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Design and Optimization of the Thermal Hydrogen Gas Turbine

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Abstract - *This paper describes the design and optimization of the air intake system for the inlet manifold of a hydrogen gas turbine. Due to variances of turbine outputs and implementations, several intake air manifolds designs are required to realize optimum volumetric efficiency, as a result, the highest performance of the turbine is selected. This paper looks at the hydrogen gas flow parameters, which moving via several types of air intake manifolds. 3D simulations of airflow during two models of the turbine air intake manifold are performed by using the commercial Computational fluid dynamics (CFD & ANSYS) software. Experimental research employing a flow bench is used to validate the simulation results. Modifications of the air intake system design, can outcome to change the mass flow-rate of the air entering into turbine combustion chamber up to 20%, according to the findings of this study also, the thermal analysis was performed on the original turbine model (OTM) and also to the modified turbine model (MTM) using two different of materials are cast iron and stainless steel, and plotted the findings in a tabular format to compare the results. Based on these findings, can infer that the stainless steel modified turbine model is the better material because it contains heat flux is low and also has directional heat flux is low, as indicated in the characteristics table (1). All of the data are presented in tabular and graph form, and the modified model is regarded as the better model in all variants because there is a considerable difference in temperature, velocity, and stress, as shown in the characteristics table (2). The designs were done by Catia, 3D software, and the analysis was carried in ANSYS software.*

Key Words: Original turbine model (OTM), modified turbine model (MTM), stainless steel, cast iron, ANSYS software, Catia, 3D software.

INTRODUCTION:

The turbine is a rotary mechanical system that can convert the fluid-flow energy into beneficial action. The turbines are considered as turbo-machine that has one moving component at least, the rotor compound is made up of blades attached with a shaft, as shown in figure 1 [1]. The rotational energy generating by the blades and the rotor receives it as they move as a result of the moving fluid/air. “Windmills and water wheels” are examples of present turbines. The aim of the research is to designing and modifying new Turbine models from different materials, to reduces the operating costs and increasing the efficiency of the turbines, which are usually calculated in $/KWh [2] As a result, the problem statement structural performance, durability requirements, safety dangers, transportation issues, noise, and aesthetic pollutions all become more difficult for designers to address. Furthermore, government-set energy policies, international treaties, legislation, and regulations must all be adhered to. As a result, the only way to solve the complicated design challenge of turbine design is to Comparing two different designs to find the best solution. As will be explained, several objective functions, design restrictions, methods, tools, and models have been suggested.

Figure 1: Turbine [3].

1.1: Types of Turbines:

1.1.1: Turbines of Steam.

They were previously used to control mechanical systems directly, like propellers of a ship, for example, the powered steam turbine in the beginning operation, however, all of these applications rely on an intermediate electrical step or the reduction gears, in which the turbine generates electricity, and then powers an electric motor connected to a mechanical load [4]. Turboelectric ship equipment was notably popular in the years leading up to and during WWII caused by a lack of sufficient cutting of gear facilities in shipyards in the United States and the United Kingdom

1.1.2: Turbines of Gas:

Turbine engines are another name for gas turbines. In addition to one or more turbines, these engines normally have an inlet, fan, compressor, combustor, and nozzle.

1.1.3: Turbine of Transonic:

During the expansion process, the gas flow in most-turbines used in the turbine of gas engines still remains subsonic. Although downstream velocities are normally subsonic, the gas-flow in a transonic-turbine becomes supersonic as a way out the nozzle guiding vanes. In spit inefficient downstream velocities are subsonic. Subsonic-turbines operate at a more pressure ratio than traditional turbines.

1.1.4: Turbines of Contra-rotating:

Axial turbines are received an efficiency advantage when in the opposite direction is a down-stream turbine rotates as an upstream unit. However, the complexity may work counterproductive. The concept consists of a nested turbine rotors pair or multistage radial turbine that operates at high efficiency and heat drop per phase as four times as a Parsons Turbine reaction and is a highly compact construction. It worked very well in back-pressure power plants. Large steam volumes, on the other hand, are difficult to handle, and the turbine can only be built with a combination of axial flow turbines (DUREX) to produce power up to 50 MW or more. In the period 1917-19 only around 50 units of electroturbine were ordered for maritime applications, which were later transferred to land factories in large numbers. And a few mechani-turbaine devices that were not particularly successful were sold throughout 1920-22 [5]. In the late 1960s, just a few electro-turbine naval factories were still in service, whereas a majority of land units were still in use in 2010.

1.1.5: Turbine of Stator-less:

The rotor blades of the turbine rotating when a gas flow is directing by a set of static (or stationary) input guide vanes in multi-stage turbines. In a turbine of stator-less, gas-flow from an upstream-motor impinges on a downstream-motor without passing through an intermediate stator set vanes “which rearrange the flow pressure and velocity energy levels”.

1.1.6: Turbine of Ceramic:

To keep the metal from overheating, turbine blades of high-pressure "and vanes" are often made of nickel-based alloys, by elaborate internal air-cooling tunnels. Blades of experimental ceramic have been produced and utilized in gas-turbines in recent years to raise rotor inlet temperatures and reduce the need for air-cooling [7]. The blades of ceramic are more delicate than blades of metal and are more likely to fail catastrophically. As a result, stator (stationary) blades have tended to be the only ones used in gas turbines and jet engines.

