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Design and Fabrication of Single Stage Reaction Steam Turbine

Md. Elahi Siam[1], Md. Shariful Isla[1], Md. Sherazul Islam Murad[1], Tushar Jahid[1], Dr. Bodius Salam[1]*
[1] Department of Mechanical Engineering, Chittagong University of Engineering & Technology, Chittagong-4349, BANGLADESH

ABSTRACT

The steam turbine is the most ideal of all heat engines and prime movers, and it is widely employed in power plants and other sectors where power is required for process. The study's purpose was to develop a power-generating single-stage reaction steam turbine. Thermal energy was used to power the turbine. The research focuses on turbine component design. The micro turbine concept's design and construction were rigorously limited. Stress loss, performance, and angle characteristics were all considered in the blade design. The overall mean temperature and heat transport, as well as other concepts, were used to construct the casing volume. When calculating the amount of tolerance, the heat distribution on the rotor and stator was taken into account. The turbine setup had been constructed according to plan. There were 14 blades made of aluminum. There had been a couple of complications. Leakage was the most important problem of them. Under these conditions, the designed power and heat rate were never achieved. This research looked into the elements and aspects that reduce the turbine's efficiency.

Keywords: Reaction turbine, Nozzle, Blade, Rotor, Aluminium.

1. Introduction

A steam turbine is a mechanical machine that extracts thermal energy from forced steam and transforms it to mechanical energy. Because it generates rotatory motion, the turbine is ideal for the usage of electrical generators. The turbine spins when the vapor stream passes over its blades because the system is driven by steam. The process of the steam cooling and expanding, which practically releases all of its energy, is ongoing. The kinetic energy of a fluid, such as water, steam, air, or combustion gases, is converted into the turbine's own rotating motion. These components, which are referred to as a type of engine, are frequently employed in propulsion systems, engines, and electrical generating. Engines are commonly referred to as such since they are essentially technologies that take an input and create an output. Steel is now one of the most preferred materials for blades in basic turbines because it allows fluid to flow into the turbine and drive the blades. After entering the turbine and losing part of its energy, the air is subsequently expelled by spinning blades. Some of the energy is captured by the turbine and put to use.

Rows of fixed blades and rows of moving blades make up a reaction turbine. As nozzles, the fixed blades serve. The steam expands and accelerates in relation to the rotating blades as well as as a result of the impulse of steam received (produced by a change in momentum). They serve as a kind of relative nozzle, in other words.

Nonlinear mathematical models based on the energy balance, thermodynamic principles, and semiempirical equations were initially constructed in order to analyze the transient dynamics of steam turbine subsections [1]. Then, based on experimental data gathered from a comprehensive set of field trials, the associated parameters of generated models were either defined by empirical relations or they were altered by using genetic algorithms (GA). The simulation results demonstrated the validity of the generated model in terms of more accuracy and reduced variance in responses between the models and eight real systems, where errors of the suggested functions were less than 0.1% and modeling error was less than 0.3%.

Condensing steam turbines' penultimate stage rotor blades lost efficiency and had a shorter lifespan due to erosion brought on by moist steam flow [2]. The amount of data needed to create and validate mathematical models to predict the service life of eroded rotor blades had not yet been sufficiently collected for the erosion process that steam turbine rotor blades were subject to during operation.

Najjar et al. looked at the steam cycle, the bottoming cycle of a combined cycle power plant, in terms of performance diagnostics and deterioration analyses. In order to calculate the steam cycle component degradation percentages, a suggested model was developed to simulate the steam turbine (ST) performance under various loads and operating situations [3]. Over the course of five operating years, performance modeling and degradation analysis were conducted on 2650 reading points (2013– 2017). The percentage of degradation was examined for full load (100%) and part loads (75% and 50%), among other load circumstances.

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*Corresponding Author Email Address: u1503027@student.cuet.ac.bd Published By: SciEn Publishing Group

The findings of an experimental investigation on single stage turbine stator setting angles were presented by Moffit et al. in detail [5]. At the Lewis Research Center, the stator assemblies for the turbine were tested with settings of 70, 100, and 130 percent of design. A description of the turbine, the stator's performance across a range of settings, taking into account both blade loss and surface velocity distribution, and the overall performance of the turbine, including efficiency and weight flow as affected by the stator setting, were all included. A discussion of the variables that may have contributed to the observed variation in efficiency was also provided.

