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Review on Modification in Geometry of Regenerative Pump

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Abstract* – Regenerative pump is one of the rotodynamic turbomachine produces high head at low flow rates. In this paper, comprehensive review is carried out to study the effect of various geometrical modification of the pump on the performance of pump. Effect of different parts and its geometrical modifications are studied. These are number of vanes, outlet and inlet angle of curved vanes, Offset angle between both sides of impeller vanes, semi-circular vane profile, straight vanes with different inclination angles, Chevron angle, aerofoil shaped vanes, impeller diameter, Variations of shape and size of channel casing. Variations of the stripper angle and stripper gap, introduction of splitter in the outlet pipe. Also the effect of these modifications on the flow visualization is studied. This review helps to design guiding and further modification in geometry of pump for performance enhancement.

***Keywords*— Kinetic Pump, Helical Corkscrew Flow Pattern, High Head, Low Flow Rates.**

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1. INTRODUCTION

Pumps are one of the largest user of electricity in industry, agriculture as well as daily water usage applications and out of those pumps, centrifugal pumps usage is nearly 73 %. The RFP is kinetic pump like centrifugal pump; however, it can offer a more effective alternative in many applications. The main characteristic of RFP is to produce high head at low flowrate and also they have self-priming characteristics. The specific speed of regenerative pumps is very low and they share some characteristics of positive displacement pumps without any problems of wear and lubrication, therefore RFP has found many applications in industry and day to day water usage in place of positive displacement machines. They are simple and easy to machine and they have no need of scrolls and diffusers.

The regenerative pump consists an impeller with 30 to 50 radial vanes at each side of its periphery. These vanes rotate in the nearly 330° annular channel. The fluid enters the channel through the inlet port and recirculates through the impeller vanes due to the centrifugal force action on fluid. The name RFP best describes the repeated fluid circulation during the flow process through the vanes. The water pressure increases continuously as it passes from inlet port to outlet port because water moves helically in the casing chamber and re-enters in the impeller vane passage many times in its peripheral path as shown in fig. 1. Each passage between impeller vanes may be act as a conventional stage of pressurization. These repetitive treatments of pressurization causes regenerative pumps with single impeller have ability to generate a head identical to that of certain centrifugal stages with equal tip speeds. The cavitation in these pumps are very less, because of its smaller pressure gradient, therefore, regenerative pumps require lower NPSH than centrifugal pumps.

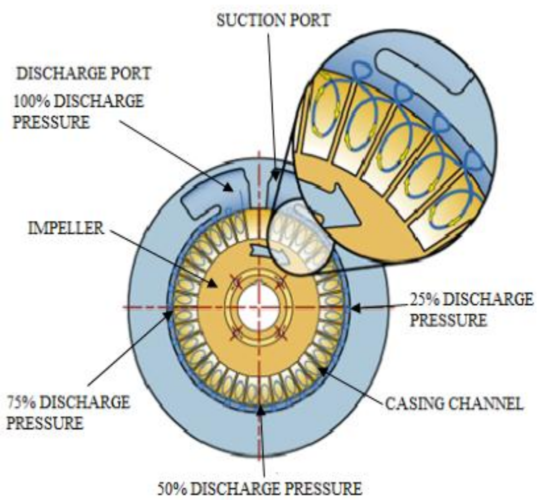

Fig.1: Regenerative pump helical flow path

CFD tool ANSYS Fluent Used to study the effect of geometry modifications like curvature in the outlet flow domain, offsetting impeller blades on either side of impeller, semicircular static fluid on the side of impeller and different number of blade on each side of impeller on regenerative pump performance [1]. Used CFD software ANSYS Fluent in order to investigate the effect of inlet and outlet angle of curved blade on the performance of a pump [2]. CFD software ANSYS Fluent used to analyse outcome of geometrical modification on pump performance. These modifications are radial inlet and exit chamber with constant width, splitter vanes used near the outlet flow domain and varying number of impeller blades [3]. Numerical and analytical technique Compares for finding the performance for a new RFP design. The performance characteristics figure out using CFD software ANSYS Fluent and a new one-dimensional model is validated to experimental results [5]. The numerical simulations using commercial CFD software ANSYS Fluent carried out to improve the head of the regenerative pump. Many alternatives were made in the geometry of pump these are providing additional splitter in the outlet passage, increasing number of vanes and inclining the straight radial vanes [6].

