transplantation. Ventricle Assist Device (VAD) were initially used to give mechanical help in patients anticipating arranged heart transplantation.
VAD is a mechanical circulatory device that is used to partially replace function of heart failure i.e., to direct blood away from failing ventricle and guide flow to the circulation. VAD is analogous to pump (Blood Pump), so the performance characteristics of the pump is very important like pump curves (H-Q curves). The H-Q curve shows the head the pump pump is able to perform at a given flow.
Plan strategy adopted for this object is computational fluid dynamics (CFD). CFD based structure to decide the response of the pressure rise, flow rate for optimization purpose.

I. INTRODUCTION

Coronary illness keeps on being the main source of death over the globe. Coronary illness is a disorder in the ordinary working of the heart. Although coronary illness might be available from birth, regularly the maturing procedure prompts higher-weight levels and decrease in the general flexibility of the vessels, making the heart incapable to produce satisfactory cardiovascular yield for fringe and heart course.

Alongside Coronary Artery Disease event of other circulatory illness gives off an impression of being rising, predominantly for men in more established age gathering. In spite of noteworthy advancement made throughout the most recent 30 years in the medicinal field and a reduction in death rate from all cardiovascular sickness up to 45% in INDIA, every year a large number of individuals experience the ill effects of interminable coronary illness and myocardial dead tissue (MI) that is usually referred to as a heart attack. Congestive Heart Failure (CHF), a condition wherein the heart can't siphon enough blood to address the issue of different body organs.

India has seen a disturbing ascent in the event of coronary illness, stroke, diabetes and malignant growths in the previous 25 years, a progression of new investigations distributed in The Lancet and its associated journals have revealed.

Definite assessments of cardiovascular illnesses, diabetes, chronic respiratory diseases, cancer, and suicide show that their commonness has gone up in each Indian state somewhere in the range of 1990 and 2016, yet there is huge variety among states.

The predominance of coronary illness and stroke has expanded by over half from 1990 to 2016 in India, with an expansion saw in each state. Coronary illness now is the leading individual cause of disease burden in India, and stroke is the fifth driving reason.

A. Treatment for Heart Disease

Pharmacological medicines are generally actualized with certain degree of progress in way of life for patients determined to have coronary illness. Careful medications are fundamental for the patients with auxiliary variations from the norm of heart, related cardio vascular framework or heart valves. Heart transplantation is the last choice to consider for the seriously influenced cardiovascular patients.

B. Need of Mechanical Circulatory Support (MCS)

Improved coordination between donor, recovery and transplantation has prompted a 10-fold increment in heart transplantations in India since 2016.

There have been almost 300 heart transplantations crosswise over India in two years, as indicated by information given by the National Organ and Tissue Transplantation Organization (NOTTO), the national planning office for cadaveric organ donation, compared to around 350 somewhere in the range of 2015 and 1994, when the first heart transplantation was done in India.

However, if we look at the need, this is only a drop. Each inside in India that does heart transplant has a holding up rundown of 10 or 20 at some random time. An expected 50,000 hearts are required for transplants.

A restricting element for cardiovascular transplantation is a huge deficiency of contributor hearts.

A normal holding up period before heart transplant is around three to a half year. Numerous patients become ineligible for cardiovascular transplant because of irreversible disappointment of indispensable organs during their holding up period.

The absence of accessible benefactor hearts accentuate the requirement for an alternative choice of treatment. Mechanical circulatory support (MCS) can give the circulatory help to patients waiting for heart transplant. Alongside circulatory help, MCS re-establishes the ideal degree of wellbeing for patient enduring heart brokenness. The extreme lack of contributor heart has developed the thought for the advancement of artificial pumping devices (artificial heart) as an answer for the current issue. Artificial hearts are otherwise called total artificial heart (TAH) that is VAD.

Another purpose behind the necessity of MCSs and TAHs is money related, which relates the expense of consideration for patients enduring cardiovascular sickness. Coronary illness is one of the top reasons for hospitalization that require longer time of remain at medical clinics, just as it expands the significant segment of the general spending on wellbeing by government. MCSs can be useful in diminishing the quantity of days for hospitalization, diminishing the measure of assets expended alongside the improvement in personal satisfaction for the patients with end state heart failure.