For maritime applications, Medica-Viola et al. presented a thermodynamic (energy and energy) study of a single extraction, low-power steam turbine. The steam turbine under analysis was split into two sections: the high pressure (HP) component and the low pressure (LP) part. Analysis revealed that LP turbine part 10 had lower mechanical, energy, and energy losses than HP turbine component, which therefore provided the bulk of the total turbine power [6].

An erosion test apparatus was used to study the droplet impact erosion resistance of five distinct but very significant steam turbine blade materials [7]. In order to produce monotonic saturating material loss gradients—ideally within a testing time period of 50 hours—the rig adjusted wetness and droplet impact speed conditions in the last stages of condensing steam turbines in such a manner that the material degradation was considerably accelerated.

Analyses of dynamic power systems were increasingly using model simulations. But no mathematical model could replicate a physical process precisely [8]. PC applications enabled simulation and the assessment of the control system performances based on mathematical models of the processes and design calculations. The study showed the steam turbine unit's mathematical modeling, which was created using the continuity equation.

A single-stage transonic axial compressor was created using the multidisciplinary design optimization technique, which merged aerodynamic performance and structural stability [9]. For global optimization within specified ranges of variables and a number of design constraints, an approximation model was developed utilizing artificial neural networks. The Pareto front was explored using the genetic algorithm to determine the value of the greatest objective function. In order to increase the optimization's precision, a second stage gradient-based optimization procedure was used to choose the final design.

Two different ways to calculate the energy of a steam turbine were contrasted by Blaevi et al. in their presentation [10]. A high pressure steam turbine from a supercritical thermal power plant (HPT) was evaluated using the energy flow stream (EFS) and isentropic (IS) techniques at three different turbine loads. The EFS method was based on the power that a steam turbine really produced as well as its input and output energy flow streams. The approach performed admirably while measuring the steam mass flow rate lost via the turbine gland seals. A comparison of turbine steam expansion processes served as the foundation for the IS approach. Because varied causes of steam turbine energy losses precluded direct comparison of observed energy analysis techniques, a comprehensive steam turbine energy analysis was given.

1.1 Objectives

The main objectives of this study are as follows.

- To design and fabricate a single stage reaction steam turbine.
- To analyze efficient designing of a turbine blade.
- To design and fabricate a nozzle for uniform steam flow.
- To produce electricity

1.2 Construction

Steam reaction turbine has various components which are given as follow

1.2.1 Casing

In essence, a steam turbine consists of a casing with fixed stationary blades on the inside and a rotor with moving blades on the outside. Rows of moving blades penetrate between rows of stationary blades when the rotor is installed inside the housing.

1.2.2 Rotor

In a steam turbine, this is the key part that carries the blades that transforms thermal energy.

1.2.3 Blades

The blades take up the energy of the high steam velocity and transfer it to the rotor. High dependability is required since the blade's shape directly affects the turbine's output.

1.2.4 Nozzle

A nozzle is a device that is used to regulate the direction or characteristics of a fluid flow as it exits (or enters) an enclosed chamber or pipe (specially to increase velocity). A nozzle is a pipe or tube with a variable cross-sectional area that can be used to guide or change fluid flow (liquid or gas).

1.2.5 The Bearing Case

When supporting the rotor, the casing and steam chest are put together. The journal bearings and rotating oil seals are contained in the bearing cases, preventing water, dust, and steam intrusion as well as oil leakage outward. The steam end bearing case contains the rotor positioning bearing and spinning parts of the excessive speed trip mechanism. An expansion of the steam ends bearing housing houses the speed-governor system's rotating parts.

1.3 Working principle

Entropy of the steam entering and leaving a steam turbine is same in a perfect steam turbine. With typical isentropic efficiencies ranging from 20% to 90% depending on the turbine's use, no steam turbine is totally isentropic. The inside of a turbine is composed of several sets of blades or buckets. The casing is where one set of the fixed blades is fastened, while the shaft is where the other pair is attached. To make the most of steam expansion at each level, the sets are mixed together with certain minimum clearances while changing in size and arrangement. High-velocity steam flowing from the nozzles strikes the spinning blades that are positioned on a disk that is mounted on a shaft. The high-velocity steam exerts dynamic pressure on the blades, which causes the shaft and blades to both start rotating in the same direction. In a steam turbine, steam pressure energy is recovered and then transformed into kinetic energy by allowing the steam to pass through nozzles. The rotor is linked to a steam turbine generator that acts as a middleman, and the steam turbine generates mechanical work for the rotor blades.

