Short Research Article

Design of a Heating Chamber for Air Turbines: A Method of Optimizing Its Efficiency

ABSTRACT

Increasing comfort, conveniences and reducing carbon-emission into the atmosphere have been the research focus of many researchers in various field of science. SDGs have one of her goals to be zero carbon emission. In order to achieve this goal, carbon combustion must be eliminated in heat engines. This can be done by developing thermodynamics processes that would not use organic fuel as their working fluid. Following this knowledge, researchers found the use of abundant natural resources such as solar, water, wind, and air known as renewable energies also hydrogen and synergy gases as replacement to carbon combustion. However, due to high first cost of these renewable energies and their low mechanical and overall efficiencies, they failed in some application.

In order to increase the mechanical efficiency of air turbines, the internal energy of air must be increases. Therefore, this research paper developed a heating chamber for air turbines working on an isobaric expansion process in order to raise the temperature of air to the required temperature for it to roll turbine rotor blades efficiently. The heating compartment is intended to follow the adiabatic compression process of an air compressor section of the air turbine layout. The heating compartment has it heat source to be an electric heater and the compressed air as it heat sink. The thermal and economic efficiency of the heating chamber as a section of air turbine was determine using Levelized Cost Method of Moran.

The heating compartment raised the compressed air temperature to the required hot temperature at a constant pressure.

1.0 Introduction

Energy is considered a player in the generation of wealth and also a critical component in economic development of a nation. [Arulkumaran & William Christraj, 2012] As important energy is, also its generation method has to be considered in order to minimize its cost of generation and other negative effects associated with its generation such as environmental factor and safety. As an attempt to develop the best method of energy generation, Renewal Energy is accepted as a key source for the future [Arulkumaran&WilliamChristraj, 2012] and in order to make the future present; a lot have done in renewal energy research. Rohatgi et al. (2020) defines renewable energy as energy derived from natural resources that replenish themselves in less than a human lifetime without depleting the planet's resources. Although renewable energies are considered to be the future of energy, they all faced a similar problem of moderately low efficiency. [Taiwo Alare, 2020]

Air which is a renewable natural resources and the cheapest fuel is less considered as renewable energy source because of its low internal energy at its free mode. Many methods have been developed to optimize the efficiency of air turbines. Falcons et al. (2016) developed power optimization for air turbine.

Although air turbine has been used in various applications such as wave energy converter [Falcons et al., 2016] but its low efficiency is still a concern. Department of Energy is seeking for methods of raising compressed air temperature. With this mission, we designed a compressed air turbine with a heating compartment to raise the temperature of compressed air at constant pressure.

Following the model of a gas turbine, the heating compartment section precedes the air compressor and follows by the turning section like the combustion chamber is of a gas turbine. The thermodynamic cycle of the compressed air turbine is close to gas turbine cycle and Bryton cycle with a slight difference of isobaric expansion. This paper reported the efficiency optimization contribution and cost rate contribution of heating compartment to an air turbine.

2.0 Materials and Methods

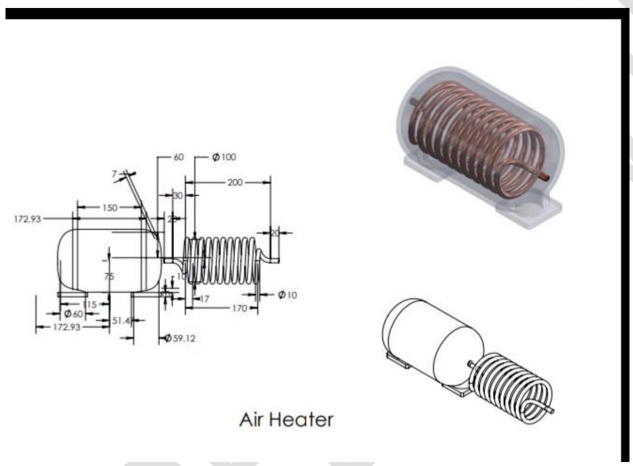

Fig 1: Air Heater

Solidwork CAD software was used to design the heating compartment section and it made of the outer chamber, liner, air liner and the heater pipe. The outer chamber is made of low carbon steel, the liner is made of brass and the heater pipe is made of copper. The heater pipe is design to be powered by 1000W of Electrical true power.

