Optimization of Laboratory Centrifuge Rotor Using Simulation Tools to Improve Performance and Productivity

[1]Himanshu J Gajjar, [2]Nikunj Modh, [3]Killol Kothari
[1]PG Scholar, [2]Asst. Professor, [3]Asst. Professor
[1]Mechanical Engineering,
[1]Venus International College of Technology, Gandhinagar, Inida

---

***Abstract* - Laboratory Centrifuge rotors are designed for high service life duty and should stand against two times the maximum operation speed in terms of the manufacture's standard. High speed micro centrifuge spins the rotor at 15000rpm which generates the high centripetal force on rotor which leads to the high stress accumulation and failure of the rotors. Design of rotor and size is prepared in SolidWorks for given High Speed Micro Centrifuge with existing power capacity with Brushless DC Motor. Design Optimization of the rotor mainly structural and weight optimization is carried out with the help of FEM using ANSYS which helps to improve the performance and productivity. Most optimum design of the rotor with higher load capacity is selected on the basis of mass, stress induced and deflection of rotor to improve the performance and productivity. Validation process of the performance and productivity improvement in the rotor carry out by comparing the experimental results of existing rotor and the optimized rotor.**

Keywords— Optimization, Finite Element Analysis, Centrifuge Rotor Failure, Stress Analysis

---

I. Introduction

A Laboratory centrifuge is a device that is used for the separation of fluids, gas or liquid, based on density. Separation is achieved by spinning a vessel (rotor) containing material at high speed; the centrifugal force pushes heavier materials to the outside of the vessel. This apparatus is found in most laboratories from academic to clinical to research and used to purify cells, subcellular organelles, viruses, proteins, and nucleic acids. There are multiple types of centrifuge, which can be classified by intended use or by rotor design. From the large floor variety to the micro-centrifuge, there are many varieties available for the researcher [7].
Centrifugation is an indispensable separation and concentration tool for many areas of research. High-speed centrifugation (approximately 15,000 to 40,000 RPMs, or 14,000 to 100,000 x g, or higher) is especially valuable in the biosciences for applications such as concentrating cells in suspension, isolating and separating cell membranes from cytosolic contents and purifying and isolating genetic material.
A laboratory centrifuge is used to spin fluid samples at high speeds. The resultant centrifugal effect causes particles suspended in the fluid to migrate to the bottom of the tube as a precipitate (the pellet). The remaining fluid is termed the supernatant. Centrifuges come in different sizes, with different maximum speed and different uses.
In the present paper, carry out design of existing rotor in SolidWorks and analysis of the same was carried out with the help of ANSYS. The results of this rotor to be helpful in comparisons with the results of the modified design of rotor. Optimize the design of existing rotor by changing structural modification to reduce the weight as well as improve the strength further. Finite Element Analysis technique was used for complex geometry of rotor to calculate the detailed stress generation and distribution on the rotor under high kinetic energy due to high centrifugal loading. Check integrated strength of the optimized rotor for enduring higher stress at two times the maximum operating speed like 15000 rpm in the existing case study.
Material of the existing 12 place Rotor of M12P Centrifuge is also Al Alloy 6082 and never received any complain of degradation of rotor material from their customers. For Optimization of this rotor, same material to be considered for Analysis.

II. LITERATURE REVIEW

During the Literature Survey, an overview of important of laboratory centrifuge rotor design and other parameter selection is presented. It is mainly focused on studying the different parameters of laboratory centrifuge rotor to improve the strength of the rotor and safety of the product.
From the literature review, it is noted that the rupture of rotor was due to insufficient integrated strength of the rotor as maximum centrifugal stress exceeds the ultimate strength of the material. Material of the rotor was as per specified grade high strength aluminium alloy and there was no degradation of material [5].
Ultra-centrifuge that runs the rotor more than 50000 rpm has complete vacuum in the chamber to minimize or eliminate the effect of air resistance and use composite material to reduce the weight of the rotor. That will affect the final price of the rotor [6].
Therefore, mechanical stress analysis using finite element method to be carried out for failure analysis by applying centrifugal force of the two times of the maximum operating speed and structural optimization to improve the performance.

III. METHODOLOGY

Study the design and performance analysis of the existing rotor. The 3D CAD model of existing rotor's has been made in SolidWorks and carried out the FEA on the same through ANSYS to understand the performance of the rotor under the 30000 rpm which is two times the maximum operating speed.

