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Modeling and Analysis of Hydraulic Reaction Turbine Blades by Varying the Guiding Blade Angle

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Abstract - The guiding blades are the heart of any turbine and in the present work; it is proposed to analyze the effectiveness of guiding blades of Francis turbine at different blade angles. The francis turbine was created using Catia V5 and further the model was analysed using Ansys 15.0, to study the equivalent von-mises stress distribution and deformation developed in the model. Further the model was tested by varying the rotational speed ranging from 0 to 600rpm to study the behavior of the model with increase of speed. Also a set of turbine models were created using Catia V5 software by varying the blade angles ranging from 25^0 to 45^0 and thereafter analyzed using Ansys 15.0 software to find the optimum guiding blade angles.

Key words: Francis Turbine, Blade angle, Guiding blade

I. INTRODUCTION

The Francis turbine is an inward-flow reaction turbine that combines radial and axial flow concepts. Francis turbines are the most common water turbine in use today, and can achieve over 95% efficiency.

Francis turbines are primarily used for electrical power production. Francis turbines are usually mounted with a vertical shaft, to isolate water from the generator. This also facilitates installation and maintenance.

II. COMPONENTS

A Francis turbine consists of the following main parts:

Spiral casing: The spiral covering around the runner of the turbine is identified as the volute casing or scroll case. Throughout its length, it has abundant openings at regular intervals to permit the working fluid to impose on the blades of the runner. These openings change the pressure energy of the fluid into kinetic energy just before the fluid impinges on the blades. This maintains a constant velocity regardless of the fact that numerous openings have been provided for the fluid to enter the blades, as the cross-sectional area of this covering decreases uniformly along the circumference.

Guide and stay vanes: The major functions of the guide and stay vanes is to change the pressure energy of the fluid into kinetic energy. It also serves to direct the flow at design angles to the runner blades.

Runner blades: These are the centers where the fluid strikes and the tangential force of the impact causes the shaft of the turbine to rotate, producing torque. Close attention to design of blade angles at inlet and outlet is necessary, as these are major parameters affecting power production.

Draft tube: The draft tube is a medium that connects the runner exit to the tail race where the water is discharged from the turbine. Its major task is to decrease the velocity of discharged water to reduce the loss of kinetic energy at the outlet. This permits the turbine to be set above the tail water without considerable drop of available head.

III. OBJECTIVE

The main objective of current work is to analyze the effect of the blade angle on the structural strength of the francis turbine. The model of the turbine is created using Catia V5, followed by structural analysis using Ansys15.0.

AT first the sketch of profile along length, inlet and outlet of blade is created in Catia V5. Then thickness is provided and there after created multiples of blades using pattern option. Thus finally the turbine model is created as shown in following figure.

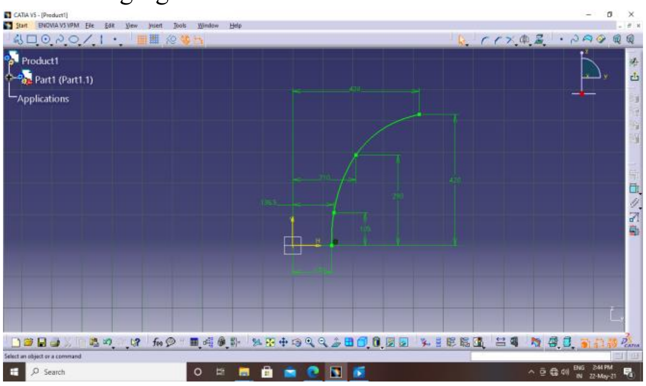

Fig. 3.1: Basic sketch of profile of blade in Catia V5

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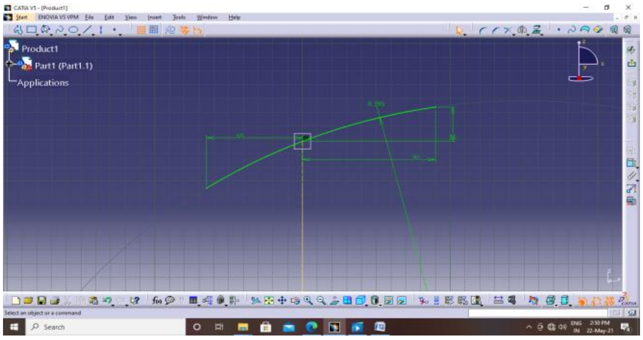

