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Optimization and Analysis of Steam Turbine Operation and maintainance

S.Gejendhiran [1], M.Winmugil[2], B.Manoj Kumar [2]

[1]Assistant Professor, [2]UG Students

Department of Mechanical Engineering, Nandha Engineering College, Erode-52, Tamil Nadu, India.

[1]geja.mechanical@gmail.com, [2]mugilmech96@gmail.com

Abstract - In India, coal is the dominant sources of energy generation. The need and conservation of energy are important. At present 60-62% of total power production in our country is accomplished by the coal-fired thermal power plant. In power plant, the power is produced by converting the chemical energy of coal into electrical energy by the generator. Due to the increased steam leakages and damage to turbine components (Blade Failures) resulting in the loss of turbine efficiency. Basically, the thermal power plant works on improved or modified Rankine cycle to run the plant at highest possible efficiency. Based on heat rate values, to improve the turbine efficiency and overall efficiency by determining the optimum process parameter levels in a steam turbine. The optimization of parameter levels is done by using Taguchi's experimental design method, Orthogonal Arrays (OA) of Taguchi's, regression analysis, Signal to Noise (S/N) ratio and are employed to find the optimal process parameter levels and also to analyze the effect of that parameters. A present effect of individual parameters on performance is estimated by using ANOVA. By using ANSYS software the turbine blades stress distribution, deflection, static and fatigue are to be analyzed. By using this technique, within the available sources, the maximum efficiency of the turbine is to be acquired.

Index words - Steam turbine, Optimization, Taguchi method, Stress analysis, ANOVA.

I. INTRODUCTION

Effective utilization of fossil fuels is becoming very important from the environmental point of view as a global warming due to CO2 emissions becomes a very serious problem. The steam turbine, which is the key components of power generation plants, is required to be more efficient.

In a thermal power plant, the conversion from coal to electricity is achieved by raising the steam in the boilers, expanding it through the turbine and coupling the turbine to the generators which converts the mechanical energy into the electrical energy.

The interior of a turbine comprises of several sets of blades. The turbine blades is a major critical component, it converts the high pressure and high-temperature steam from linear motion into a rotary motion of a turbine shaft. In this project, our main objective is to find the minimal loss which affects the performance of the turbine and in turn decrease the power production in 210MW LMW steam turbine and also to find the root cause of blades failures.

This project discusses how to overcome this difficulty to improve the efficiency of the turbine and to implement the resultant forces and also analyze the blade failure by using a computer-based numerical technique, Finite Element Analysis (FEA) to calculate the strength and behavior of the steam turbine blade. By using the optimizing techniques of Taguchi’s experimental design method the optimum heat rate values are founded and Signal to Noise (S/N) ratio are employed to find the optimal process parameter levels.

The Analysis of Variance (ANOVA) is employed to find the present effect of individual parameters on performance. By using this methodology’s the enhancing performance efficiency of the steam turbine are to be obtained. Utilization of such techniques reduces iterative and time-consuming approach. Finally, the confirmation experimental study showed that Taguchi method precisely optimized the control parameters on steam turbine.

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II. LITERATURE SURVEY

[1] **Umesh Kumar** et al. discussed the optimization of organic Rankine cycle for recovering low-grade industrial waste heat by Taguchi's robust design method. The parameters selected are waste steam flow rate, selected waste steam temperature, turbine speed, and type of refrigerant. By using Taguchi's method optimum combinations of these control parameters are obtained and individual effect of parameters on the performance of organic Rankine cycle are determined.

By using Analysis of Variance (ANOVA) the present effect of individual parameters on performance is estimated. By using this approach identifying the importance of each parameter and also used in assigning effort as the experiments to be performed for a cycle for optimization. By using an orthogonal array for the different condition of operating parameters are designed.

[2] **P. Vaishaly** et al. studied and analyzed a stress in a typical steam turbine blade by using Finite Element Method (FEA). Due to the high centrifugal and aerodynamic loading the Low pressure turbine is very critical from strength and rigidity. In order to avoid the blade failures and cracking it is required to evaluate the stress in these highly twisted blades. By using customized software the stacking 2D profile sections including blade root attachments are created by using this profile data the 3D blades for the last stage of a typical steam turbine is generated. By using the generated model are meshed in ANSYS software and on the blade surface pressure distribution is mapped. The dynamic behavior of the blade is understood by generating Steady state stress analysis.

[3] **Luc G. Frechette** et al. developed the system level and component design of a micro-steam turbine power plant- on-a-chip which implements the Rankine cycle for micro power generation. An integrated micro-pump, generator and also two-phase flow heat exchanges to form a complete micro heat engine unit. By using the (MEMS) technology to the creation of power systems at an unprecedented small scale. By this technologies the possibility of high power density micro systems upto 12KW/kg with efficiency level of 1-11% based on various applications. By this development, the Micro- Rankine device could allow light weight and compact power source for portable application from waste heat (or) solar radiation.

