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Finite Element Analysis of Impeller of Centrifugal Blower By using Inconel 740

[1]Sachin G. Dongre, [2]Mr. Gaurav P. Deshmukh, [3]Dr. Kiran C. More

[1]Master Student, Mechanical Engineering Department, DYPIET, Ambi, [2]Assistant Professor, Mechanical Engineering Department, DYPIET, Ambi, [3]Associate Professor, Mechanical Engineering Department, DYPIET, Ambi
[1]D. Y. Patil Institute of Engineering & Technology, Ambi, Pune, India

Abstract: In recent years, the optimization of the impeller blade by reducing the weight is getting attentions to the researchers. A numerical study for weight optimization of impeller blade is presented to reduce the vibration and noise of the centrifugal blower. In this present work, the vibration analysis has been carried out to investigate the optimum suitable thickness and rotating speed for the present model. A Numerical impeller model of Inconel 740 material has been designed and modelled for the numerical analysis. Different parametric study were done with three different centrifugal impeller. A finite element analysis has been done with different geometric and boundary conditions applied on specimen. A maximum deformation and natural frequency has been found for three different thicknesses (t = 1.5, 2 and 3mm) and rotating speed (N_r = 2550, 2650, and 2750 RPM) numerically. It was observed that, thickness of the blade affects the natural frequency and noise of the centrifugal blower. The maximum deformation and natural frequency were found for 1.5 mm thickness with 2750 RPM, while the minimum deformation and natural frequency were found for 1.5 mm thickness and 2550 RPM. This study can be helps to design and optimize the weight of impeller blade**.**

Index Terms - Impeller blade, Inconel alloy 740, weight optimization, vibration, FEA.

1. INTRODUCTION

Vibrations are detected in all mechanical structures or equipment's subjected to rotating and dynamic loading. Industrial air blowers are used in various process equipment's like dryers, evaporators, providing draft for boilers. The moving impeller provides kinetic energy to the fluid which can generate pressure against the resistance caused by the casing and other components in the system like ducts, dampers etc. The impeller receives the energy from the rotating shaft and transmits it to the air imparting it velocity with slight increase in pressure energy. Blowers are important in providing proper draft to the boiler, which will have an impact on the efficiency of the boilers, as adequate air is supplied to the combustion chamber to ensure proper combustion of the fuel. The blower can be installed in front of the boiler which will supply air at positive pressure against boiler pressure which can be at room temperature or elevated temperature as in case of air pre-heater, hence they are called as forced draft (FD). Similarly flue gases can be drawn out of the combustion chamber which can be slightly below atmosphere which is called as Induced Draft (ID). The primary air blowers (PA) are used to atomization of fuel, whereas Secondary air blowers are used for transferring the fuel through duct conveying system. Centrifugal blowers are widely used in different industrial applications, which are proficient of as long as restrained to high pressure rise and flow rates. Centrifugal blowers are mainly two main parts, namely, casing and impeller. The impeller is often considered an integral part of the suction motor since its housings and the motor are assembled as a unit. The impeller, driven by the blower shaft adds the velocity component to the fluid by centrifugally casting the fluid away from the impeller vane tips. The key idea here is that the energy created is kinetic energy. The amount of energy given to the fluid corresponds to the velocity at the edge or vane tip of the impeller. Impeller is the most important part of the blower components because of the fact that its performance inadvertently determines the blower's performance. An impeller is essentially a disk shaped structure with vanes that create the actual suction in a blower. The impeller is always placed directly onto the shaft of the electric motor so that it spins at a very high speed. The effects of centrifugal force acting upon the spinning air within the impeller create the suction. As the impeller rotates, Von Cube and Steimle (1981) confirms that the spinning air moves outward away from the hub, creating a partial vacuum which causes more air to flow into the impeller. Atre Pranav C. et al., 2012 the numerical design procedure is developed for it and the CFD optimization has been carried out for volute casing to improve the results which have got from the numerical procedure only. A case is studied from technical bulletin[1] for this purpose and the results are correlated with those obtained from the numerical procedure developed. The concept of MRF (moving reference frame) is applied in the CFD analysis of the centrifugal fan as a rotating region around the impeller, keeping the components of the impeller stationary. The volute casing was optimized by decreasing the volute clearances by 10-14% and increasing the cut off height by 5% keeping it at 35% of impeller diameter. Thus the design methodology which includes the assistance of CFD optimization has been developed successfully. [1]