Fig. 3.2: Sketching of outlet end of turbine blade

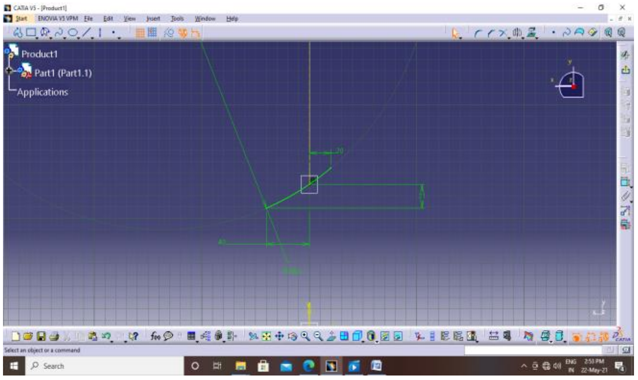

Fig. 3.3: Sketching of inlet end of turbine blade

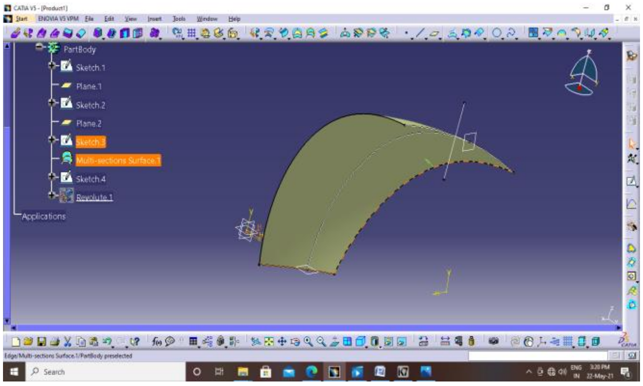

Fig. 3.4: Turbine blade creation in generative shape design

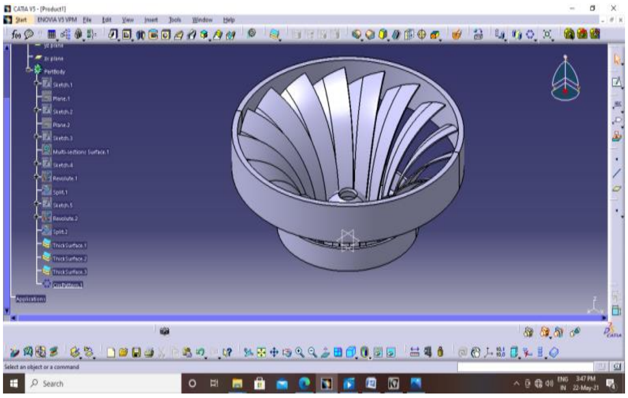

Fig 3.5: The final model created in Catia V5

Similarly remaining models were created by varying the turbine blade angle in the range of 25^0 to 45^0.

IV. ANALYSIS OF FRANCIS TURBINE

4.1 Step by Step Structural Analysis Procedure (Francis Turbine blades with 25^0 angles at stable condition)

Step 1: At first the ansys structural analysis is to be loaded. Then the material required is selected, then the Catia model is to be imported in igs format as shown in fig 4.1

Step 2: The model is divided in finite parts and meshed model is as shown in fig 4.2

Step 3: The fixed constraints are applied as shown in fig 4.3.

Step 4: The torsion moment is applied to the model as shown in fig 4.4.

Step 5: Then to solve the problem using solver option.

The same procedure is applied for all the models and results and discussion over them are presented in the next section.

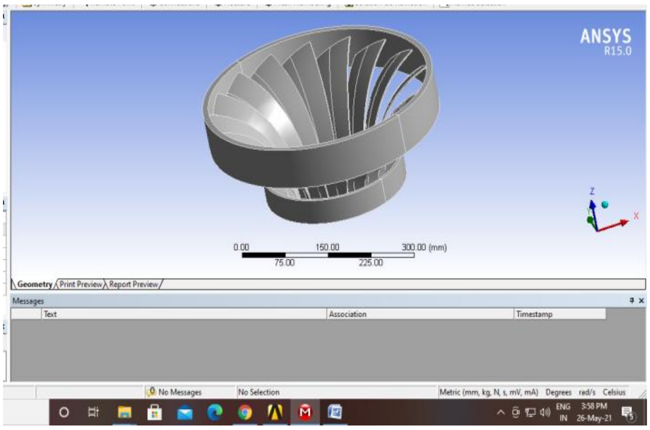

Fig 4.1 The catia model of turbine imported to Ansys 15.

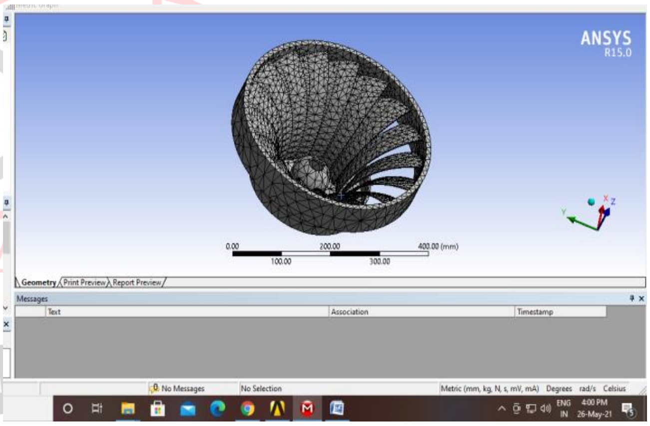

Fig 4.2 Meshed model of francis turbine in Ansys15.0

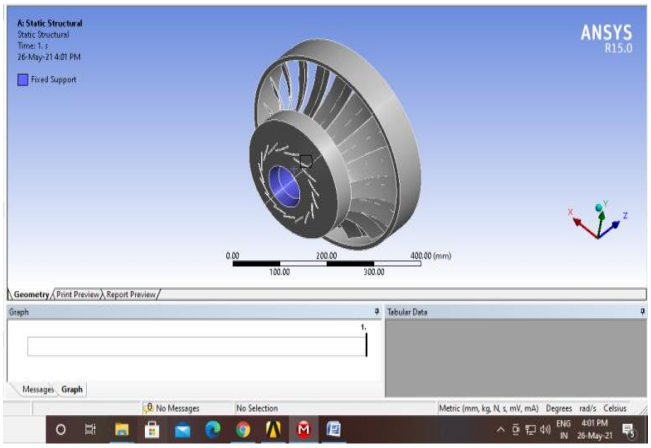

Fig 4.3 Applying fixed constraints in Ansys 15.0

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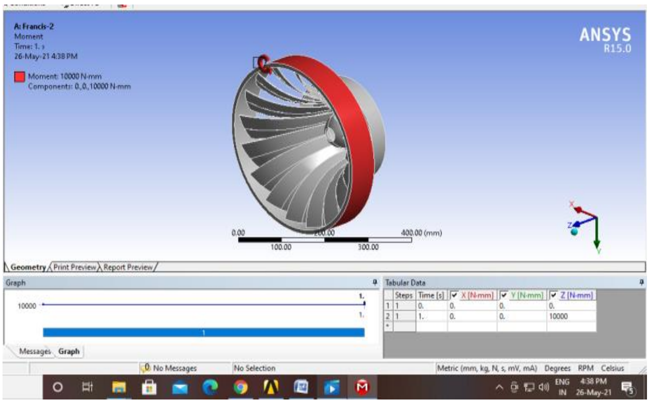

