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Redesign of the Aeration Centrifugal Fan Impeller in a Steam Power Plant to Reduce Vibration Issues

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ABSTRACT

The aeration centrifugal fan (ACF) functions to inject pressurized air into the aeration pond containing wastewater from power plant operations. This increases the water's oxygen content before discharge. However, as a rotating device, the ACF often faces high vibration issues, including at a steam power plant in Cilacap Regency. Vibration in this unit exceeded permissible limits. Analysis identified blade pass and surging, linked to the impeller design, as the cause. This indicates the existing impeller was not suited to actual operational conditions. This study aims to redesign the impeller to reduce vibration. The redesign involved increasing the number and width of blades, followed by CFD simulations and vibration testing. Results showed volumetric flow rate and pressure increased from 50,887.1 m³/s to 61,185 m³/s and from 226.9 kPa to 696.3 kPa. Vibration dropped from 19.96 mm/s to 2.916 mm/s (below the 7.1 mm/s limit). Thus, the redesign successfully reduced excessive vibration.

INTRODUCTION

The aeration centrifugal fan is one of the wastewater treatment components for service wastewater generated from the activities of steam power plants. The service wastewater is collected in a temporary storage pond (aeration pond). The aeration centrifugal fan injects pressurized air into the aeration pond to increase the oxygen content in the service wastewater before it is discharged into the environment. Therefore, the aeration centrifugal fan is a key component in this process (Tong et al., 2024). Service wastewater from steam power plants activities is one of the water pollutants that can damage aquatic ecosystems, including the organisms living within them, if discharged directly into the environment without undergoing any treatment process (Speight, 2020).

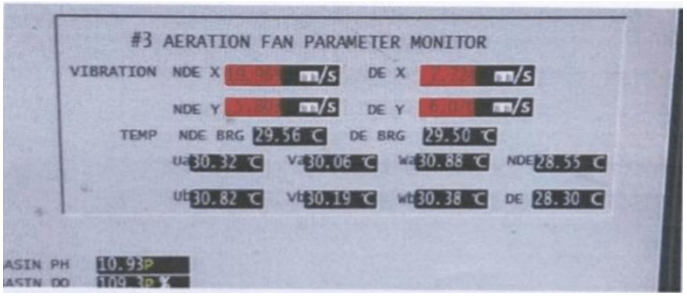

Figure 1. Vibration test data of the aeration centrifugal fan unit

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At one of the steam power plants located in Cilacap Regency, Central Java, an issue occurred with the aeration centrifugal fan unit driven by a motor. The problem was the occurrence of high vibration in the aeration centrifugal fan unit. High vibration issues are commonly found in rotating components (Rahman et al., 2022). Based on vibration testing using a vibration analyzer, the non-drive end (NDE) and drive end (DE) bearings of the aeration centrifugal fan unit recorded vibration values on the X-axis of 19.96 mm/s and 7.72 mm/s, respectively, and on the Y-axis of 5.8 mm/s and 6.0 mm/s, respectively, as shown in Figure 1.

Meanwhile, the allowable vibration limit based on the manufacturer's manual is 4.5 mm/s before the alarm is triggered and 7.1 mm/s before the unit trips, as shown in Table 1. This means that the vibration values of the non-drive end and drive end bearings in the aeration centrifugal fan unit exceed the allowable vibration limits. High vibration levels can lead to operational restrictions or even a complete shutdown of the affected unit (Eskandari et al., 2016).