Reviewed the status of the RFP and proposed a design guideline, with the aim to improve the performance and efficiency of the RFP. All previous work focused on the fully developed flow region in the regenerative pump and this work expanded the attention to the developing region [7]. An improved and modified theoretical model proposed that can explain the change in the circulatory velocity caused by variation in channel area. This work extend to the developing region. Furthermore, in order to make the suggested model, several loss models were assumed and the results of predictions were compared with experimental and CFD data [8]. An experimental study carried out to investigate the effect of Straight blades with inclined blade angles and chevron angles on head and efficiency of pump. Detailed numerical investigation of airfoil blading regenerative compressor carried out for optimizing performance [14].

After the extensive literature revealed, it is need to study effect of different geometrical modification suggested by different researchers. And is reviewed in order to study its effect on performance enhancement of regenerative pump. The main purpose of CFD analysis is to visualize the complex flow field in regenerative pump like Flow field of liquid at both side of impeller and flow of liquid from inlet port to outlet port.

2. NUMERICAL MODDELLING

Numerical simulation of regenerative pump (0.5 HP, 36 blades on each side of impeller, stripper at outlet chamber) is carried out by using CFD software ANSYS CFX. In this study, multiple reference frame (MRF) modelling approach is used. MRF modelling is also referred as “frozen rotor” technique. The inner region near to the impeller is rotating reference frame and channel region with inlet and outlet region is treated as a stationary reference frame. ANSYS Workbench software is used for grid generation. From the grid independence test it is understood that grid independent solution obtain at 1.8 million nodes. SST model is used for analysis.

The main purpose of CFD analysis is to visualize the complex flow field in regenerative pump like Flow field of liquid at both side of impeller shown in fig.2 and flow of liquid from inlet port to outlet port shown in fig.3.

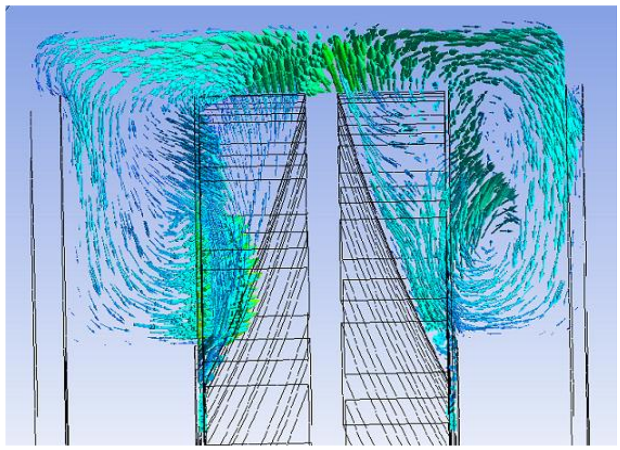

Fig.2: Flow field of liquid at both side of impeller

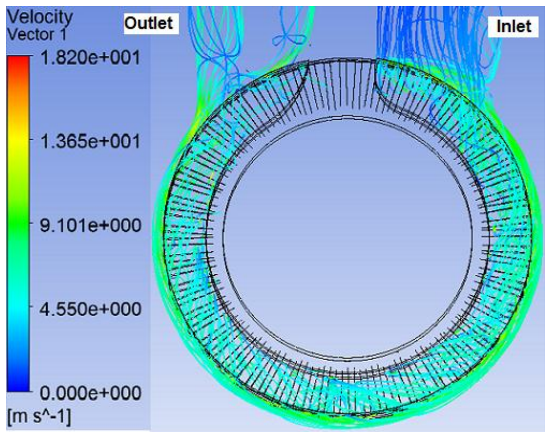

Fig.3: flow of liquid from inlet port to outlet port

3. RESULTS AND DISCUSSION

This comprehensive study is carried out to study the effect of various geometrical modifications on the regenerative pump performance. By reviewing the extensive literature the effect of modification in impeller, channel casing and inlet and outlet chamber on the performance of regenerative pump like head generated by pump, efficiency, power input to pump and other parameter are studied. These are as follows;