[4] **Md. Abdul Raheem Junaidi** et al. designed and analyzed the optimization of the steam turbine rotor Grooves. The investigations of the steam turbine rotor grooves are to reduce fillet stress concentration factor and its associated deformation. For the effective modification of the blade rotor grooves ANSYS work bench that is used to determine the fillet stresses. As a result of high rotational speed partly due to high pressure temperature and speed steam loading they suffer from tensile stresses due to the centrifugal force. Thus as a result is to make the rotor blade of variable cross section instead of straight.

III. STEAM TURBINE DETAILS

The Specification of 210MW LMW steam turbine type has c.210.130 condensing, three cylinder horizontal disc and diaphragm type with regenerative feed water heaters and nozzle governing.

Number of cylinders	3 cylinder
Make	LMW (Russian make)
Capacity	210MW

Number of stages per cylinder,

HP turbine	12 stages
IP turbine	11 stages
LP turbine	4+4 stages
Exhaust pressure	0.09kg/sq.cm absolute
Exhaust temperature	44 ^{0}C
Critical speeds	1585, 1881, 2017 and 2489 rpm

Weight and dimensions of turbine,

Total weight of turbine	560 tons
Weight of heaviest part of turbine for erection	70 tons
Weight of HP rotor	7.05 tons
Weight of IP rotor	16.2tons
Weight of LP rotor	34.5tons
Overall length of turbine	20307mm
Overall length of HP rotor	4538mm
Overall length of IP rotor	6076mm
Overall length of LP rotor	7175mm

IV. STEAM TURBINE BLADE FAILURES

Turbine blade failure occurs time to time in power plants. To increase the reliability and efficiency of turbine, it is necessary to perform detailed investigations of the failed turbine blade. The most common failure mechanisms exist in turbine blade includes fatigue, creep, oxidation, degradation of coating of turbine blade, corrosion, erosion and surface degradation due to overheating.

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The degree of deterioration of individual blade differs due to processing temperature, rotational speed, mode of operations, total service time and manufacturing differences. The failure of steam turbine blade is due to the combination of aforesaid failure mechanisms.

Due to inappropriate parameter conditions the blade has tip cracks on both leading edge and trailing edge. In order to identify the root causes of blade failure the finite element analyses is established as shown in Fig. 1.

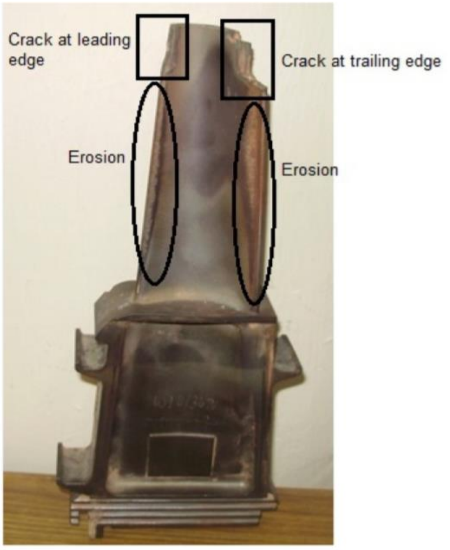

Fig. 1 Blade Failure

The different forms of failures in the steam turbine blade as shown in Fig.2, that will causes the major losses in efficiency.

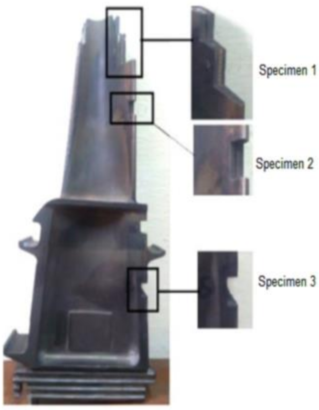

Fig. 2 Different Forms of Failure

V. TURBINE PROCESS PARAMETERS AND THEIR LEVELS

The steam turbine having number of parameters like steam temperature, steam pressure, quantity of steam flow, hot reheat temperature, cold reheat temperature, condensed vacuum and feed water.

Out of these the most important processing parameters are Steam Temperature (T), Steam Pressure (P), and Quantity of Steam Flow (Q).

The number of experiments and input levels are decided based on the design of experiments and the input parameters and their levels are in Table 1.

Table 1: Input Parameters Levels.

Input Parameter	**Steam Temp (T) (^{0}C)**	**Steam Pressure (P) (kg/cm^2)**	**Quantity of steam flow (Q) (Tons/hrs)**
Symbols	**A**	**B**	**C**
Level 1	540	130	646
Level 2	545	132	648
Level 3	550	134	650

VI. OVERVIEW OF TAGUCHI METHOD

Taguchi’s robust design method involves in reducing the variation in a process. To study the entire parameter space with only a small number of experiments the Taguchi method, uses a special design of Orthogonal Arrays (OA). By utilization of this method, it has greater advantage in conducting experiments, saving efforts, saving experimental time, reducing the cost and discovering significant factors quickly. It is a powerful tool for the design of a high-quality system. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. Depending on the particular design problem, different S/N ratios are applicable, including “Higher is Better” (HB), “Lower is Better” (LB), “Nominal Is Best” (NB).