Table 1. Permissible operating criteria data based on the aeration centrifugal fan unit manual

Description	Settings	Comments or Action
Limit switch for outlet isolating gate	Isolating gate closed	Permission to start fan
Fan bearing thermal	DE above 78 °C NDE above 60 °C	Bearing temperature alarm
Resistance thermometer (RTD)	Above 80 °C above 65 °C	Bearing temperature trip
Fan bearing vibration limit	Above 4.5 mm/s	Bearing vibration alarm
	Above 7.1 mm/s	Bearing vibration trip
Motor bearing thermal	Above 100 °C	Bearing temperature alarm
Resistance thermometer RTD	Above 105 °C	Bearing temperature trip
Motor winding thermal	Above 130 °C	Winding temperature alarm
Resistance thermometer RTD	Above 140 °C	Winding temperature trip

Bearing damage is one of the common causes of vibration in equipment with rotating components (B. R. Aravindh Raj , P. Jeyaraman, B. R. Aravindh Raj, 2018). However, after disassembly, inspection, and the necessary adjustments to the bearings of the aeration centrifugal fan unit, including realignment, the vibration levels remained high. Subsequently, data collection was carried out to conduct an initial analysis of the cause of the high vibration in the aeration centrifugal fan unit. The collected data included technical unit data, operational parameter data, initial field inspection and final alignment data, as well as data from the vibration analyzer.

From the collected data, it was determined that the high vibration in the aeration centrifugal fan unit was caused by blade pass. Additionally, the hydrostatic pressure of the aeration pond was measured at 78.4 kPa, which is higher than the static pressure rise of the aeration centrifugal fan unit, which is 33.487 kPa. Since the hydrostatic pressure of the aeration pond is greater than the operating pressure of the aeration centrifugal fan unit, it effectively causes the unit to operate as if the damper were partially closed.

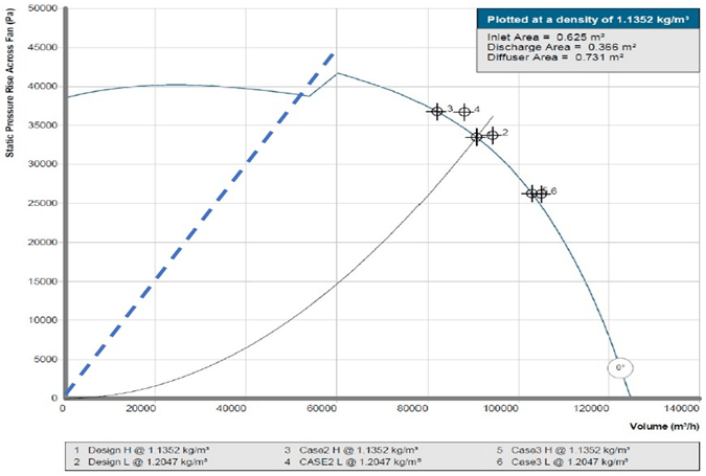

Figure 2. Operating curve showing the aeration centrifugal fan unit operating above its performance line

As shown in Figure 2, it is estimated that the aeration centrifugal fan unit operates beyond its performance curve, shifting its operating point to high pressure and low flow conditions. Alternatively, the aeration centrifugal fan unit may be operating in a region where it has entered a surging condition, resulting in high vibration.

The occurrence of blade pass and surging is closely related to impeller design (Shahin, 2017). Therefore, it was concluded that the impeller design of the aeration centrifugal fan unit was not well-suited to the operational conditions in the field, resulting in high vibration. To address this issue, a redesign of the aeration centrifugal fan impeller was undertaken. Impeller redesign is commonly performed to improve performance or resolve existing problems, as demonstrated by (Rachmanu, 2016) and (Busthomi, 2019). The objective of this study is to redesign the impeller to produce a design that can reduce vibration in the aeration centrifugal fan unit.

RESEARCH METHODS

The redesign of the impeller in the aeration centrifugal fan unit was carried out through the stages shown in Figure 3 below.