A. Impeller Geometry

From the extensive literature review, it is understood that impeller blades angle and geometry have major contribution in the pump performance. In this paper different impeller Geometry modifications are studied. These are number of impeller blades, symmetric and nonsymmetric curved blades with different inlet and outlet angle, offset angle between both sides of impeller blades, semi-circular profile blades, radial straight blades with forward and backward inclination angle, radial chevron blades, aerofoil blades and impeller diameter. An effect of these modifications on pump performance is as follows;

i. Number of impeller blades

CFD study carried out by [3] and [6] to investigate effect of the number of impeller blades on performance of pump. It is found that the number of blades have effect on head generation by pump. As the number of blades increases, the static and total pressure increases because of losses due to slip are decreases and increase in number of pressure compounding stages of the impeller. Maximum number of impeller vane have limit. As vanes increase above particular number the friction losses increases and could affect adversely on the fluid circulation between the impeller vanes. However, the ideal number of vanes will depend on different designs. From [11] and [12] the size of the side channel and diameter of the impeller decides the optimal number of impeller vanes and spacing between them. By keeping constant side channel area and increasing impeller diameter, the ideal number of blades will Increase relative to the diameter.

Different number of blades on either side of the impeller (35 & 36), causes increase total pressure and static pressure by 4.40% and 3.40% respectively by comparing with original pump model (36 vanes on each of impeller) [1] .

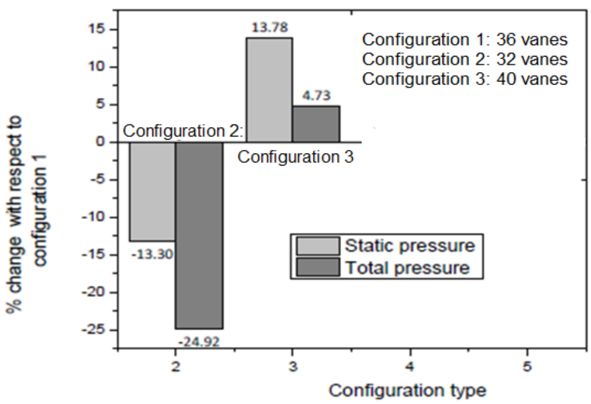

Fig.4: effect of the number of impeller vanes on static and total pressure [3]

ii. Curved blade with different inlet and outlet angle

a. Symmetric blade angle [2]

Pump with Backward Symmetric blades have lower head performance than those of pump with radial blades, as shown in figure 6. For forward symmetric blades, head coefficient increases as angle increases up to $+30^0$ and above that it decreases. Forward symmetric blades pump have high efficiency relative to radial blades pump due to improve in energy transfer between the impeller and the fluid by increase the fluid circulation [13]. From among all tested blade, 10^0 symmetric angle forward blade have maximum efficiency, which is about 2.2% higher than that of radial blades, shown in figure 7.

b. Nonsymmetric blade angles [2]

For both backward and forward nonsymmetric blades pump have lower head and efficiency performance than radial blades pump. At angles of $\pm 10^0$, there are not any significant changes in efficiency curves relative to that of radial blades as shown in figure 7.