From the analysis of the existing rotor, structural and wight optimization were carried out in the existing rotor after identifying the parameters from where materials needs to be removed or added to the rotor to get the optimized strength; And made number of iterations in CAD and performed FEA on the same.

The most feasible optimized design of the rotor and it's results discuss in this paper.

Material of rotor consider for this study is Al Alloy 6082 (HE 30). And other parameters of the existing rotor is shown in Table 1.

Table – 1
Design Parameters of Existing 12 place Rotor

Input Parameters (Fixed)	
Maximum Rotor Speed	15000 rpm
Maximum RCF	15596 g
Tube Mounting Angle	45°
Power Supply	24 VDC 6A
Rotor Material	HE 30 (Al Alloy 6082 T6)
Input Parameters (Variable)	
Rotor Weight	0.499 kg
Geometry of the Rotor	
Output Parameters:	
Peak Current	7.5 Amp
Rated Current	2.6 Amp
Acceleration Time	38 ±2 Seconds
Deceleration Time	40 ±2 Seconds

Von-Mises Stress Distribution in the existing rotor shown in Figure 1. FEA shows that the peak value of stress obtained is 297.8MPa. which is less than the ultimate strength 340MPa of the rotor material Al Alloy 6082. From that we can conclude that there is possibility to reduce the weight and optimized the rotor further without considering the more reduction in strength of the rotor.

IV. MODIFICATIONS

Iteration: 1

In Iteration 1, the thickness t near tube assembly holes and web thickness T have been reduced as shown in Fig 4.5 from the study of stress generation and distribution in the the existing rotor's Finite Element Analysis report done with the help of ANSYS. Also the excess material between the tube holding holes has been removed by holes diameter 9 mm as shown in Figure 1. By doing this exercise, the weight of the rotor has been reduced by 25%. Now the rotor weight is 0.375 kg with this modifications.

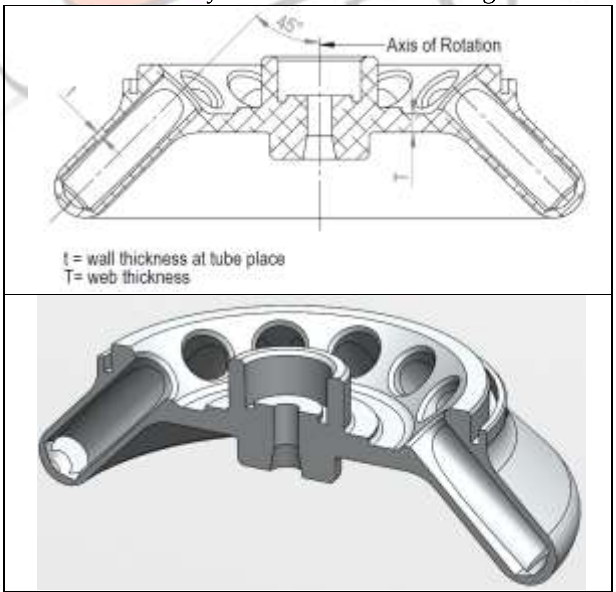

Figure 1: Fixed Angle – Optimized Rotor with Iteration 1 (12 Tubes)

Iteration: 2

In Iteration 2, the thickness t near tube assembly holes and web thickness T have been reduced as shown in Figure 2. Also the excess material between the tube holding holes has been removed revolve cut depth of 12 mm and extra holes of diameter 8mm shown in Figure 3. By doing this exercise, the weight of the rotor has been reduced by 31.4%. Now the rotor weight is 0.343 kg with this modifications.

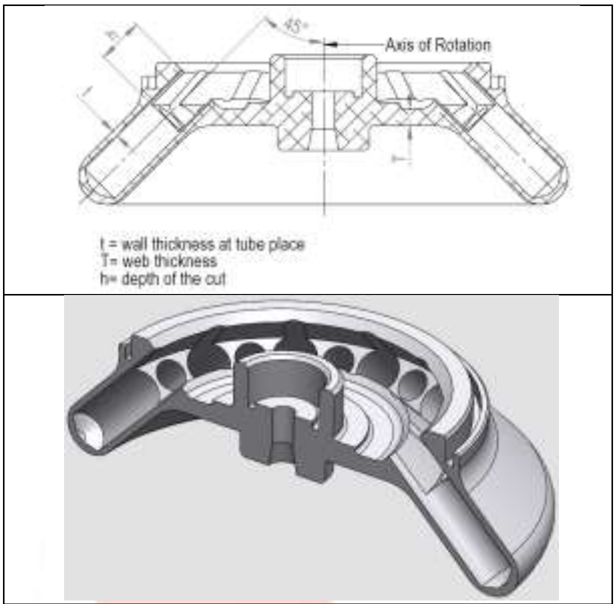

Figure 2: Fixed Angle – Optimized Rotor with Iteration 2 (12 Tubes)

V. FINITE ELEMENT ANALYSIS OF ROTORS

Figures shown below shows the FEA of existing as well as both the iterations of the rotor. Analysis was carried out for identical centrifugal loading condition at 30000 rpm with the same material Al Alloy 6082.