Parameters d_c=100mm, n_c=10, d_t=10mm

The total length of tube of the circular section of pipe (L) = $n_c P_c = \pi n_c \emptyset_c$ =1000πmm =πm

3.0 Heat Transfer

1000w of electrical power will be supply to the copper tube conductor to raise it temperature from 0°C and the heat generated will be transferred to the air and to the outer casing.

$$Q' = -K_C \frac{dT}{dx} \quad Q' = \frac{P}{A} \quad P = 1000w \quad A = \pi r(r + L) \quad r = \frac{d_t}{2} \quad r = 0.005m \quad L = \pi m \quad dT = T_0 - T_1$$

$$dx = L \quad T_0 = 0^O C \quad T_1 = ? \quad T_1 = 158.51^O C$$

The temperature of the outer casing is determine by the heat of convection from the heater pipe to the casing through forced air $Q' = h_{FA}(T_1 - T_{out}) \rightarrow Newton\ law's\ of\ coolng\ with\ forced\ air\ as\ it\ medium.\ h_{FA} = 500\ wm^{-2}k^{-1}$ $Q' = 17123.29\ wm^{-2}$ $T_1 = 158.51^oC$ $T_{out} = ?$ $T_{out} = 124.25^oC$

4.0 Thermodynamics

It is the isotopic expansion process with a slight change in volume

$\frac{T}{Cp(T)} = \frac{\partial T}{\partial s}\Big|_P$ [Harding, 2018] Tds = Cp(T)dT $ds = CpdT$ $ds = Cp(T_1 - T_0)$ $T_0 = OK$ $T_1 = 158.32°C = 431.52K$ $ds = Cp\ (T_1 - T_0)$ $ds = 1.005kg = 431.52$ $ds = 433.6776\ kJ/Kg \rightarrow entropy$

Therefore there’s an increase on energy of the working fluid (compressed air) by 433.68kJ for every kilogram of air

5.0 Energy Costing Analysis

The cost contribution of a heating compartment to an air turbine per year is determined by using levelized Cost method of Moran.

The cost rate

$$\dot{C}[\$\text{ per year}] = [\text{PEC} - (\text{SV})\text{PWF}(\text{i},\text{n})\text{CRF}(\text{i},\text{n})]\ [Goriji - Bandpy\ et\ al., 2011]\ \ Sv = 0.1\ \ PEC = 4122\left[\frac{\dot{M}g(h_{in} - h_{out}}{18\Delta T_{imaph}}\right]^{0.6}\ [Goriji - Bandpy\ et\ al., 2011]$$

$\Delta T_{imaph} = T_1 - T_o = 431.51K$ $h_{out} = \frac{1}{ds}$ $=0.0023kJ^{-1}K$ $PEC = 4122\left[\frac{\dot{M}g(h_{in} - 0.0023}{7767.36}\right]^{0.6}$ $PWF(i,n) = (1+i)^{-n}$ $CRF(i,n) = \frac{i}{1-((1+i)^{-n})}$

$$\dot{C}[\$\text{ per year}] = PEC - \frac{0.1(1+i)^{-n}}{1-(1+i)^{-n}} = 4122\left[\frac{\dot{M}g(h_{in} - h_{out}}{18\Delta T_{imaph}}\right]^{0.6} - \frac{0.1(1+i)^{-n}}{1-(1+i)^{-n}}$$

The energy cost rate of the heating compartment = $4122\left[\frac{\dot{M}g(h_{in} - h_{out}}{18\Delta T_{imaph}}\right]^{0.6} - \frac{0.1(1+i)^{-n}}{1-(1+i)^{-n}}\ \$/year$

6.0 Conclusion

The heating compartment is able to raise the energy of air by $433.6776\ kJ/Kg$ at the same compressed pressure; therefore the efficiency of compressed air turbine is being optimized by the addition of a heating compartment.

7.0 Nomenclature

d_c diameter of the circular pipe — n_c number of cycles.

P_c circumference of the circular section — L length of pipe

K_C *conductive heat transfer coefficient of copper* — P *electric power supply*

d_t tube diameter — Q' *quantity of heat*

A area of the circular section — r radius of the circular section

T temperature

h_{FA} *convective heat transfer coefficient of forced air*

ds entropy — Cp *specific capicity of air at pressure*

h enthalpy — $\dot{C}$ cost rate

PEC Purchased equipment cost of air heater — SV salvage value

PWF Present worth factor — CRF capital recovery factor

i interest rate — n time period

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