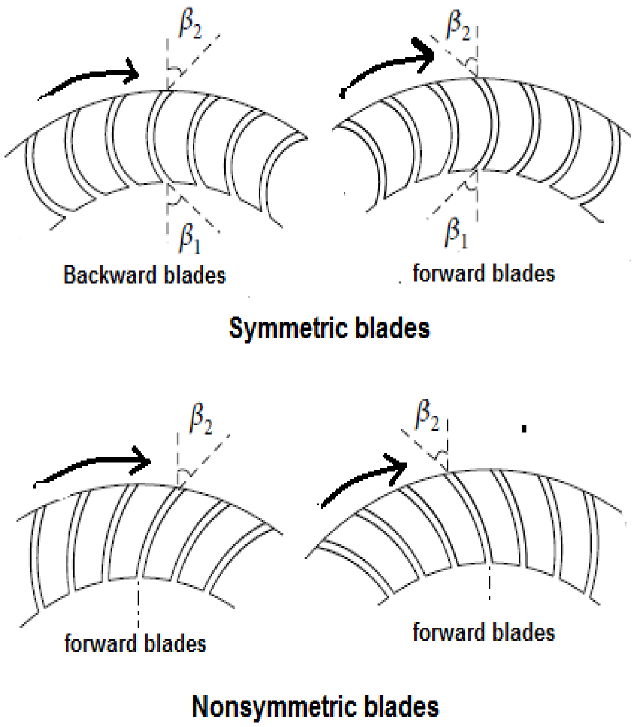

Fig.5: Curved blade with different inlet and outlet angle

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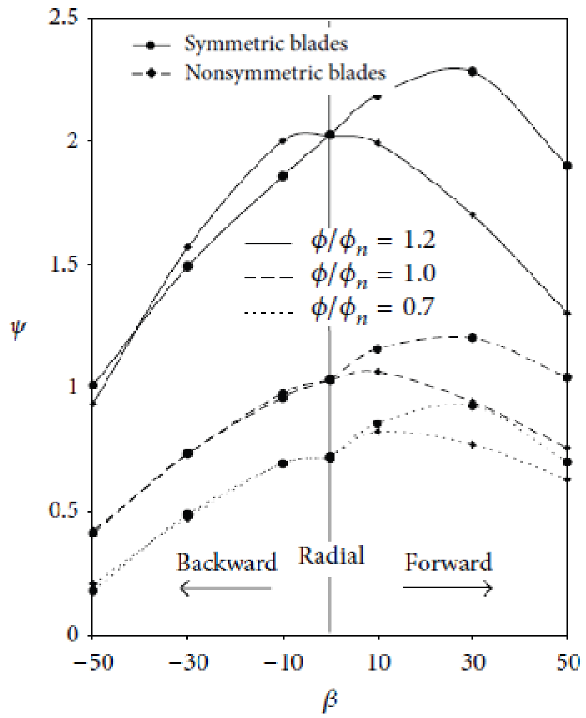

Fig.6: Comparison of head coefficients between impellers has different blade angles at different flow coefficient [2]

Where,

Ψ - Head coefficient

Φ/φn - Flow coefficient

β_1 - Blade angle

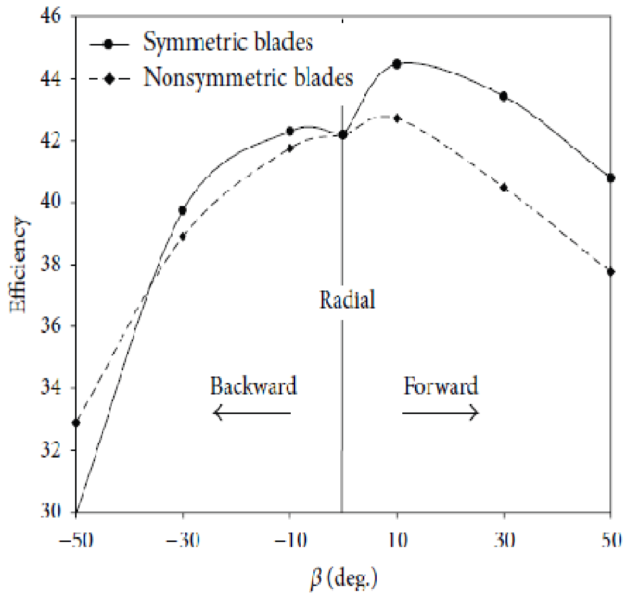

Fig.7: Comparison of efficiency between impellers with different blade angles at design flow coefficient. [2]

iii. Offset angle between both sides of impeller vanes.

Pump with offset angle between both sides of impeller vanes (shown in figure 8) have better performance than ordinary pump (without offset) shown in figure 9. [1] Carried out CFD study for 36 impeller vanes pump with both sides vanes offseted by 2°, results found that total and static pressure increases by 3.82% and 3.08% respectively than ordinary pump (without offset).