Fig 4.4 Application of torsion load to the model in Ansys 15.0

V. RESULTS AND DISCUSSIONS

5.1 Ansys Results of Francis Turbine blades with 25^0 angles at stable condition (0rpm): Case-I

The fig 5.1 shows the equivalent von-mises stress distribution during analysis using Ansys 15.0 under the application of torsion moment. The results show that the maximum stress develops at the outlet end of the blades, the same as expected due to application of torsion moment near the inlet end being fixed at the outlet end of the blades. This strengthens the usage of this software for analysis the considered problem. The maximum von-mises stress developed is found to be 4.6037MPa. Hence the runner diameter at the outlet plays the key role in withstanding the hydraulic pressure that acts on the turbine blades [4]. Also, the resulting color image also gives interesting information with dark blue color even next to the inlet and outlet end, mentioning very low stress intensity. This may be due to the reason that the inlet and outlet of blades are in two perpendicular planes, thereby leads to torsion, as well as bending throughout the blade length. But, at the same time the width of the blade and blade angle is varying along its length, which thereby all together the effects leads to lower stress intensities next to the inlet as well as outlet.

The fig 5.2 shows the total deformation developed in the francis turbine blades under stable condition during analysis using Ansys 15.0. The resulting color image represents that the deformation decreases from the inlet to outlet of turbine blades with a maximum of 0.018478mm at the inlet end. This clearly mentions that the inlet ends of the blades are to be designed carefully for further strengthening of the blades. Also it is observed that trailing edge of the blade is under higher deformation than that of the leading edge, which is desired to have a positive rate of the flow of fluid. Especially this difference can be observed in the color image with green color in the trailing edge of the blades at the middle of the blade along its length. This indicates that a careful design is to be carried regarding the trailing edge of the turbine blade for further enhancing its performance.

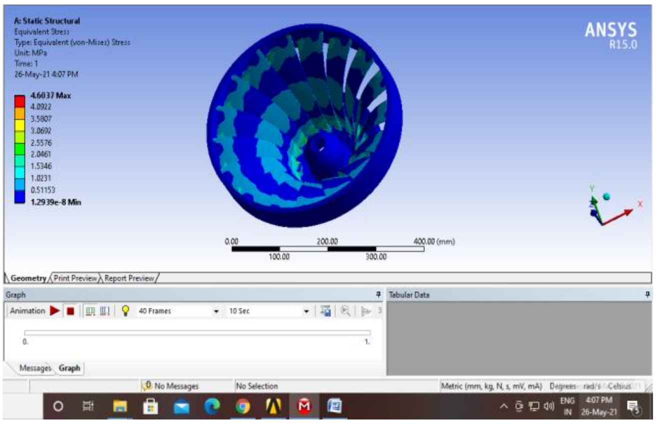

Fig 5.1 Equivalent von-mises stress distribution in Francis turbine blades under stable condition

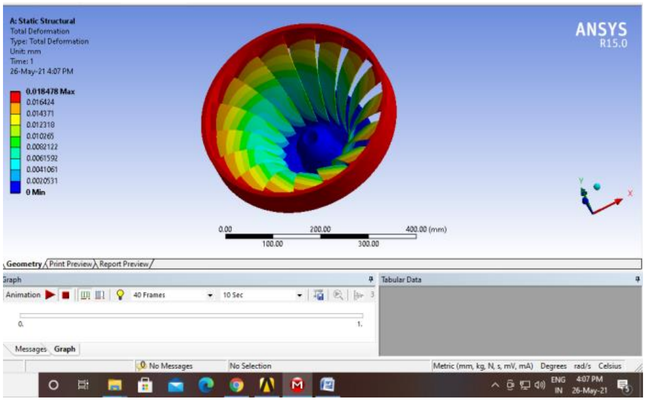

Fig 5.2 Total deformation developed in Francis turbine blades under static condition in Ansys 15.

5.2 Ansys Results of Francis Turbine blades with 25^0 angles at 100rpm: Case-II

The fig 5.3 shows the von-mises stress distribution in the turbine blades with 25^0 vane angle at 100rpm speed.The resulting color image, especially it can be observed with increase of light green color area along the length of the blade, shows very clearly that the intensity of the stress has been increased, compared to the previous results. The dark color zones at two areas along the length of the blade represents the twisting effect of the blade about the those particular zones due to application of torson. This shows that the effect of inlet and out ends of the blades being in two different planes results in variation the stress intensity along the length of the blade[. These resulting picture giving an idea to make changes further the planes of oulet end of the blades to study the variation in stress intensity for optimum design. The stress distribution pattern in this is also same as that of previous case. The maximum von-mises stress developed is found to be 4.9115MPa, which is 6.6% higher than that of case-I. The effect of the speed of the runner shows prominent effect on the intensity of the stress development.

The fig 5.4 shows the deformation developed in the turbine blades at 100rpm. The results reveals that the pattern of the deformation development is similar to the case-I, with decrease of deformation from inlet to the outlet of the turbine blade, but a slight increase in deformation was observed along the trailing edge side of the blade, which

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strengthen the twisting effect on the blades due to hydraulic force at the inlet of the blades. The maximum deformation developed in this case-II is found to be 0.020955mm, which is 13.4% higher than that of the deformation in case-I.