Many researchers has been studied related with the effect of number of blade as well as shape of the blade. Iratkar et al. (2017) did a FEA analysis centrifugal pump impeller to find the overall performance using different efficiency calculations. An FEA analysis using static structure had been done in commercial software ANSYS to examine the different stress and displacements. A glass fibre material is used for the both analysis *viz.* experimental and numerical. Authors concluded that, glass fibre material is suitable for replacing the conventional MS material due to its properties

[2]. Elyamin et al. (2019) did a study on the effect of number of blades on the performance of the centrifugal pump. A numerical investigation has been carried out for different number of blades for different rotating speed. They found that, the head coefficient and the hydraulic efficiency was higher for the 7 number of blades [3]. Srivastava et al. (2014) presented a study on the design of mixed flow pump impeller blade using numerically and experimentally. A Von Misses stress had been studied for the different position of the meridional positions. They found, an inlet inclined blade position is suitable for the mixed flow impeller blade [4]. Mane et al. (2017) did a FEA study for Mild still and Inconel 625 made centrifugal pump impeller. A modal analysis was done for the dynamic analysis. The natural frequency and the mode shapes of the MS impeller was extracted [5]. Liu et al. (2015) did a FEA study for analysis of fatigue life assessment of impeller used in centrifugal compressor. The stress concentration and mean stress was found using FEA for maximum stress point [6]. Lu et al. (2012) presented numerical optimization on the vibroacoustics of a centrifugal volute impeller. An optimization was carried out using local thickness variation and experiments are conducted and results are compared with numerical results, which was found good agreement. A natural frequency and total deformation was extracted for the optimization of the volute fan. The results are used for the designing of such type of impeller [7]. Jayapragasan et al. (2017) work describes, a numerical results are compared with experimental values. ANOVA is used to find out the percentage contribution of parameters on the output. Using Minitab software the optimum combination is identified. The result shows that the optimum combinations are 190 mm outer diameter, 80° blade angle and 8 numbers of blades [8]. Parshi et al. (2017) the objective of their study was to increase the life period of centrifugal blower impeller by considering different types of materials, designs and by varying the thickness of base plate of centrifugal blower impeller. Using ANSYS software implemented static analysis under different boundary conditions also implemented Taguchi optimization technique to grab the best material, design and thickness. Total deformation under static analysis considered for Taguchi optimization technique and using ANOVA method obtained best results were Stainless steel, 12 Blades impeller and 8 mm as base plate thickness provides very less deformation under static analysis [9]. Wang et al. (2017) the fatigue damage of compressor blade steel KMN-I was investigated using nonlinear ultrasonic testing and the relation curve between the material nonlinearity parameter β and the fatigue life was obtained. The results showed that the nonlinearity parameter increased first and then decreased with the increase of the fatigue cycles. The microstructures were observed by scanning electron microscopy (SEM) [10]. Wang et al (2017) did a theoretical, experimental and numerical study of impeller blade used in centrifugal pump. The study mainly aims to improve the performance using backward and forward blade analysis [11]. Fehse and niese (1998 and 1999) studied a generation mechanism of low frequency noise of a centrifugal fan. A different experiments had been performed with five centrifugal fan impeller and they found reduced flow separation, reduced noise, more uniform flow with less turbulence [12 and 13]. From the above literature, there is lack of work found for the optimization of the weight of the impeller as well as vibration analysis.