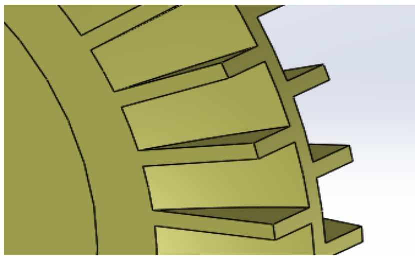

Fig.8: Vanes with offset angle

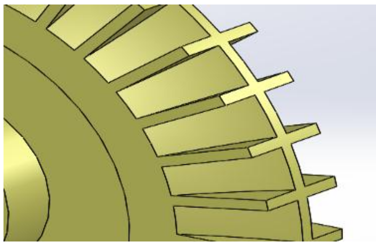

Fig.9: Vanes without offset angle (offset angle 0°)

iv. Semi-circular profile blades

The static fluid on the sides of the impeller made semi-circular by using semi-circular profile blades which helps to increase the circulation of fluid [1]. Pump with semi-circular profile blades have high static pressure, total pressure and efficiency relative to radial blade pump.

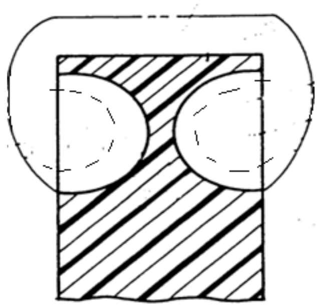

Fig.10: semi-circular profile blades

v. Straight blades with inclined blade angles

From the experimental study of [10], it is found that as an inclined blade angle of forward and backward blades increases, the head generated by pump and efficiency decreases. From Figure 13 it is understand that pump with radial blade impeller has better head performance than pump with forward and backward inclined blades impeller.

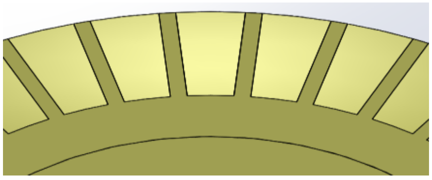

Fig.11: Radial blade

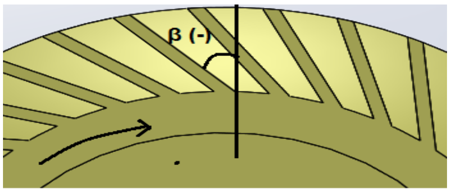

Fig.12: forward inclined blade

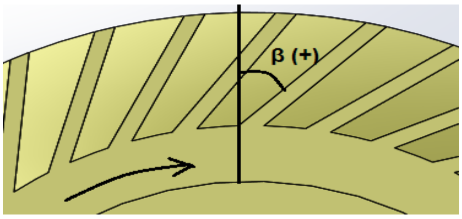

Fig.12: Backward inclined blade

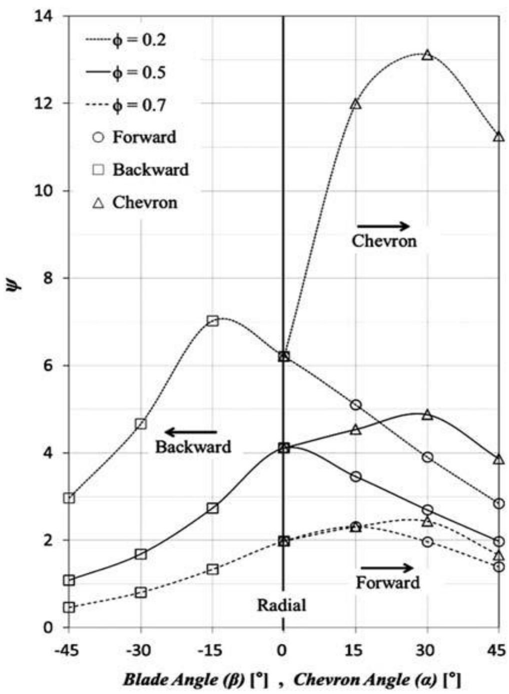

Fig.13: Comparison of head coefficients between impeller types at different Flow coefficient (φ [10]