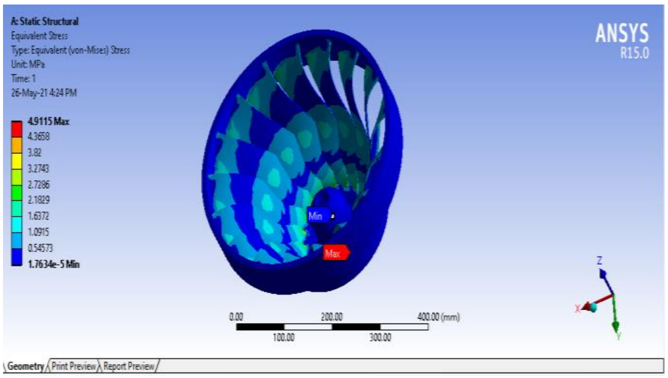

Fig 5.3 Equivalent von-mises stress distribution in Francis turbine blades at 100rpm in Ansys 15.0

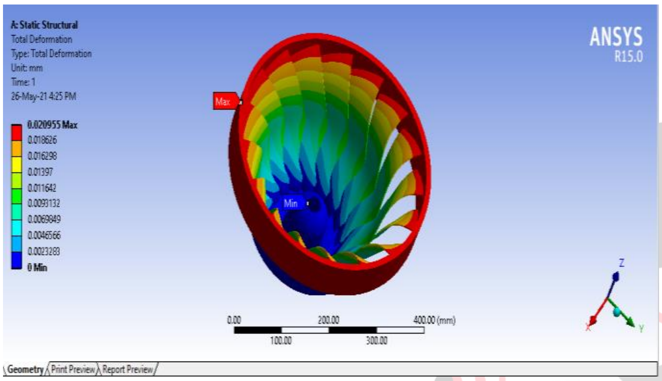

Fig 5.4 Total deformation developed in Francis turbine blades at 100 rpm in Ansys 15.

5.3 Ansys Results of Francis Turbine blades with 25^0 angles at 200rpm: Case-III

The fig 5.5 shows the von-mises stress distribution in the turbine blades at 200rpm using Ansys 15.0. The resulting color image shows that the pattern of distribution os stress is similar to the previous two cases. The maximum stress developed is found to be 5.8462MPa, which is 26.9% higher than that of stress in case-I and 19.01% higher than that of case-II. This shows that variation of speed from 100rpm to 200rpm has more influence over the blades than that of speed variation from 0 to 100rpm. The color represantation in the result image also shows the increase of stress intensity in the middle of blades along its length compares to previous cases, which may be due to action centrifugal force because of apllying the rotational speed.

The fig 5.6 shows the total deformation developed in the turbine blades at 200rpm using Ansys 15.0. The pattern of deformation development in this case-III is similar to the previous two cases. The maximum deformation developed is found to be 0.0291mm, which is 57.5% higher than that of in case-I and 38.86% higher than that of in case-II. Though the speed increment is same from case-I to case-II and from case-II to Case-III, the effect on the blades is highly influences in later case.

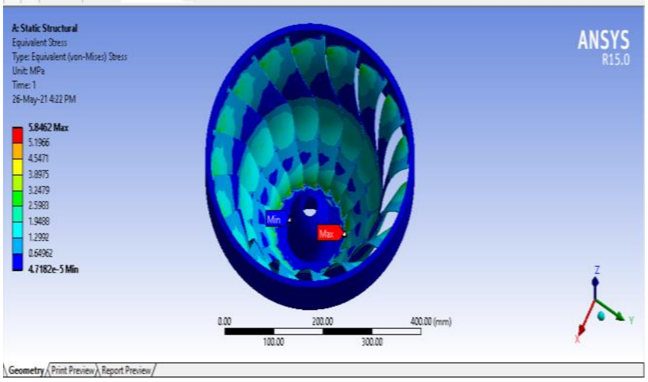

Fig 5.5 Equivalent von-mises stress distribution in Francis turbine blades at 200rpm in Ansys 15.0

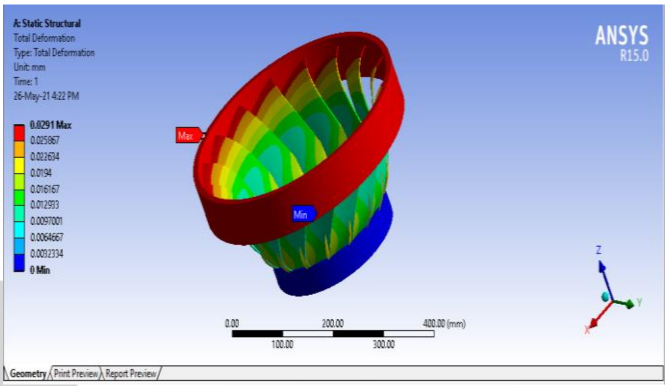

Fig 5.6 Total deformation developed in Francis turbine blades at 200 rpm in Ansys 15.0

5.4 Ansys Results of Francis Turbine blades with 25^0 angles at 300rpm: Case-IV

The fig 5.7 shows the equivalent von-mises stress distribution in the turbine blades at 300rpm. The pattern of the stress distribution in this case-IV is similar to the previous case, but with higher intensity of the stresses. The maximum von-mises stress developed is to be found 9.7395MPa, which is 111 higher than that of in case-I and 66.5% higher than that of in case-III. The fig 5.8 shows the deformation developed in the turbine blades at 300rpm using Ansys 15.0. The resulting color image represents the same pattern of distribution of the stress in this case-IV, compared to the previous cases. The maximum deformation developed is found to be 0.0437mm, which is 136% higher than that of deformation in case-I and 50.1% higher than that of in case-III.