1.1.7: Turbine of Shrouded:

There are shrouding at the top of the many turbine rotor blades overlap with that of neighboring blades to minimize blade flutter and thereby increase damping. Lacing wires are frequently used in big ground-electricity generation steam-turbines to supplement the enshrouding, especially in the low-pressure turbine that has lengthy blades. Brazed are these wires to the blades in the point where they pass into drilled of holes into the blades are located on appropriate distances of the blade root [8]. Lacing wires reduce blade flutter in the blade's middle region. Laced wires have significantly reduced the failures blade cases in low-pressure turbines.

1.1.8: Turbines of Water:

a. Turbine of Pelton, impulse water type turbine.

b. Turbine of Francis, widely used water type turbine.

c. Turbine of Kaplan, the deference of the Francis Turbine.

d. Turbine of Turgo, the modified form of the Pelton wheel.

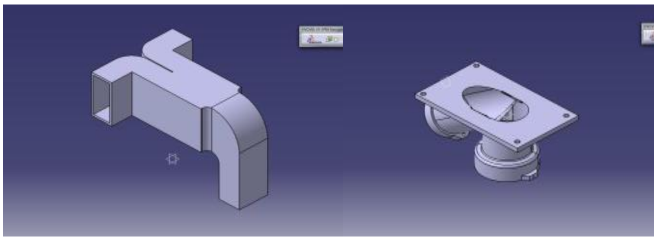
e. Turbine of Cross-flow, also known as turbine of Ossberger or turbine of Banki-Michell.

1.1.9: Turbine of Wind:

These are usually used as a single-stage with no nozzles or interstate guide vanes. The ÉolienneBollée is an exception, as it has both a stator and a rotor.

2: Analysis of Models Flow:

The hydrogen turbine inlet-manifold original-model and modified-model turbine, as shown in figure (2), was created from 2 different materials are Cast-iron and Stainless-steel, using commercial CFD software, ANSYS, 3D simulations of airflow during 2 designs of the air-intake manifold into the turbine will be performed by five types of cases, as shown in figures (4, 5, 7, 9).



(a) **(b)**

Figure 2: **(a)** Original Model of Hydrogen Turbine and **(b)** Modified Turbine Model:

2.1: Analysis of Thermal Cast Iron Turbine, Original Model:

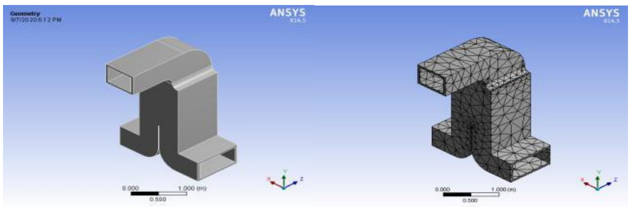


Figure 3: Geometry and Mesh of the Original Model Respectively :

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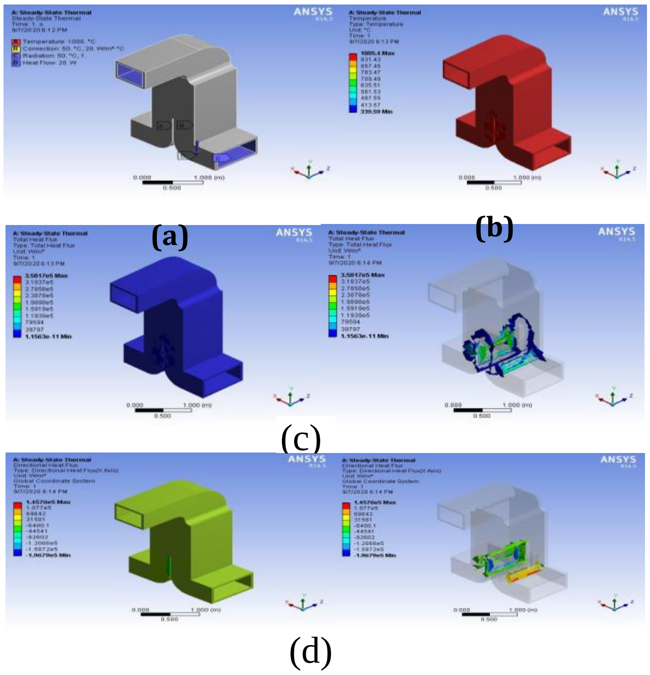


Figure 4: Illustrating the (a) Thermal of steady state, (b) Temperature, (c) Total heat flux, and (d) Directional heat flux respectively

2.2: Analysis of Thermal Stainless steel Turbine, Original Model.