The turbine generator transforms the mechanical energy gathered by the rotor into electrical energy. Despite the fact that different kinds of controlling systems are employed to raise turbine speed, the vibration of a steam turbine is far lower than that of other engines with the same rotational speeds. The reaction turbine's rotor blades are set up to resemble converging nozzles. In this kind of turbine, the reaction force produced when the steam rushes past the nozzles is produced by the rotor. Steam is directed onto the rotor via the stator's fixed vanes. It emerges from the stator as a jet that completely encircles the rotor. The steam then changes direction and moves faster than the blades. There is no net change in the steam velocity across the stage as a result of the steam accelerating through the stator and decelerating through the rotor, but the pressure and temperature do drop, showing the work done in the rotor drive. The disk installed on the shaft is tightly attached to the spinning blades, allowing the higher pressure steam to emerge from the nozzles to directly contact them. The shaft and blades of the system produce energetic pressure as a result of the steam's increased velocity, which causes them to start rotating in the same direction. Generally speaking, the steam turbine separates the steam's energy and transforms it into kinetic energy, which then travels through the nozzles.

2. Design

2.1 Blade design

The shape of the rotating blades in impulse and reaction turbines, however, differs. The flow area of reaction turbines changes as the blades move. They have the form of nozzles which accelerate the steam as it flows through them. Steam turbine blade is modeled as shown in Fig. 1.

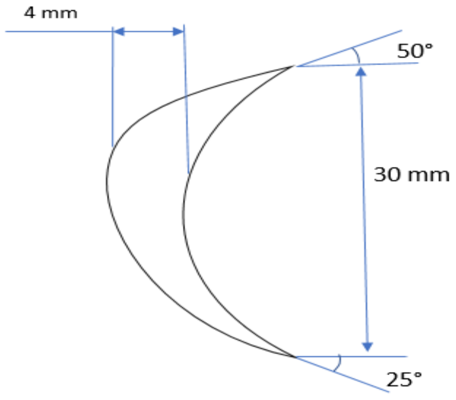

Fig.1 Model of steam reaction turbine blade

2.2 Nozzle design

A nozzle is a system that controls the direction and characteristics of a fluid flow as it leaves an enclosed chamber or pipe. The convergent nozzles are used to increase fluid velocity and thus convert most of the fluid energy into its kinetic energy. Such nozzles are used to run turbine blades in impact turbine electric generators. Model of steam reaction turbine nozzle is shown in Fig. 2.

Here, the steam is saturated with a mass flow rate of 19 kg/hr and pressure drop is 10 bar to 6 bar.

From steam table, corresponding to a pressure of 10 bar, the enthalpy of dry saturated steam,

$$h_1 = 2776.14 \text{ kJ/kg}$$

And the entropy of the dry saturated steam,

$$s_1 = 6.5828 \text{ kJ/kg K}$$

And corresponding to a pressure of 6 bar the enthalpy, Hence the entropy,

$$s_{f2} = 1.9307 \text{ kJ/kg K}$$

And

$$s_{fg2} = 4.8274 \text{ kJ/kg K}$$

therefore,

Entropy of steam at inlet (s_1) = Entropy of steam at exit (s_2)

$$s_1 = s_{f2} + x_2\, s_{fg2} \qquad [x_2 = \text{dryness fraction}]$$

$$6.5828 = 1.9307 + x_2\, 4.8274$$

$$x_2 = .96$$

Now enthalpy or total heat of steam of exit,

$$h_2 = h_{f2} + x_2\, h_{fg2}$$
$$= 670.30 + (.96 \times 2085.24)$$
$$= 2672.13 \text{ kJ/kg}$$