The present work describes numerical analysis of vibration and total deformation of impeller used in centrifugal blower. Design and optimization of the impeller has been done by varying different geometric and operating parameters to optimize the weight reduction with improved surface quality. Different thickness of the blade *viz.* t = 1.5, 2, and 3 mm are considered to analyse the natural frequency and total deformation. A Numerical impeller model of Inconel 740 material has been designed and modelled for the numerical analysis to study the performance with different operating parameters. A model analysis is done using commercial software ANSYS version 14.5 to predict natural frequency and total deformation of the impeller for different input rotating speed. A Numerical results has been created with the ANSYS software. A natural frequency and total deformation is calculated using FEA model used in ANSYS 14.5. The main objective of this work to find the optimum weight of the impeller with three different blade thickness using natural frequency and total deformation for different rotational speed.

2. OPTIMIZATION METHOD

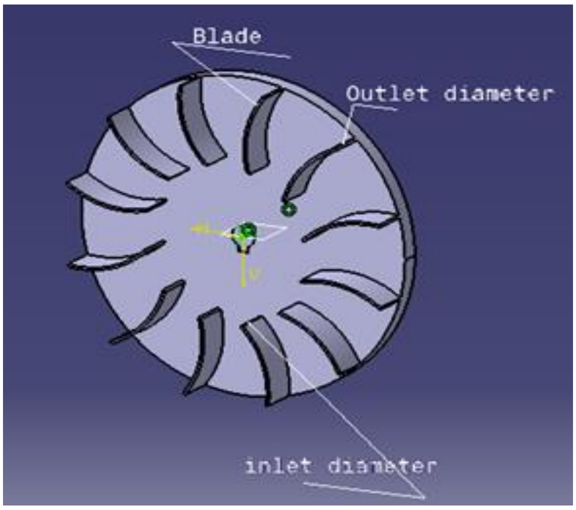
A Taguchi method based experimentation scheme is used to find the main effects and statistical significance of various performance parameters of the impeller blade to optimize the weight. Table 1 shows the selected operating parameters for the experimentation and similar for the numerical work. An L_9 orthogonal array of Taguchi method was employed to perform different trial conditions for numerical study. Three levels of impeller blade thickness, rotating speed and three levels of other parameters were selected to fix the trial conditions. In present work, the raw data analysis and S/N data analysis have been performed. The effect of selected process parameters on the EDM process have been investigated through the main effect plots based on raw data. The optimum condition for each of the quality characteristics has been established through S/N data analysis aided by the raw data analysis. A high value of S/N ratio implies that signal is much higher than the random effect of noise factor. In three different ways S/N ratio results may be investigated are “smaller the better”, “larger the better” and “nominal the best”.

Table 1: Selected performance parameters for the analysis

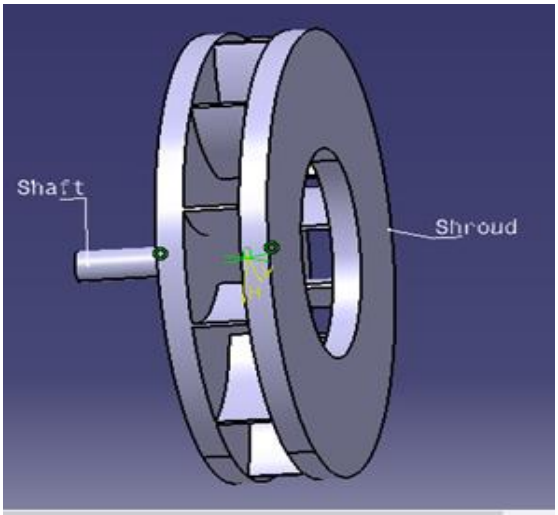
Process parameters	Parameters for Numerical study		
	1	**2**	**3**
Thickness of impeller blade (mm)	1.5	2	3
Mode number (Numerical analysis)	1	2	3
Rotating speed (RPM)	2550	2650	2750