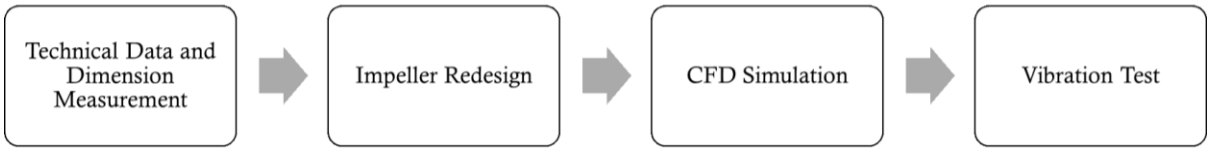

Figure 3. Redesign stages

The process began with collecting the necessary data, including technical and operational data from the field, as well as the dimensions, material specifications, and manufacturer manuals of the aeration centrifugal fan unit. The dimensions of the components, including the impeller, were obtained using 3D scanning, allowing for the creation of a CAD document through reverse engineering. Next, the impeller was redesigned, focusing primarily on its width and the number of blades, resulting in a new impeller design. The number of impeller blades influences the pressure generated (Al-Obaidi, 2020). Following the redesign, a CFD simulation was conducted for both the original manufacturer's impeller (original impeller) and the newly redesigned impeller. This allowed for a comparison of volumetric flow rate and pressure between the two designs. CFD simulation is commonly used in impeller design processes, as demonstrated by (Rosa & Emerick, 2018), (Li et al., 2023), and (López et al., 2017), since it enables performance evaluation before proceeding to the manufacturing stage. Volumetric flow rate is one of the key parameters indicating impeller performance (Dewangga & Yamin, 2021). Finally, a vibration test was conducted on the aeration centrifugal fan unit equipped with the redesigned impeller to assess its vibration levels.

The technical data of the aeration centrifugal fan unit is presented in Table 2 below, as obtained from the unit's manual books. The technical drawing of the aeration centrifugal fan unit is shown in Figure 4.

Table 2. Technical data of the aeration centrifugal fan unit

Parameter	Value
Type/model	Centrifugal Fan/L2N 1386.06.88SBN6T
Inlet flow	80,000 Nm3/h
Static pressure rise	33.487 kPa
Inlet temperature	35.2 °C
Fan speed	2,970 rpm
Inlet Density	1.1352 kg/m3
Diameter of fan bearing	100.01 mm
Effective diameter of impeller	1,469 mm
Manufacture	Beijing Hoandunhua Engineering.co.Ltd