II. OBJECTIVES

A. Design an axial flow pump that can satisfy the hydraulic requirement of VAD.
B. CFD based statistical design of experiment, investigation of the design parameters to determine the response of the pressure rise, flow rate for the range of the rotating speed of VAD impeller
C. Optimization of the design parameters using CFD.

1) *Hydraulic Requirements*
a) The pump should able to generate 60 to 120mm Hg pressure rise.
b) A volume flow rate of 6-12L/min
c) Speed range: 5000 -10000rpm

III. METHODOLOGY

Design method adopted for the purpose of this thesis is computational fluid dynamics (CFD).

A. Design of the axial flow pump is derived from satisfying the hydraulic requirement of LVAD that is 6L/min of flow rate at 100mmHg pressure head.
B. Design of Experiment has been carried out to investigate the response of design parameters for the range of rotating speed up to 10,000 RPM.
C. Goal-Driven Optimization using CFD is used to investigate the range of rotating speed that can generate the flow rate and pressure rise.
D. The axial flow pump performance as a continuous flow VAD carried out for the optimized range of speed of rotation.

IV. COMPUTER AIDED DESIGN (CAD) OF AN AXIAL FLOW PUMP

Computer aided design (CAD) is helpful in visualising derived geometry using classical theory. For the purpose of this thesis and study, commercially available CAD tool SOLID GEOMETRY has been used to develop 3D geometry of various components of VAD. Geometry creation for an impeller requires the skill to generate surfaces for complex impeller geometry.

A. *Size Requirements*
1) Hub diameter of impeller: ≤ 18mm.
2) Blade Tip diameter of impeller: ≤20mm.
3) Clearance between the inner wall and blade top: 2-4mm.
4) Number of blades: 4.
5) Blade thickness: 0.5mm.

V. CONVERTING CAD GEOMETRY FOR CFD ANALYSIS

Acquiring a satisfactory design of a pump is an iterative technique. The determined estimations of design parameters need an investigation to help the structure hypothesis and design theory. A test at each phase of the design procedure can be extravagant and time-consuming. Numerical tools like computational fluid dynamics (CFD) can be utilized in the beginning periods of the plan procedure as well as in later phases of optimization. Alongside included advantages of the detail stream representation and objective oriented optimization codes, CFD is an extremely valuable tool for reducing the number of examinations required for the design of a blood pump.

A pump impeller is a solid object that creates the pressure difference over the pump by rotating within the fluid region. For the study of the flow behaviour over the impeller, this fluid region should be created using the solid work geometry of an impeller. With the end goal of this thesis and study commercially available —ANSYS software has been utilized. Ansys platform supports the smooth flow of data amongst various meshing and numerical tools.

VI. CFD ANALYSIS OF AXIAL FLOW PUMP

The design of axial flow VAD is an iterative methodology that requires investigating different impeller geometries and shapes; in addition, it includes the confirmation of those shapes for their reasonableness to be utilized as a VAD. CFD simulations results displayed with the end goal of this proposal and in this section are restricted to the specific structure that was chosen for in vitro trial assessment of VAD. This section gives simulations result of a VAD working as a flow pump that incorporates the results of CFD based parametric investigation. This was done to analyse the effect of working speed on the characteristic structure parameters. The performance of the pump as a continuous flow pump is computed using the result of optimization. The results of the steady-state CFD simulations for pressure are discussed to picture the inward flow details.

The CFD based Design of experiment study has been carried out to investigate the response of the dependent parameters mainly Pressure rise, the mass flow rate for the range of the independent parameter that is a rotating speed of VAD. The design matrix is generated for the range of VAD rotating speed-varying from 5000 to 10,000 RPM, pressure rise of 5mmHg to 120mmHg, and flow rate varying from 3L/min - 9L/min.

A. Blood Properties

At the large scale, there exist various models with various degrees of precision in catching the rheological behaviour of blood. In CFD investigation of stream amounts inside VADs blood is generally considered as a Newtonian liquid, although it is known to show non-Newtonian properties.