vi. Radial chevron angles of impeller blade

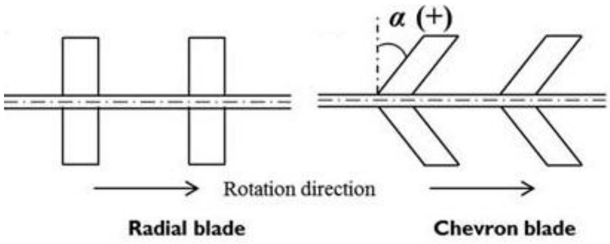

Fig.14: Schematic of radial and chevron blades [10].

From the experimental study of [10] it is found that as radial chevron impeller pump have high head and efficiency than radial impeller pump at every flowrate, shown in figure 13. This is due to the reduction in incident loss at the blade inlet and subsequently higher circulation. An optimum chevron angle is obtained from results is around 30^0.

vii. Aerofoil blades

Aerofoil blades help to enhance the pump performance like head and efficiency. These blade have most favourable result in the regenerative flow compressors. Aerofoil blade profiles are fitted with a core around periphery to guide the flow which helps to reduce the vortices formed at tips of the blades. Symmetrical blade profile has a higher efficiency than other profiles of blade [13, 14].

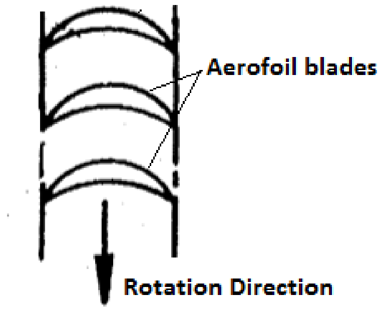

Fig.15: Aerofoil blade profile

viii. Impeller Diameter

Misalignment of the fluid and blade angles cause increase in slip and shocks, hence increases losses in flow field. Losses could be minimised by reducing the radius of impeller hub and increasing radius of impeller tip [16].

B. Channel Casing Geometry

Channel casing geometry modifications are splitter vane across the exit chamber, stripper angle and stripper gap, axial and radial clearance. An effect of these modifications on pump performance are as follows;

i. Splitter vanes across the exit chamber

Pump without splitter vane across the exit chamber have large recirculation zone shown in figure 16. This recirculation leading to a rotating stall causes loss of pressure. Recirculating zone decreases by introducing the splitter vanes at the exit chamber, shown in figure 17, causes increase in static and total pressure rise of pump [3].

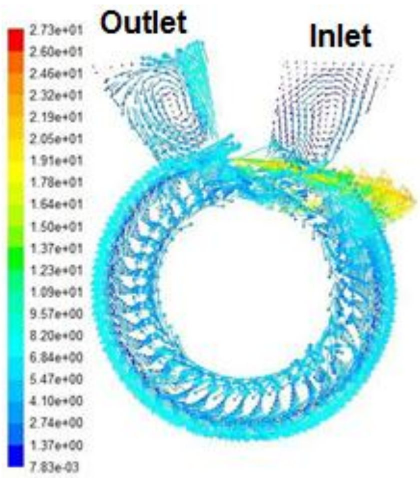

Fig.16: Velocity vector plot without splitter vane at exit chamber [3]

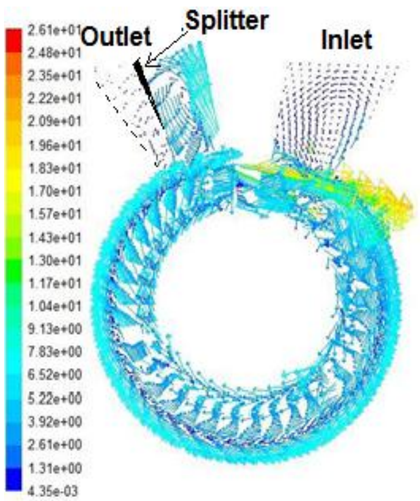

Fig.17: Velocity vector plot with splitter vane at exit chamber [3]

ii. Stripper angle and stripper gap

Stripper is situated between the suction and discharge ports and helps in isolate the high pressure discharge side from low pressure suction side. Limited literature available on the effect of stripper angle and gap between stripper and impeller. Small stripper angle causes increase the channel area that is pressurisation area. Striper gap is the gap between stripper and impeller. It have significant effect on the pump performance, as it increases the leakage from discharge side to suction side increases [18].