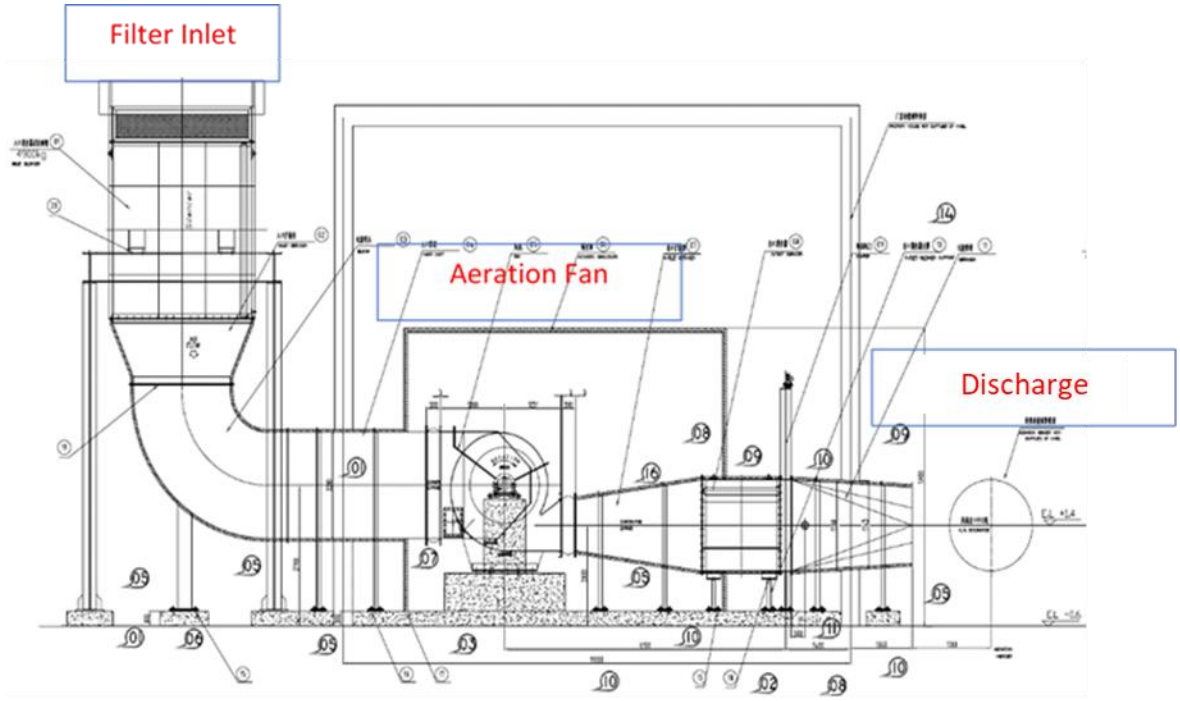

Figure 4. Technical drawing of the aeration centrifugal fan unit

The temporary holding pond for steam power plants service wastewater (aeration pond) has a length of 50.99 m, a width of 32 m, and a depth of 8 m. From the depth of the aeration pond, the hydrostatic pressure can be determined as 78.4 kPa (calculated as the product of the water density, gravitational acceleration, and pond depth). At the bottom of the pond, there is a 1.5 inch diameter pipe that functions to inject pressurized air into the pond. The aeration pond is shown in Figure 5 below.

Figure 5. Aeration pond

RESULTS AND DISCUSSION

Impeller Redesign

The impeller along with its shaft was removed from the casing of the aeration centrifugal fan unit to measure its dimensions using a 3D scanning device (Einscan HX Shining 3D), as shown in Figure 6. The 3D scanning results were then processed to obtain 2D and 3D CAD documents of the original impeller. The original impeller has an outer diameter of 1300 mm, with a blade width of 130 mm and a total of 12 blades.

Figure 6. (left) Impeller and shaft removed from the casing, and (right) 3D scanning process of the impeller

The redesign of the impeller for the aeration centrifugal fan focuses on the number and width of the blades, as these factors significantly influence the performance of a centrifugal pump (Aldio et al., 2023). The number of blades was increased from 12 to 16, while the blade width was increased from 130 mm to 142 mm. The number of blades affects the pressure generated by the impeller (Anam et al., 2022). A higher number of blades results in higher pressure output (Sakran et al., 2024). Additionally, the number of blades also influences the flow rate (Iskandar et al., 2021), where an increase in blade count leads to a higher flow rate (Afendy & Fahruddin, 2024). The blade width affects the volumetric flow rate, as wider blades provide more space, allowing the impeller to push or hold a larger volume of fluid. The designs of the original impeller and the redesigned impeller can be seen in Figure 7, with their dimensional differences presented in Table 3.