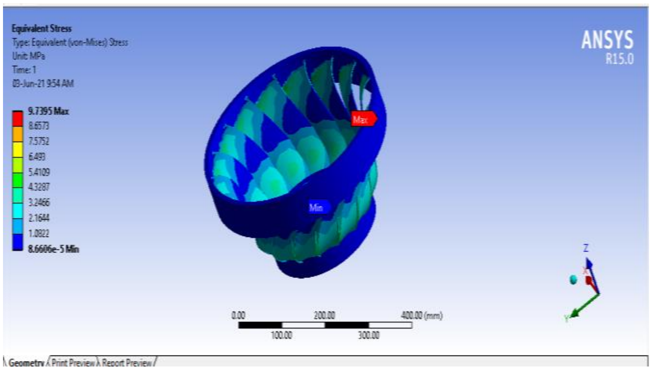

Fig 5.7 Equivalent von-mises stress distribution in Francis turbine blades at 300rpm in Ansys 15.0

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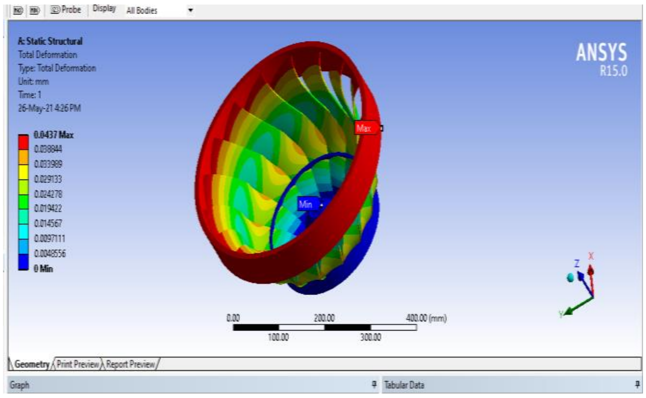

Fig 5.8 Total deformation developed in Francis turbine blades at 300 rpm in Ansys 15.0

5.5 Ansys Results of Francis Turbine blades with 25^0 angles at 400rpm: Case-V

The fig 5.9 shows the von-mises stress distribution in the turbine blades at 400rpm. The resulting color image shows the same pattern as in previous cases. The maximum stress developed is found to be 15.427MPa, which is 235% higher than that of the case-I and 58.3% higher than that of case-IV.

The fig 5.10 shows the deformation developed in the turbine blades at 400rpm. The deveopment of deformation follows the same trend as in the previous cases. The maximum deformation is developed at the inlet end of the blade and also on the middle of the blade at the trailing edge, with a magnitude of 0.064826mm, which is 250.8% higher than that of the case-I and 48.3% higher than that of the case-IV.

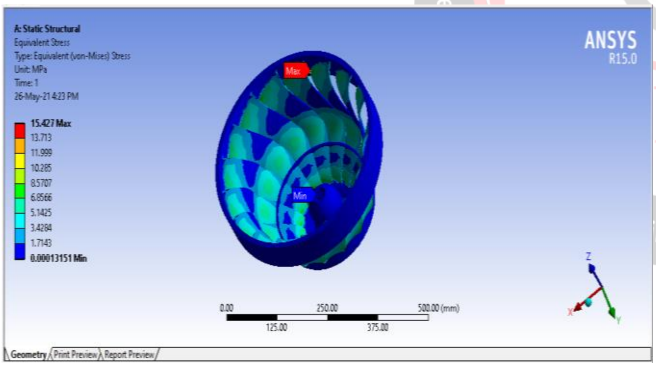

Fig 5.9 Equivalent von-mises stress distribution in Francis turbine blades at 400rpm in Ansys 15.0

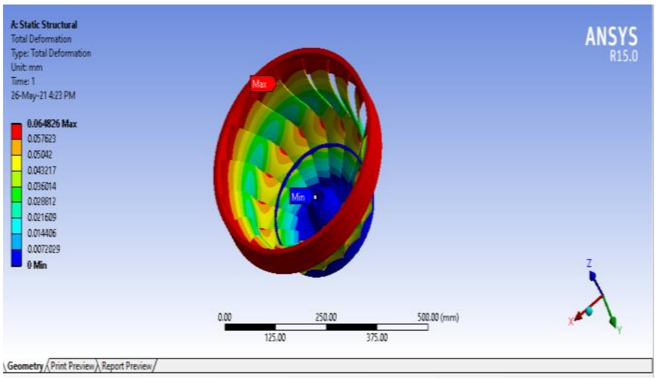

Fig 5.10 Total deformation developed in Francis turbine blades at 400 rpm in Ansys 15.0

5.6 Ansys Results of Francis Turbine blades with 25^0 angles at 500rpm: Case-VI The fig 5.11 shows the von-mises stress distribution in the turbine blades at 500rpm. The pattern of development of stress is similar to all the previous cases, but little higher intensity. The maximum stress is found to be 23.134MPa, which is 402% higher than that of the case-I and 49.9% higher than that of case-V.

The fig 5.12 shows the deformation developed in the turbine blades at 500rpm. The deformation development follows the same trend as in the previous cases, with a maximum value of 0.092355, which is 400% higher than that of the case-I and 42.5% higher than that of the case-V.

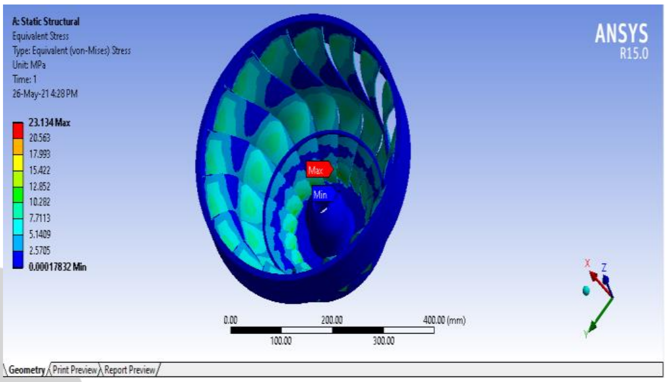

Fig 5.11 Equivalent von-mises stress distribution in Francis turbine blades at 500rpm in Ansys 15.0