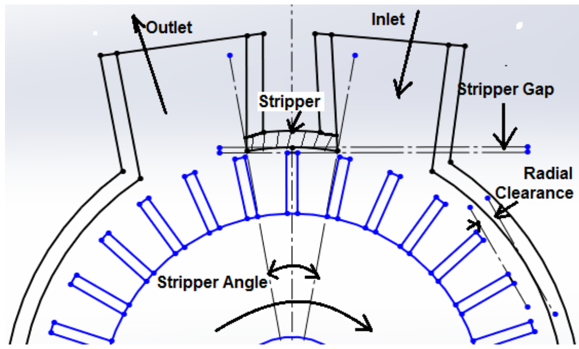

Fig.18: Stripper angle, stripper gap, radial clearance

iii. Axial and radial clearance

Axial clearance plays important role in head performance of pump. It isolate high pressure channel fluid from the low pressure central passage fluid and suction side fluid. Research has shown that a decrease in axial clearances will provide an increase in efficiency, due to reduction in backflow from the high-pressure discharge side to the low-pressure suction side and central passage [15]. Through comparison of theoretical and experimental results of different axial clearance values (0.01-0.08 mm) found that a higher head and better efficiency obtain at 0.01 mm axial clearance [17]. Radial clearance have less effect on performance of pump. The radial clearance has an effect on losses due to shock, these were minimised by increasing the radial clearance [16].

C. Suction & Discharge chamber

From the CFD study it is observed that Radial inflow of fluid causes large losses occur at inlet [1], [3]. This losses can be minimise by guiding the fluid flow that it enters and leaves the pump in an axial direction because of smooth entry of fluid at the inlet. It also reduce the axial thrust Quail et al [6]. Shape and size of inlet and outlet chamber have greater impact on the pump performance. The outlet chamber is designed taper to convert velocity energy in to pressure energy. To avoid vortex losses at exit chamber, splitter introduced across the exit chamber, it minimizes the recirculating flow hence performance of pump increases [3]. A slight curvature in the outlet flow domain minimizes rotating stall at outlet and helps to improve in static and total pressure [1].

4. CONCLUSION

From the extensive literature review of the effect of various geometrical modifications on performance of regenerative pump, it is concluded that.

- As number of blades increases, the static and total pressure of pump increases. When blades increases above particular number, the friction losses increases and could affect adversely on the fluid circulation between the impeller vanes.
- Forward Symmetric curved blades have better performance than backward symmetric blades and radial blades.
- Nonsymmetric curved blades with forward and backward blade angle have lower performance relative to radial blades
- Providing offset angle between both sides of impeller blades results increase in static and total pressure of pump.
- A semi-circular profile blade helps to increase circulation of fluid, results enhancement in static pressure, total pressure and efficiency relative to radial blades.
- Radial Straight blade with forward and backward inclination angle have lower performance relative to radial blade.
- Radial chevron blades have better performance than radial blade.
- Aerofoil profile blades help to enhance performance of pump like head and efficiency.
- Slip and shock losses could be minimised by reducing the radius of impeller hub and increasing radius of impeller tip.
- Splitter vane across the exit chamber reduces recirculation of flow at outlet hence improvement in the pump performance.
- Increase in stripper angle results decrease in flow channel area that is pressurization area. Leakage loss and pressure loss increases with increase in stripper gap.
- Decrease in axial clearance will provide an increase in efficiency, due to reduction in backflow from the high-pressure discharge to the low-pressure suction and central passage. A higher head and better efficiency obtain at 0.01 mm axial clearance
- Smooth entry of fluid at inlet improves pump performance by avoiding vortex flow. Axial inflow and outflow helps to reduce circulation losses at inlet and outlet. Small curvature to outlet chamber minimizes rotating stall at outlet and helps to improve in static and total pressure.

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