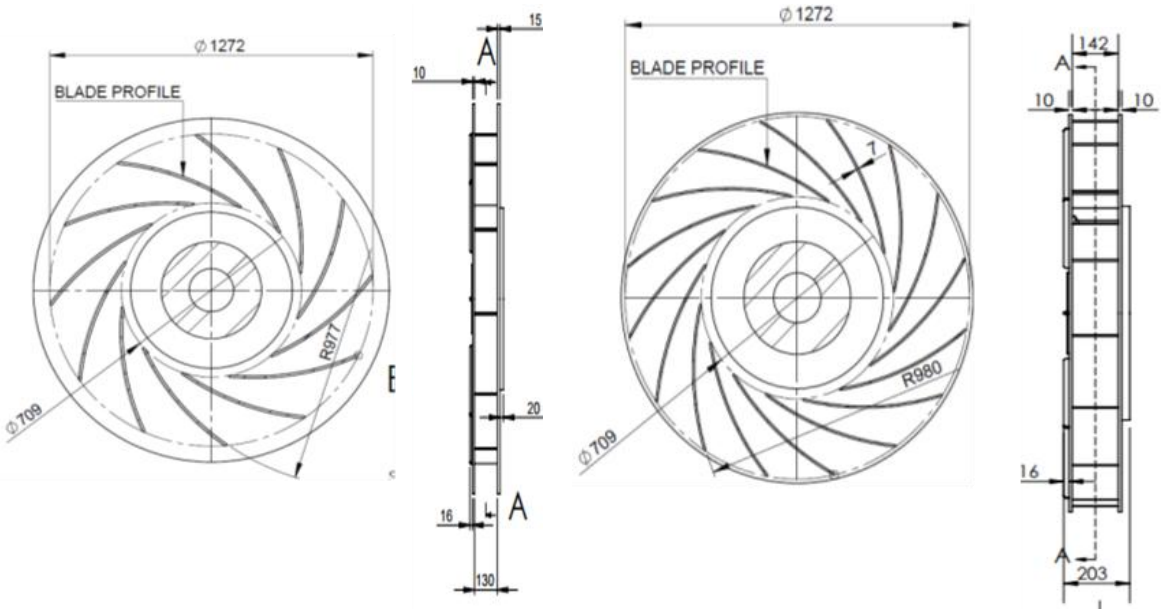

Figure 7. Design of (left) original impeller and (right) redesigned impeller

Table 3. Comparison of dimensions between the original impeller and the redesigned impeller

Dimensions	Original Impeller	Redesigned Impeller
Outer diameter	1300 mm	1300 mm
Impeller width	130 mm	142 mm
Number of blades	12	16
Blade inclination angle	28,74 °C	28,74 °C
Total weight	673 kg	850 kg
Inner diameter	198 mm	198 mm

CFD Simulation

The original impeller and the redesigned impeller were then subjected to CFD simulations to determine the volumetric flow rate and pressure generated by each design. The CFD simulation was conducted using SolidWorks software. Both the original and redesigned impellers utilized the same casing from the aeration centrifugal fan unit. The input parameters used in the simulation were, flow inlet 80,000 Nm³/h, inlet pressure 0 kPa, inlet temperature 35.2°C and rotor rotation speed 2,970 rpm. These parameters were set according to the specifications in the aeration centrifugal fan unit's manual. The results of the CFD simulations for the original and redesigned impellers can be seen in Table 4 and Figure 8.

Table 4. CFD simulation results parameters

Simulation Parameters	Original Impeller	Redesigned Impeller
Volumetric flow rate	50,887.1 m^3/s	61,185 m^3/s
Pressure	226.9 kPa	696.3 kPa