3. NUMERICAL MODEL OF THE IMPELLER

A numerical modelling of impeller has been done using FEA and can be divided into different steps *viz.* 3D modelling, meshing, analyses using different boundary conditions and post processing the results. A 3D model is built with commercial software CATIA and then it is imported into a FEA based model analysis in ANSYS. A numerical domain of the impeller considered for the vibration analysis is shown in figure 1. A total 12 number of blades is considered by changing thickness of the blade. Inconel 740 material is selected numerical analysis of the impeller blade and the properties are listed in table 2. The meshing is an important part in the analysis and it is done by keeping an optimal ratio between the accuracy of selected performance parameter and the overall analysis time. A simple static modal analysis is done by applying different boundary conditions of loads and moments. Structural loads can be used *viz.* nodal forces or pressure on different faces or edges of the model. The modal analysis set is created for obtaining natural frequency and total deformation of the impeller blade for different rotational speed. Three different rotational speed (N_p = 2550, 2650 and 2750 rpm) are considered for the analysis.



(a) Geometry Of the impeller with backward curved blades



(b) Backward curved impeller with shroud

Fig. 1: Numerical domain selected for the analysis.

Table 2: Properties of the impeller material (Inconel alloy 740)

Properties	Inconel 740
Young modulus (MPa)	2.21×10^5
Density g/cm^3	8.05
Poisson's Ratio	0.37

4. RESULTS AND DISCUSSION

A Table 3 shows the quantitative results for natural frequency and total deformation found in numerical analysis for L_9 array of Taguchi method. A modal analysis has been performed to investigate the maximum deformation and frequency at different modes of the geometries. Theoretically there are an infinite modes of the vibration but the modes can be selected with the largest deformation. Three modes has been selected to investigate the maximum frequency and the maximum deformation in it for different thickness and rotating speed. It can be seen in table that, the maximum total deformation has been found 11.522 mm and maximum natural frequency of 8.27 E-04 for the thickness of 1.5 mm, third mode and 2750 rpm.

Table 3: Numerical results of natural frequency and total deformation with selected cases as per L_9 orthogonal array.

Material Thickness	**Mode Number**	**RPM**	**Natural Frequency (HZ)**	**Deformation (mm)**	**Weight (kg)**
1.5	1	2550	3.10E-06	10.113	7.53
1.5	2	2650	4.82E-04	11.521	7.53
1.5	3	2750	8.27E-04	11.522	7.53
2	1	2650	4.18E-05	11.326	7.75
2	2	2750	4.18E-05	11.344	7.75
2	3	2550	3.60E-04	11.369	7.75
3	1	2750	2.75E-05	10.169	8.08
3	2	2550	3.10E-04	11.119	8.08
3	3	2650	7.34E-04	11.129	8.08

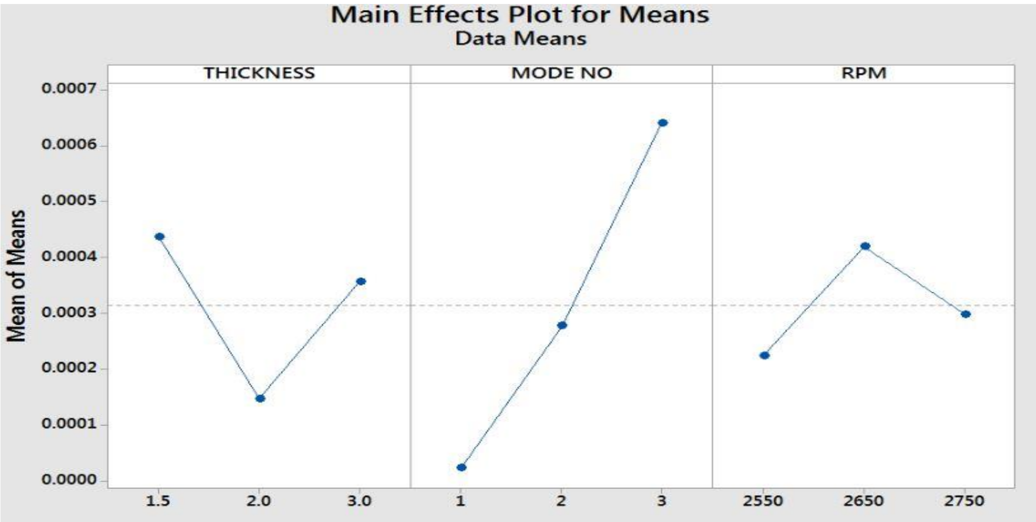


Figure 2 Mean effect plot for optimization of the impeller blade.