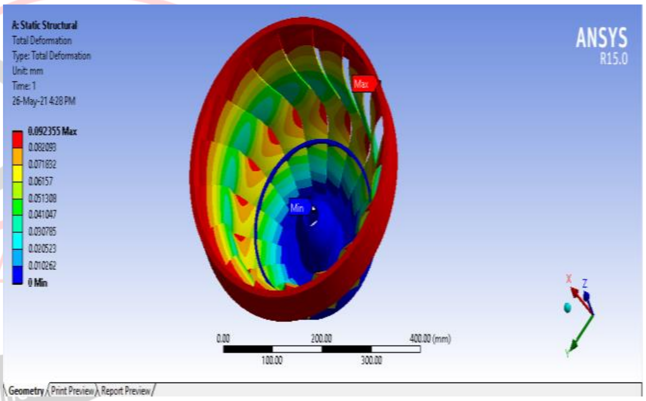

Fig 5.12 Total deformation developed in Francis turbine blades at 500 rpm in Ansys 15.0

5.7 Ansys Results of Francis Turbine blades with 25^0 angles at 600rpm: Case-VII

The fig 5.13 shows the von-mises stress distribution in turbine blades at 600rpm. The distribution of stress follows the same trend as in previous cases. The maximum stress magnitude is 32.64MPa, which is 41% higher than that of case-VI.

The fig 5.14 shows the deformation developed in turbine blades at 600rpm , with a maximum magnitude of 0.1262, which is 36.6% higher than that of case-VI.

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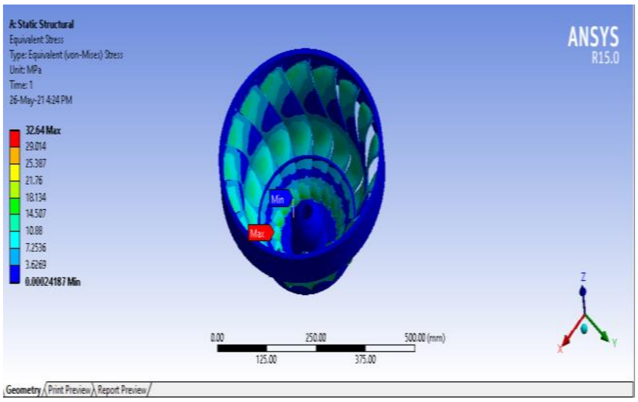

Fig 5.13 Equivalent von-mises stress distribution in Francis turbine blades at 600rpm in Ansys 15.0

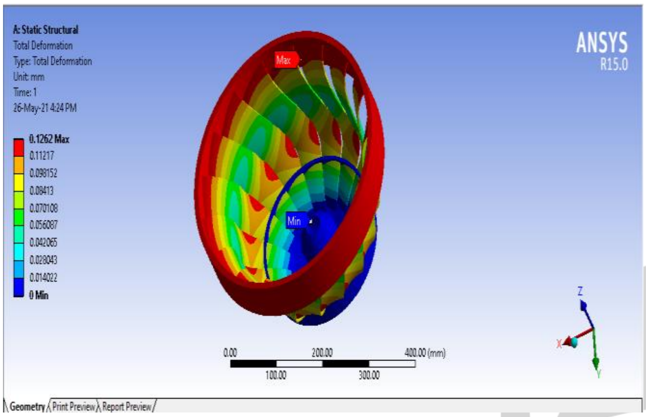

Fig 5.14 Total deformation developed in Francis turbine blades at 600 rpm in Ansys 15.0.

5.8 Ansys Results of Francis Turbine blades with 30^0 angles

The fig 5.15 shows the Von-mises stress distribution the turbine blades at 30^0 blade angle. It is observed from the resulting color image that the pattern of distribution of the stress follows the same trend as in the case of 25^0 angles. But the intensity of the stress is found to be reduced with a maximum of 5.6811MPa, developed at the outlet end of the blade. This may be due to the increase of resisting cross sectional area of the blade, which has to face the applied moment in its normal direction. The torsion moment applied leads to bending action on the blade, which got reduced with that increase of blade vane angle. The maximum stress developed in this case is found to be 28.2% lower than that of the blades with 25^0 blade angles.

The fig 5.16 shows the deformation developed in the turbine blades of 30^0 blade angle. The deformation development follows the same trend as in the case of 25^0 blade angle. The maximum deformation developed is found to be 0.02203mm, which is 24.3% lower than that of the blades with 5^0 blade angle.

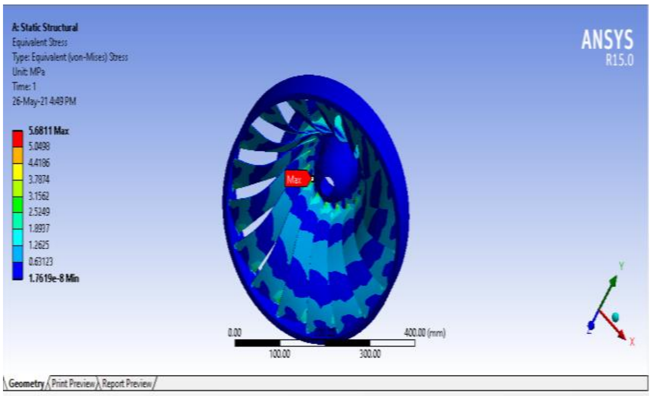

Fig 5.15 Equivalent von-mises stress distribution in Francis turbine blades of 35^0 blade angle in Ansys 15.0

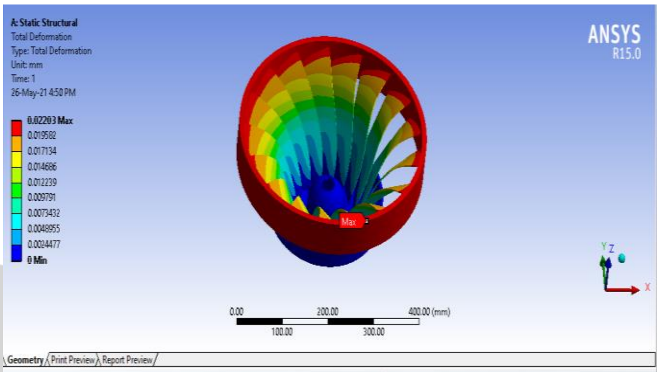

Fig 5.16 Total deformation developed in Francis turbine blades of 35^0 blade angle in Ansys 15.0

5.9 Ansys Results of Francis Turbine blades with 35^0 angles

The fig 5.17 shows the von-mises stress deformation distribution in the turbine blades with 35^0 blade angle. The stress developed in this case follows the same trend as in the previous cases, but the intensity has been reduced with a maximum value of 5.0807MPa. The maximum deformation in this case is 10.5% lower than that of the deformation in the blades of 30^0.