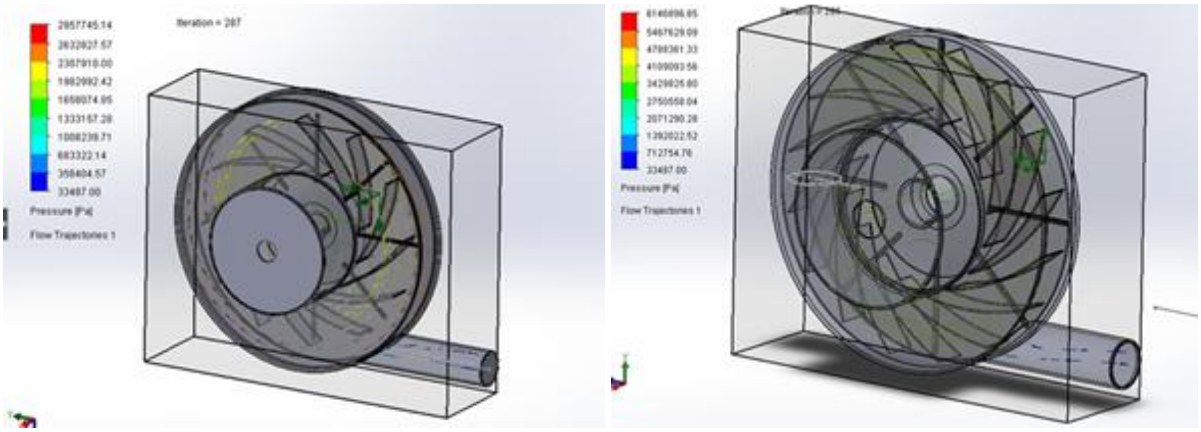

Figure 8. CFD simulation of (left) original impeller and (right) redesigned impeller

From Table 4, it can be observed that the volumetric flow rate and pressure produced by the redesigned impeller are higher than those of the original impeller, with values of 61,185 m^3/s and 696.3 kPa, respectively. This confirms that the redesign, by increasing the number of blades and widening them, has a significant impact on improving the volumetric flow rate and pressure generated by the impeller.

With the increase in the number of blades on the impeller, the friction coefficient between the blade surface and the fluid also increases (Abo Elyamin et al., 2019). Additionally, the available fluid volume decreases due to the narrowing of empty spaces, which can potentially reduce the volumetric flow rate and overall efficiency of the aeration centrifugal fan. However, by increasing the number of blades, the fluid pressure is expected to increase, as the blades exert a greater driving force on the fluid. The number of impeller blades significantly affects the performance of the aeration centrifugal fan, particularly its impact on fluid pressure (Susilo & Setiawan, 2021), as confirmed by the CFD simulation results. Furthermore, blade width plays a crucial role in the fan's performance, especially in terms of volumetric flow rate (m^3/s). A wider blade creates more empty space, thereby increasing the amount of air that can be pushed by the impeller.

Vibration Test

Table 5 presents a comparison of vibration test results between the original impeller and the redesigned impeller installed on the aeration centrifugal fan unit in the field.

Table 5. Vibration test results compared to permissible limits

Impeller	Vibration (mm/s)		Bearing Vibration Permissible Limit	
	X	Y	Alarm (4.5 mm/s)	Trip (7.1 mm/s)
Original Impeller:				
NDE	19.96	5.80	Above the permissible limit	Above the permissible limit
DE	7.72	6.07	Above the permissible limit	Above the permissible limit
Redesigned Impeller:				
NDE	2.916	1.125	Below the Permissible Limit	Below the Permissible Limit
DE	2.947	1.351	Below the Permissible Limit	Below the Permissible Limit

From Table 5, it can be seen that the redesigned impeller significantly reduces the vibration values of the NDE and DE bearings in both the X and Y axes, bringing them below their permissible limits, including both alarm and trip thresholds. Thus, the impeller redesign effectively reduces vibration occurrence.

CONCLUSION

The impeller of the aeration centrifugal fan unit has been redesigned by increasing the number of blades from 12 to 16 and widening the blade width from 130 mm to 142 mm. Based on the results of CFD simulations and vibration tests on both the original and redesigned impellers of the aeration centrifugal fan unit, the following results were obtained. The volumetric flow rate of the fluid increased from 50,887.1 m^3/s in the original impeller to 61,185 m^3/s in the redesigned impeller. The fluid flow pressure increased from 226.9 kPa in the original impeller to 696.3 kPa in the redesigned impeller. Furthermore, the vibration values were reduced to below the permissible limits, specifically at the NDE to 2.916 mm/s and 1.125 mm/s in the X and Y axes, respectively, and at the DE to 2.947 mm/s and 1.351 mm/s in the X and Y axes, respectively. Thus, the impeller redesign effectively reduces vibration levels in the aeration centrifugal fan unit. As a recommendation, further CFD simulations should be conducted using Ansys Fluent to obtain more optimal simulation results.

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