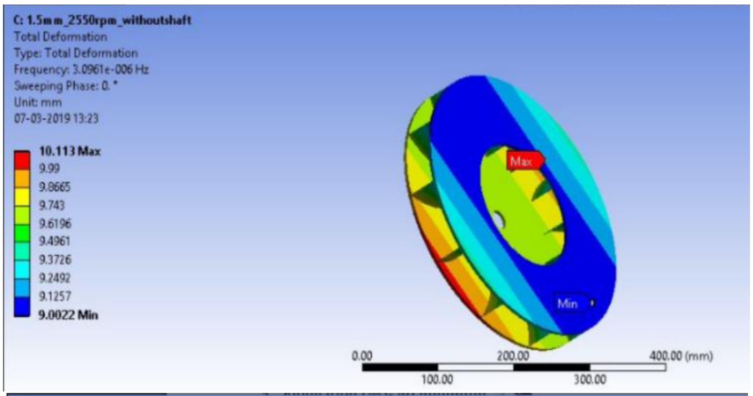
Figure 2 implies that main effect plot for means for different process parameters. From the figure, it shows that, the maximum S/N ration was found for the lower thickness and 2650 RPM.

Level	Thickness	Mode number	RPM
1	79.39	96.32	83.07
2	81.34	74.70	72.20
3	74.69	64.40	80.15
Delta	06.65	31.92	10.87
Rank	3	1	2

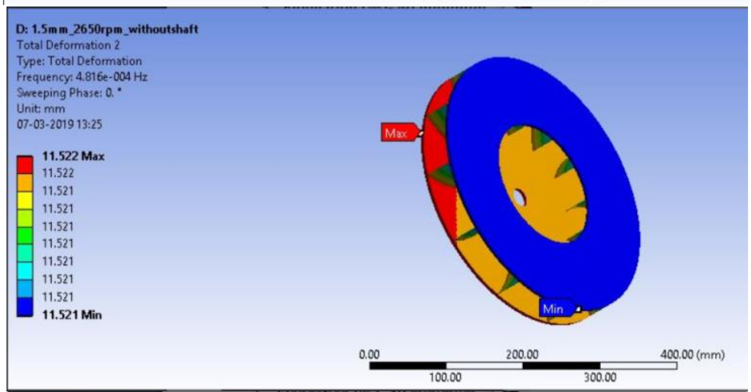
Table 4 Response table for signal to noise (S/N) ratio.

Figure 3 (a to i) depicts the contours of natural frequency and maximum total deformation for L_9 array of Taguchi method used for the analysis. It can be seen from the figure that, the maximum total deformation and the frequency is found for the blade thickness of 1.5 mm and 2750 RPM rotating speed. There are total six mode shapes has been found from the numerical analysis. The results below indicates for 3 mode shapes for different thickness and rotating speed. The various contours shows that, the location of the maximum total deformation is different for different mode shapes. According to the Taguchi methodology, the maximum total deformation has been found for 1.5 mm thickness blade for 2750 RPM. It can be seen from the figures that, the weight and rotating speed of the impeller affects the natural frequency as well as performance of the impeller.