Isentropic enthalpy drop,

$$h_1 - h_2 = (2776.14 - 2672.13)$$
$$= 104.14 \text{ kJ/kg}$$

Assuming nozzle efficiency, actual enthalpy drop,

$$h_1 - h_2 = (104.14 \times .85)$$
$$= 88.519 \text{ kJ/kg}$$

Now, energy equation for nozzle,

$$h_1 + \frac{v_1^2}{2} = h_2 + \frac{v_2^2}{2}$$

As the inlet velocity of the nozzle is negligible, $v_1 \approx 0$

Then,

$$\frac{v_2^2}{2} = (h_1 - h_2)$$
$$\Rightarrow v_2 = \sqrt{2000 \times (h_1 - h_2)}$$
$$= \sqrt{2000 \times 88.519}$$
$$= 420.76 \text{ m/s}$$

Now for 19 kg/hr of mass flow rate of the steam at the exit of the nozzle,

$$\dot{m} = \rho\, A_2 v_2 \qquad [\dot{m} = 19 \text{ kg/hr} = \frac{19}{3600} \text{ kg/s}]$$
$$\Rightarrow \frac{19}{3600} = (3.17 \times A_2 \times 420.76)$$
$$\Rightarrow A_2 = 7.04$$
$$\Rightarrow \frac{\Pi d_2^2}{4} = 7.04$$
$$\Rightarrow d_2 = 2.99$$
$$\Rightarrow d_2 \approx 3 \text{ mm}$$

So the exit diameter of the nozzle should be 3 mm.

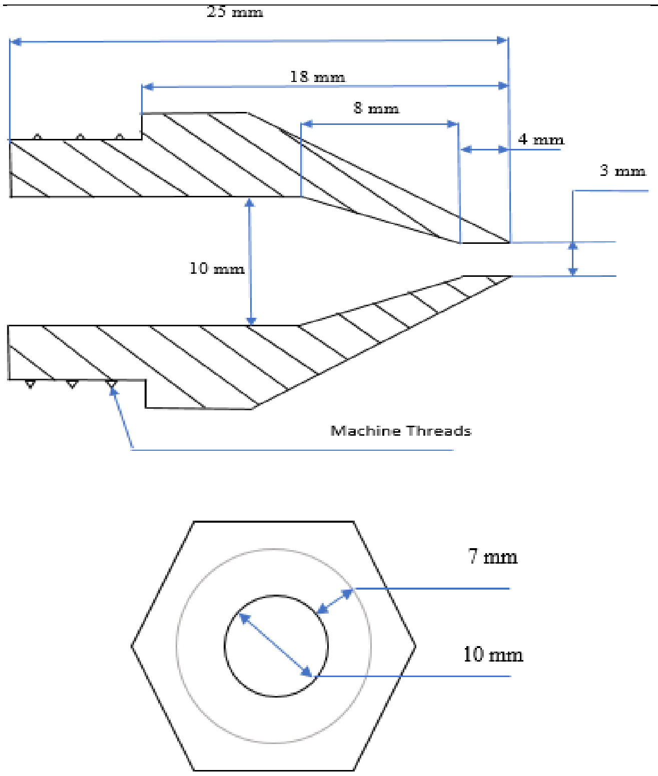

Fig.2 Model of steam reaction turbine nozzle

2.3 Material selection

The material choice for various turbine components is influenced by the strength or tension/compression that a component can bear. The turbine's total weight is maintained to a minimum thanks to the heat transfer coefficient and thermal resistance. Lightweight materials that can withstand the stress and strain of that specific component were favored over heavy or bulky components while selecting materials. The components' materials, estimated prices, and suggested production techniques were chosen after a thorough analysis.

Mostly aluminium is used here. It has a low density and a good resistance to corrosion.

3. Experimental Setup and Procedure

3.1 Reaction turbine model

Fig. 3 shows the picture of the reaction turbine model. The turbine was connected to a spindle that was supported by two bearing bushes. Aluminum metal was used to cast the turbine blades. To accomplish so, a wooden blade sample was initially created in a wood workshop. After then, the molding process was completed.

Fig.3 Picture of reaction turbine model

Total 14 blades were produced. Each of blades was welded very strongly with the circular disc. The blades were welded to a 80-mm-diameter circular disc. Fig. 4 shows the single blade picture.