There are major two factors considered during this design modifications, first being the maximum stress encountered in the component and other being the zone affected by this maximum stress as well as the less stress effected zone from where the material can be removed for the weight optimization. The stresses generated in the rotors even out leading to the reasonably uniform stress distribution. Thus the modified geometry results in rotors having lesser weight and at the same time it is able to respond the applied high centrifugal loading condition.

The maximum stress generated because of high centrifugal loading generated due to 30000 rpm is 290.97 MPa, 305.7 Mpa and 335.68 MPa respectively in existing rotor, iteration 1 of rotor and iteration 2 of rotor as shown in Figure 4, 5 and 6 respectively.

The peak value of stress generated in both the iterations are within the ultimate strength of the material Al Alloy 6082. The value of peak stress generated in iteration 1 is nearer to the existing design of the rotor as well as well with in the ultimate tensile strength that's why it has been selected to make the prototype and also more feasible & having less machining process time compared to the iteration 2.

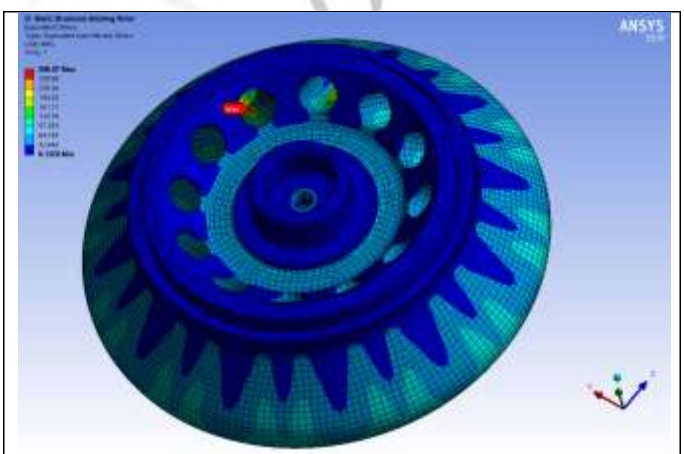

Figure 4: Von-Mises Stress Generation at 30000 rpm in Existing Rotor (NTPL, Ghandinagar)