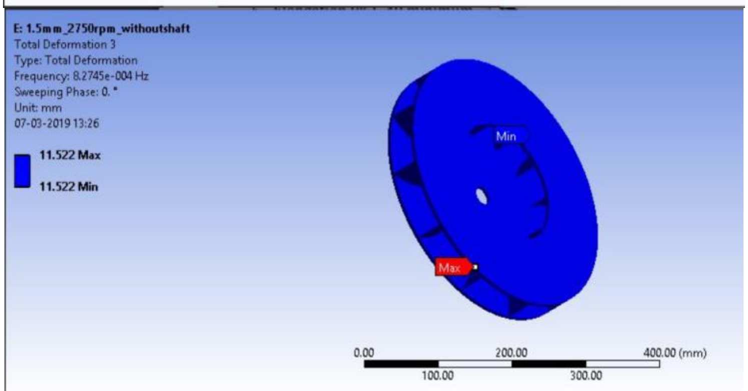
(a) First Mode shape of impeller 1.5 mm thickness and 2550 RPM



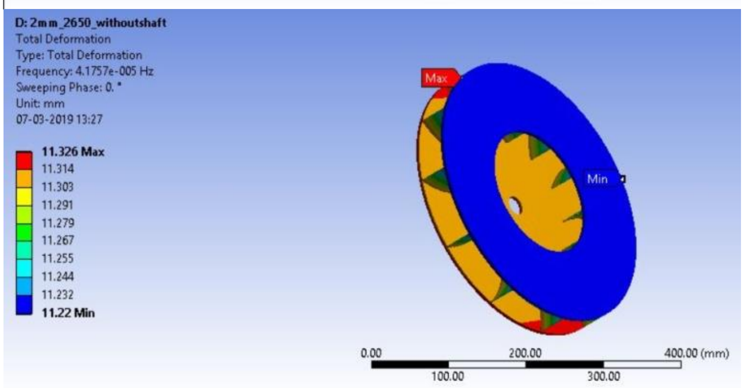
(b) Second Mode shape of impeller 1.5 mm thickness and 2650 RPM



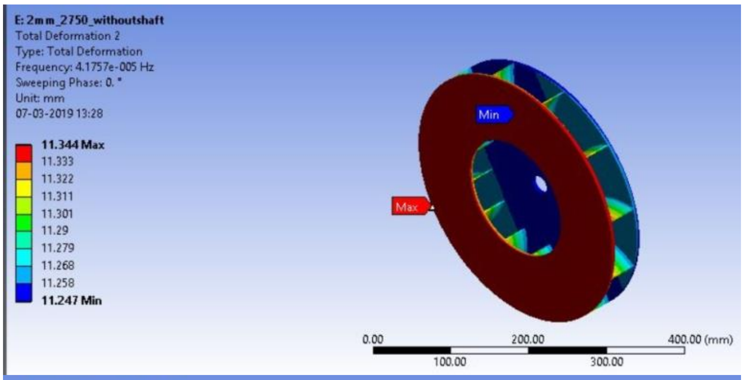
(c) Third Mode shape of impeller 1.5 mm thickness and 2750 RPM



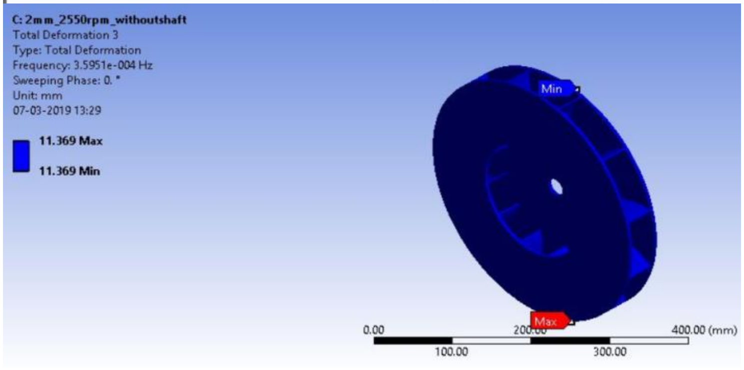
(d) First Mode shape of impeller 2 mm thickness and 2650 RPM