The fig 5.18 shows the deformation developed in the turbine blades with 35^0 blade angle. The intensity of deformation in this case is still reduced, which may be due to the same reason mention in the previous case, with a maximum value of 0.021312mm. The maximum deformation in this case is 3.2% lower than that of in blades of 30^0.

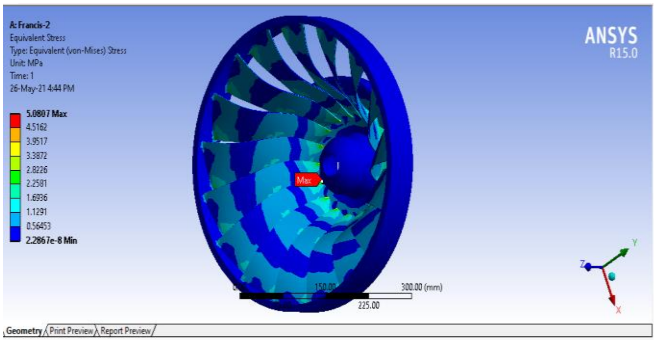

Fig 5.17 Equivalent von-mises stress distribution in Francis turbine blades of 30^0 blade angle in Ansys 15.0

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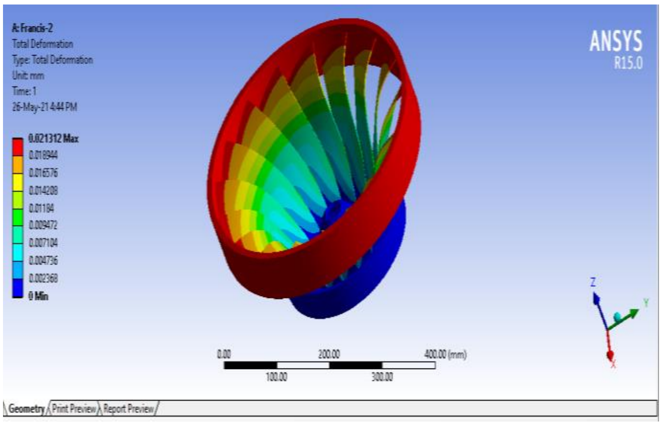

Fig 5.18 Total deformation developed in Francis turbine blades of 30^0 blade angle in Ansys 15.0

5.10 Ansys Results of Francis Turbine blades with 40^0 angles

The fig 5.19 shows the von-mises stress distribution in tha turbine blades with 40^0 blade angle. The pattern of distribution of stress is same as that of in previous cases, but the intensity has been again increased, compared to the previous case. The increase in blade angle further from 35^0 results in increase of intensity of stress, this may be due to the reason that the increase in angle increases the distance of blade end from the center axiis of the runner, which in turn increases the effect of the torsion moment. Thereby the stress development intensity increased in this case compared to the previous case. The maximum stress developed in this is found to be 6.4647MPa, which is 27.2% higher than that of the stress in blades with 35^0 angle.

The fig 5.20 shows the deformation developed in the turbine blades with 40^0 blade angle. The pattern of deformation distribution in this same as that of in previous cases. The maximum deformation developed in this case is found to be 0.025068mm, which is 17.6% higher than that of in blades with 35^0.

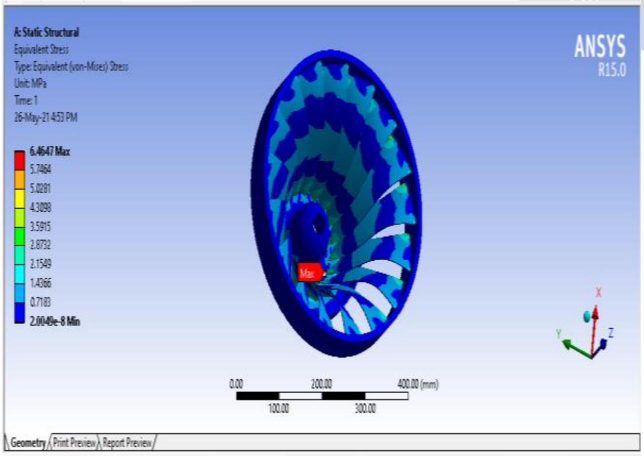

Fig 5.19 Equivalent von-mises stress distribution in Francis turbine blades of 40^0 blade angle in Ansys 15.0

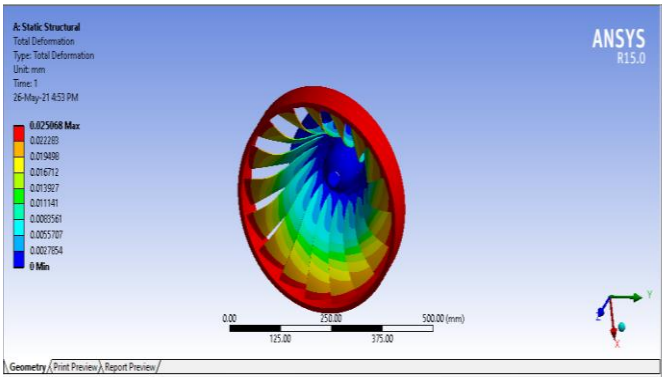

Fig 5.20 Total deformation developed in Francis turbine blades of 40^0 blade angle in Ansys 15.0

5.11 Ansys Results of Francis Turbine blades with 45^0 angles

The fig 5.21 shows the von-mises stress distribution in turbine blades with 45^0 angles. The pattern of stress distribution is similar to the previous cases with a maximum magnitude of 6.7001MPa, which is 3.6% higher than that of the blades of 40^0 angles.