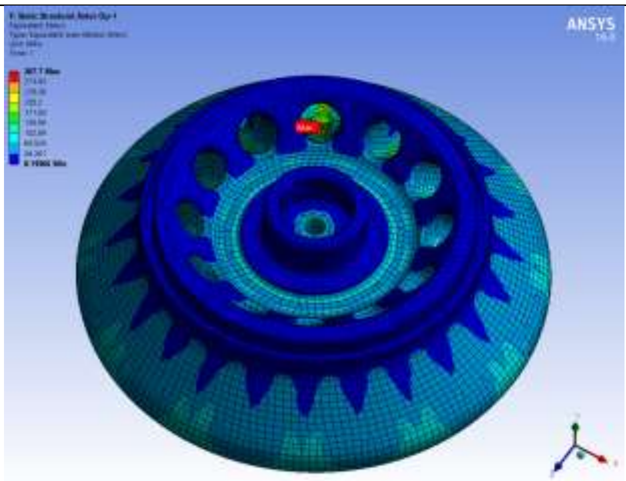

Figure 5: Von-Mises Stress Generation at 30000 rpm in Iteration 1

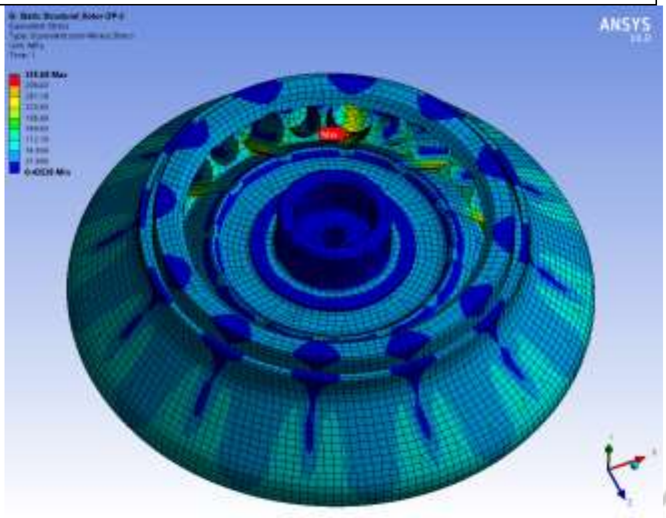

Figure 6: Von-Mises Stress Generation at 30000 rpm in Iteration 2

I. EXPERIMENTAL SETUP

Experimental setup has been made as shown in the below Figure 7 to monitor the real-time value of the peak current generated to reach the maximum speed 15000 rpm of the high speed micro centrifuge. The multimeters placed in between the centrifuge and power supply line to monitor the current and voltage to be drawn by the centrifuge which is carrying the optimized rotor.

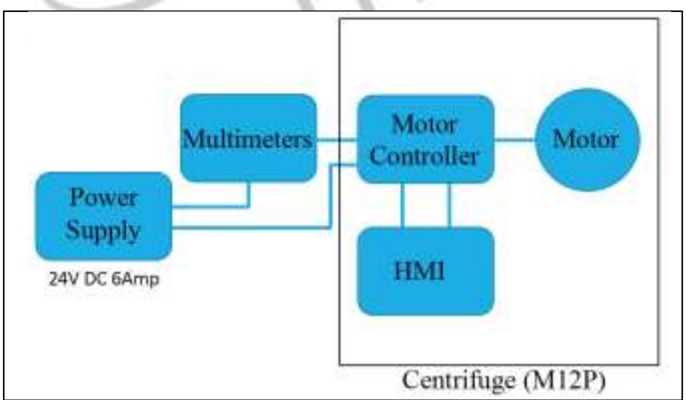

Figure 7: Experimental Setup

VI. RESULTS AND CONCLUSION

Table 2 shows the comparison of the experimental results of existing and optimized rotor.

TABLE - 2
Comparison of Output Parameters

	Existing Rotor	Optimized Rotor (Iteration 1)
Peak Current	7.5 Amp	6.4 Amp
Rated Current	2.6 Amp	2.44 Amp
Acceleration Time	38 Seconds	33 Seconds
Deceleration Time	41 Seconds	39 Seconds

Results shows that the acceleration time required to reach the maximum speed of 15000 rpm is reduced to 33 seconds from 38 Seconds and also Peak Current to reach the maximum speed is also lower down to 6.4Amp from 7.5Amp. The stable rated current drawn at maximum speed is reduced to 2.44Amp from 2.6 Amp.

The experimental results of the optimized rotor shows that the performance of the rotor is increased. The results of Finite Element Analysis shows that the optimized rotors have the almost same strength as the existing rotor and sustains the higher centrifugal loading generated due to the two times of maximum speed.

REFERENCES

[1] S. Rao, Engineering Optimization – Theory and Practice. NY: John Wiley & Sons, Inc., 1996.
[2]. Robert D. Cook, Finite Element Modeling For Stress Analysis NY: John Wiley & Sons, Inc., 1995.
[3]. ANSYS V 16.0 Documentation Manual, Advanced Analysis Techniques Guide Design Optimization-Optimization Techniques
[4]. S-Y. Chen, "Integrating ANSYS with Modern Numerical Optimization Technologies", ANSYS Solutions Magazine, Published in Winter Issue 2001.
[5] Xuan Hai-jun, Song Jian, "Failure analysis and optimization design of a centrifuge rotor", Science Direct, Engineering Failure Analysis Vol. 14 (2007) Pages: 101–109
[6] Hak Gu Lee, Jisang Park, Ji Hoon Kim, "Design theory and optimization method of a hybrid composite rotor for an ultracentrifuge", Science Direct, Mechanism and Machine Theory, Volume 59 (2013), Pages: 78-95
[6] M. Bayat , B.B. Sahari , M. Saleem, Aidy Ali, S.V. Wong, "Bending analysis of a functionally graded rotating disk based on the first order shear deformation theory", Science Direct, Applied Mathematical Modelling Vol. 33 (2009), Pages: 4215–4230
[7] website: www.neuation.com