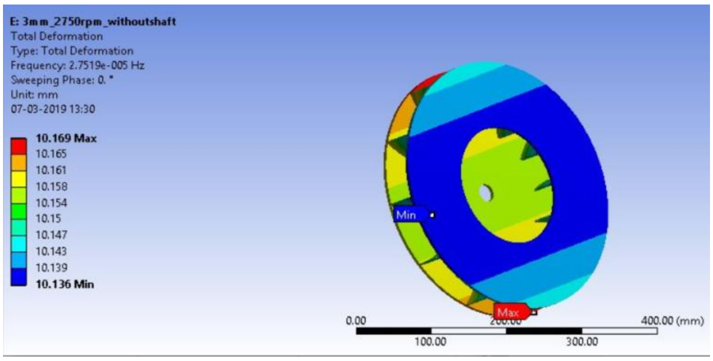
(e) Second Mode shape of impeller 2 mm thickness and 2750 RPM



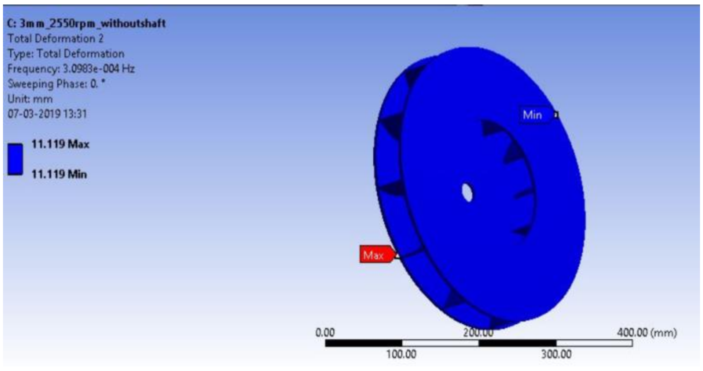
(f) Third Mode shape of impeller 2 mm thickness and 2550 RPM



(g) First Mode shape of impeller 3 mm thickness and 2750 RPM



(h) Second Mode shape of impeller 3 mm thickness and 2550 RPM



(i) Third Mode shape of impeller 3 mm thickness and 2650 RPM

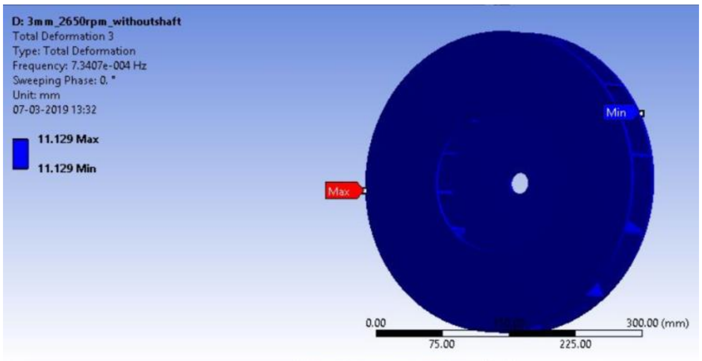


Fig. 3 (a to i) : Contours of total deformation and natural frequency for different operating conditions.

5. CONCLUDING REMARK

In this work, the impeller of INCONEL 740 material is analyzed by the finite element method for the optimization of the weight by varying thickness of the blade. A total deformation and frequency of the impeller was obtained for different parameters such as rotating speed and thickness of the impeller blade. A different parametric study had been performed with use of Taguchi method for design of experiments and results were tabulated with numerical analysis performed in commercial software ANSYS version 14.5. The studied cases shows the effect of thickness of the impeller blade and rotating speed on the vibration of the impeller. The following conclusions had been drown,

1. Thickness of impeller blade was reduced from 3mm to 1.5 mm with changing the rpm of rotation 2550, 2650, 2750.
2. The maximum deformation of Inconel 740 impeller is 11.522 mm for 2750 RPM, 1.5mm blade thickness with natural frequency of 8.27E-04 Hz.
3. The minimum deformation of Inconel 740 impeller is 10.113 mm for 2550 RPM, 1.5mm blade thickness with natural frequency of 3.10E-06 Hz.

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