Taguchi’s L9 orthogonal array is chosen to design the experiments and 9 tests are conducted to study the effect of various process parameters like Steam Temperature, Steam Pressure, and Quantity of steam flow on the heat rate.

As the objective is to obtain the high efficiency, it is concerned with obtaining larger value for heat rate. Hence, the required quality characteristic for getting higher efficiency is larger the better, which states that the output must be as large as possible.

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Regardless of the category on a performance characteristics, a greater S/N value corresponds to the better performance.

Therefore, the optimal level of the turbine parameters is the level with the greatest S/N value. Finally, confirmation experiments are conducted using optimal levels of process parameters are represented in Table 2.

Table 2: L_9 Orthogonal Array.

Expt. No.	FACTORS			RESPONSE	S/N ratios
	A	B	C	HEAT RATE	
1	1	1	1	2113.88	66.501
2	1	2	2	2117.48	66.516
3	1	3	3	2124.00	66.543
4	2	1	2	2132.61	66.578
5	2	2	3	2105.69	66.707
6	2	3	1	2113.63	66.500
7	3	1	3	2129.05	66.563
8	3	2	1	2132.94	66.579
9	3	3	2	2145.49	66.630

VII. ANALYSIS OF VARIENCE

The analysis of variance (ANOVA) is a common statistical technique to determine the percent contribution of each factor for results of the experiment. The ANOVA is used to calculate the parameters known as Sum of Squares (SS), Degree of Freedom (DOF), variance and percentage of each factor. Further, the Fisher's F-ratio, the ratio between the regression mean square and the mean square error, is used to identify the most significant factor on the performance characteristic. The Fisher's ratio is also called F value. The principle of the F test is that the larger value for a particular parameter, the greater the effect on the performance characteristics due to the change in that parameter. The P-value reports the significance level (suitable and unsuitable).Percent (%) represents the significance rate of the Steam turbine parameters on the response.

VIII. REGRESSION ANALYSIS

Regression analysis is a statistical tool for estimating the relationships between variables. By using the regression analysis dependent variable changes when any one of the independent variables is varied are analyzed. This method is used to understand the independent variables which are related to the dependent variables and also to explore these relationships.

IX. RESULTS AND DISCUSSION

The main effect plot for S/N ratio, for Steam Temperature, Steam Pressure, Quantity of Steam Flow factors are plotted graphically as shown in Fig. 3.

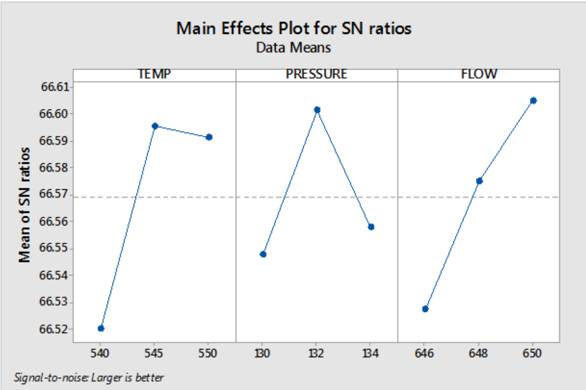

Figure. 3 Main effect plot for S/N ratio

The graphical representation reveals that the combination (2, 2, 3) is the best combination for getting higher heat rate. This corresponds to Heat rate at 545 ^{0}C temperature, 132 kg/cm^2 steam pressure with 650 tons/hrs Flow rate factor. The prediction is matching with the experimental trial.

For establishing the significance of each parameter, a response table for S/N ratio is constructed. The difference between the maximum and minimum is termed as Delta. The calculated value of delta for the different parameters is compared to find out the significance of each parameter. The response table for S/N ratio along with rank is shown in Table.3.

Table.3. Response Table for S/N Ratio

Level	Temp	Steam Pressure	Steam Flow rate
1	66.52	66.55	66.53
2	66.60	66.60	66.58
3	66.59	66.56	66.60
Delta	0.08	0.05	0.08
Rank	**2**	**3**	**1**

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It was earlier observed that the temperature, pressure and steam flow rate are crucial parameters for the process and its variation has a major impact on the heat rate. From the response table, it can be concluded that, the steam flow rate is the most significant parameter followed by temperature and pressure.

X. CONCLUSION

Finite element stress and modal analysis were carried out for the moving blades on a low pressure steam turbine using customized software, in which dedicated for analysis the steam turbine blades. Steady state stress analysis of the blade is carried out by applying the centrifugal and aerodynamic loading.

Stress categorization on the critical location of a blade root is carried out to find the membrane and membrane + bending stress on those locations. Furthermore, the turbine blade failures have to be analyzed and the root causes of the failures are acquired.

This study has discussed an application of the Taguchi method for investigating the effects of heat rate on the steam temperature, steam pressure and quantity of flow rate values in the steam turbine. From the analysis of the results in the steam turbine process parameters using S/N ratio approach, analysis of variance (ANOVA) and Taguchi's optimization method, the following can be concluded that the steam flow rate is the most significant parameter followed by temperature and pressure.

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