Since blood is not pure Newtonian fluid, if we use the non-Newtonian fluid to simulation, can make the simulation procedure to be very complicated. But, in some cut strain, blood can be viewed as Newton fluid; numerous local and outside researchers likewise treat it like this. Blood viscosity is normally 3 ~ 4 (10-3) Pa . s, here take 0.0035 Pa . s. Normal adult heart blood flow rate 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. Pressure-outlet as an exit boundary condition and set exit pressure as 100mmHg (13332Pa). Pick the steady-state condition, using $\varepsilon-k$, which is a standard turbulence model, use solid wall without slipping as wall condition. Choosing Power Law-Three Coefficient method Blood viscosity = 0.0035, Temperature reference = 273.16 K, n = 0.6, Blood Conductivity - 0.52 W/m. K, Blood Specific Heat - 3617 J/kg.K.
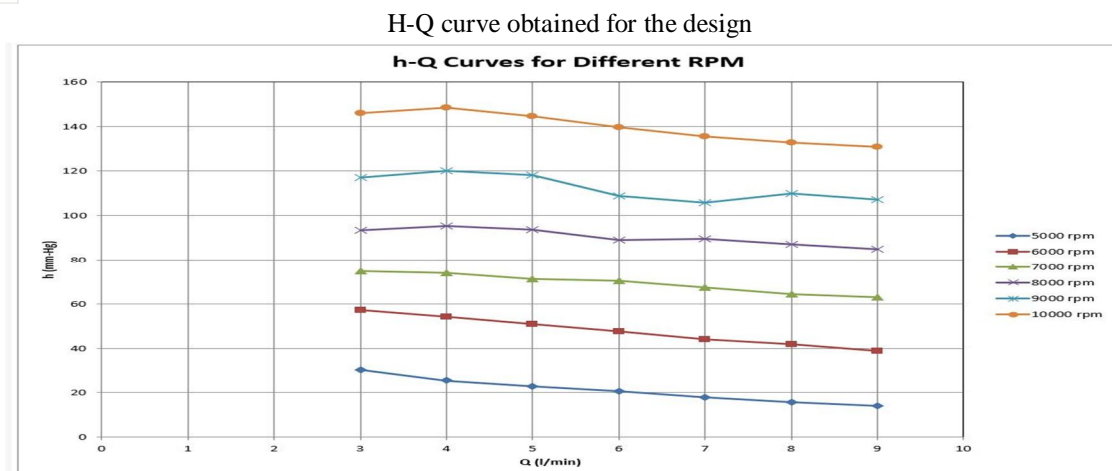
Pressure contour of optimized design

H-Q curve obtained for the design
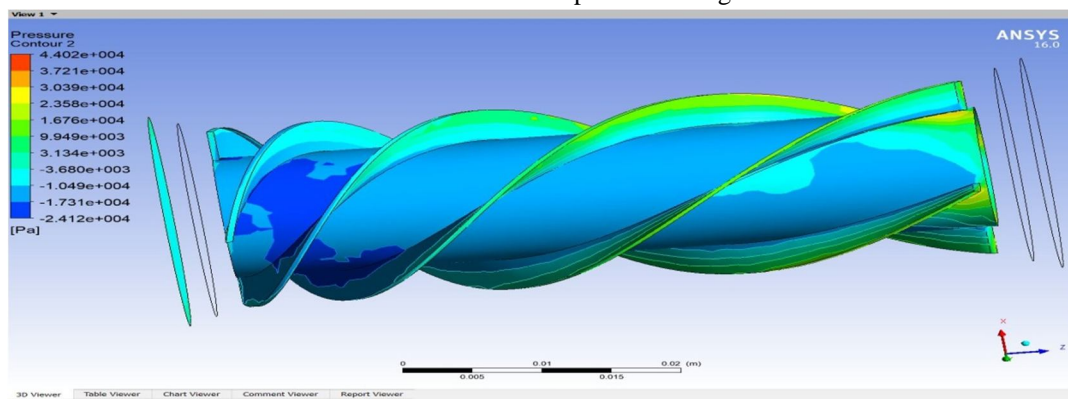
Fig: H-Q curves for optimized design

B. *Optimized Values*

Name	Parameter
Number of blades	4
Chord Length	54.97mm
Import Angle	12°
Export Angle	75°
Airfoil Placed Angle	38°
Hub Diameter	14.8mm
Outer Diameter of Blades	18.5mm

VII.   CONCLUSION

This postulation shows the plan and advancement of a 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 fulfil 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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