Fig.4 Blade

The disc was made of aluminium. Then the turbine was set on a shaft. Two bearing bushes were made. The spindle was passed through the whole of the bearings. As shown in the Fig. 5, the front view and the right side view are clear to understand.

Fig.5 The turbine

The nozzle shown in Fig. 6 was fabricated from a steel bolt. It was drilled from both sides to make the steam flow path. Two types of drill bit was used to make. The nozzle was fitted at 20º of angle with the turbine like the design. It was also connected with the boiler with a metal pipe including a valve. The valve was to control the steam flow. Fig. 7 shows the full experimental setup of steam reaction turbine.

Fig.6 Nozzle

Fig.7 Full experimental setup

3.2 Working Procedure

At first the coal was ignited on the tray. The heat produced from the coal was absorbed by the water. The water was turned into steam and it created the boiler pressure. The average pressure was 3.5 bar. The pressurized steam was exerted on the turbine blade through nozzle. Continuous rotation was occurred by the steam pressure. The mechanical energy of the turbine was converted into electrical energy by generator mounted on the turbine shaft. Then the voltage data was taken.

4. Result and Discussion

Another instruments which was used for the experiment was a tachometer for measuring turbine speed, a boiler for steam production and electrical system in which there is an electric motor of 12 volt which is connected with a volt meter through a wire for generation of electricity.

4.1 Calculation from boiler

Here, mass of water = 2 kg
Time period = 30 min = 1800 s
Feed water temperature = 25°C
At, 3.5 bar
t_{sat} = 138.86°C
h_{fg}= 2147.7 kJ/kg
The amount of heat required in a given time,

$$Q = m.C_p.dT/t$$
$$= \{2 \times 4.2 \times (138.86-25)\}/1800$$
$$= 0.54 \text{ kW}$$

The amount of steam produced,

$$m_s = Q/hfg$$
$$= 0.54 \text{ kW}/ 2147.7 \text{ kJ/kg}$$
$$= 2.47 \times 10^{-4} \text{ kg/s}$$

The amount of heat supplied,
H = calorific value of fuel × mass flow rate of fuel
Here, coal was used as fuel and 2 kg coal was used to burn the total water and it was done in 30 minutes.
So, the mass flow rate of coal = (2/1800) kg/s
$= 1.11 \times 10^{-3}$ kg/s
Here, calorific value of coal= 32084 kJ/kg
So, the amount of heat supplied,

$$H = 32084 \text{ kJ/kg} \times 1.11 \times 10^{-3} \text{ kg/s}$$
$$= 35.61 \text{ kW}$$

Here,
$m_s = 2.47 \times 10^{-4}$ kg/s
$m_f = 1.1 \times 10^{-3}$ kg/s
CV = 32084 kJ/kg
$h_s = h_g$ = 2732 kJ/kg [at 3.5 bar]
h_w = 104.83 kJ/kg [at 25°C]

Boiler efficiency (η) = $[\{m_s \times (h_s - h_w) \times 100\} / (m_f \times CV)]$
$= [\{2.47 \times 10^{-4} \times (2732-104.83) \times 100\} / (1.11 \times 10^{-3} \times 32084)]$
= 1.83 %

Boiler efficiency here is considerably low for leakage problem. By reducing this flaw efficiency can be increased and it can be practically used.

4.2 Reaction turbine data

The speed of the shaft was measured with a tachometer.
Here, speed, N = 900 rpm
And electricity is produced which was measured by a voltmeter. The voltage measured was 3 V.

4.3 Discussion

Small-scale turbines are on the rise, and they have the potential to boost power generation and productivity. The improvement is flexible and has the potential to meet the energy needs of developing countries. The practical execution of the design could open up a new frontier for allowing creative private power generation to supplement the public supply. More research can be done in the areas of developing a long-lasting gearing system to handle overloads and an insulating system to reduce heat loss. This paper provides an analysis of how to improve the performance of steam power turbine electricity generation.

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NOMENCLATURE

s : specific entropy, kJ/kgK
h : specific enthalpy, kJ/kg
h_f : specific enthalpy of saturated water, kJ/kg
h_{fg} : specific enthalpy change of vaporization, kJ/kg
s_f : specific entropy of saturated water, kJ/kgK
s_{fg} : specific entropy change of vaporization, kJ/kgK