The fig 5.22 shows the deformation developed in the turbine blades with 45^0 blade angle. The development of deformation is similar to the previous cases, but slightly increased with a maximum magnitude of 0.025376mm, which is 1.2% higher than that of in blades with 40^0 angles.

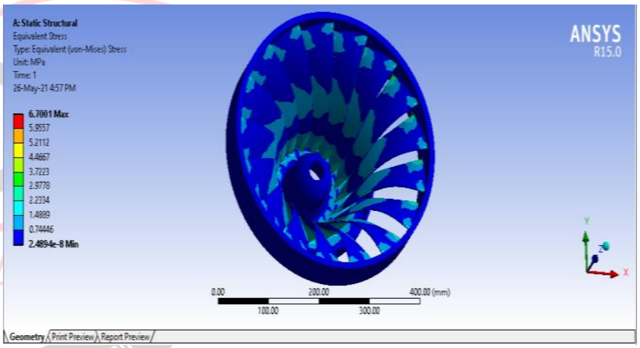

Fig 5.21 Equivalent von-mises stress distribution in Francis turbine blades of 45^0 blade angle

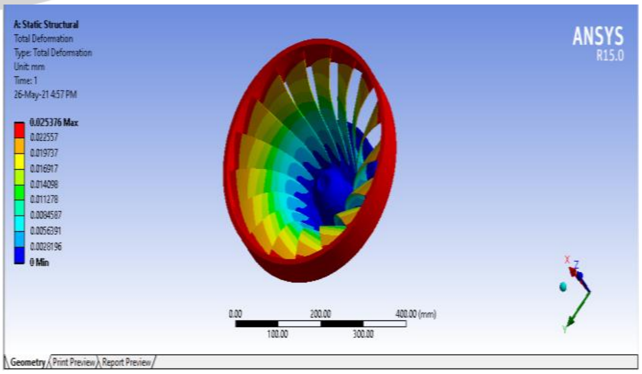

Fig 5.22 Total deformation developed in Francis turbine blades of 45^0 blade angle in Ansys 15.0

5.12Effect of Blade angle on von-mises stress and deformation development.

The fig 5.25 and fig 5.26 shows the effect of the blade angles on the stress and deformation develop in the turbine blades. The graphical result shows that the von-mises stress

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decreases with increase of blade angle from 25^0 to 35^0 and again increases thereafter. The minimum stress and deformations takes place at 35^0 blade angle.

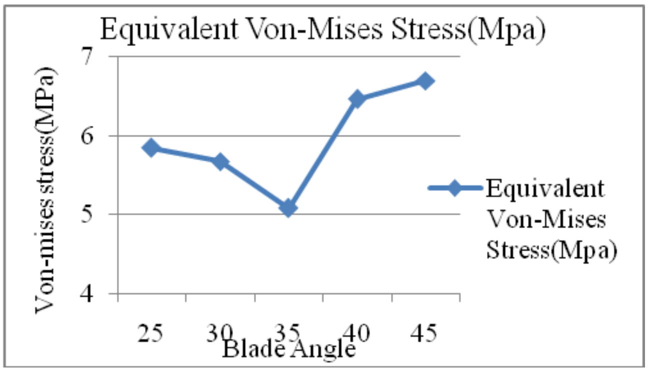

Fig 5.25 Effect of the blade angle on the von-mises stress developed

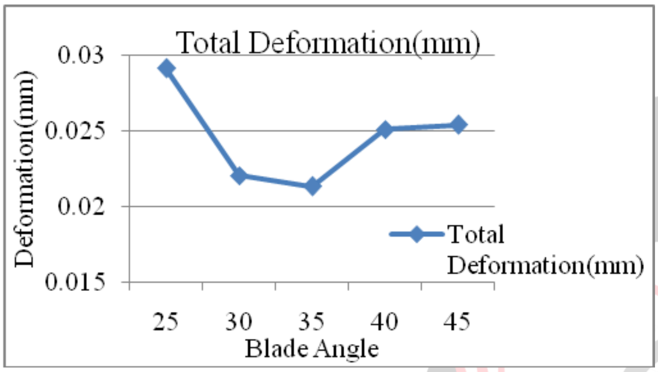

Fig 5.26 Effect of the blade angle on the deformation in the turbine blade

VI. CONCLUSIONS

The following conclusions were drawn by conducting analysis tests on the francis turbine blades by varying the rotational speed and blade vane angle.

- The maximum von-mises stress in the turbine blades increases with increase of speed, with an average of 1.402 times increment in stress intensity for every 100rpm increase of speed.
- The total deformation in the turbine blades increases with increase of the speed, with an average of 1.383 times increment in deformation for every 100rpm increase of speed.
- The von-mises stress decreases with increase of turbine blade angle from 25^0 to 35^0 and again increases up to 45^0 blade angle.
- The total deformation in the blades decreases with increase of turbine blade angle from 25^0 to 35^0 and again increases up to 45^0 blade angle.
- The von-mises stress intensity developed is lowest at turbine blade angle of 35^0, which is 13.09% lower than that of the blades at 25^0 blade angle and 24.1% lower than that of the blades at 45^0 blade angle.
- The minimum deformation is developed at turbine blade angle of 35^0, which is 26.76% lower than that of the blades at 25^0 blade angle and 16.02% lower than that of the blades at 45^0 blade angle.

  Thus it is concluded that turbine blade with 35^0 blade angle is optimum in achieving lower stress and deformations.

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