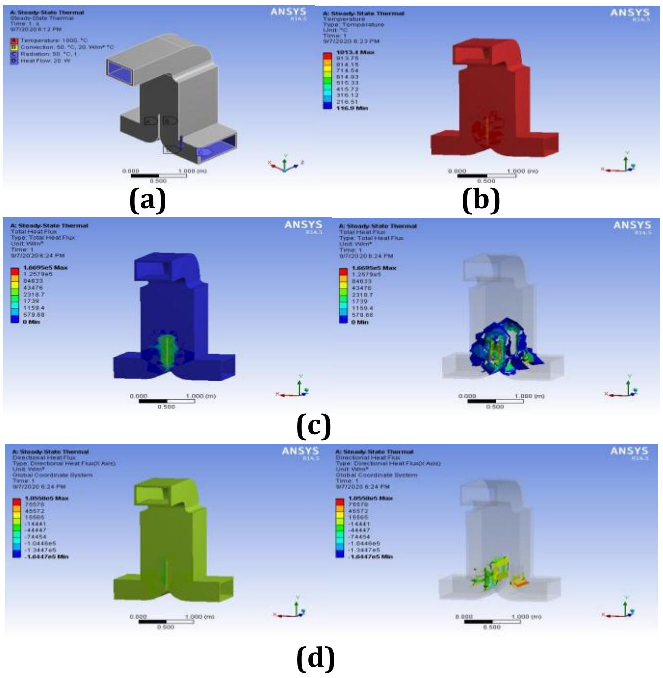


Figure 5: Illustrating the (a) Thermal of steady- state, (b) Temperature, (c) Total heat flux, and (d) Directional heat flux respectively:

2.3 Analysis of Thermal Cast Iron Turbine, Modified Model:

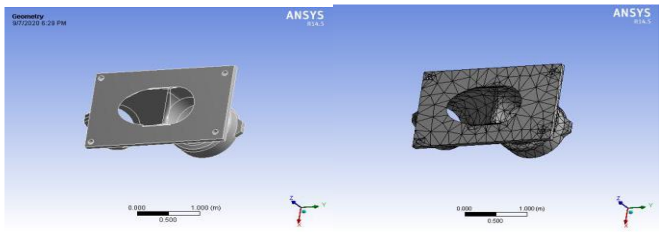


Figure 6: Geometry and Mesh of the Modified Model (b) Respectively

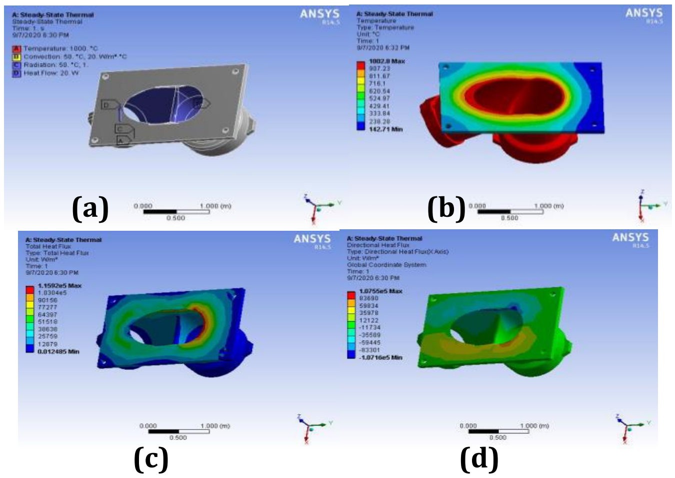


Figure 7: Illustrating the (a) Thermal of steady- state, (b) Temperature, (c) Total heat flux, and (d) Directional heat flux respectively

2.4: Analysis of Thermal Stainless Steel Turbine, Modified Model:

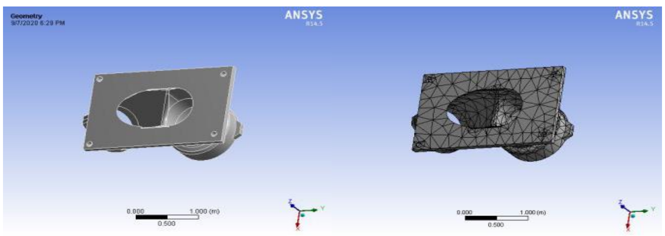
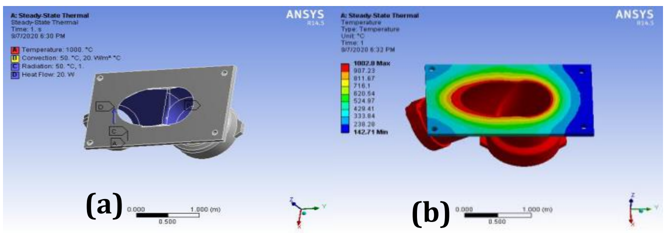
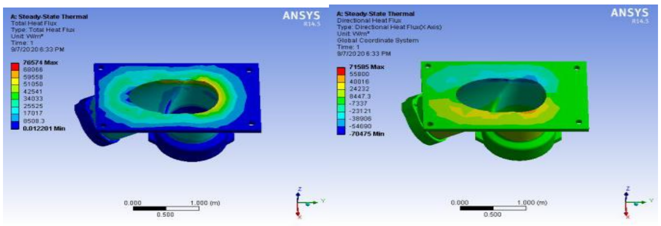


Figure 8: Geometry and Mesh of the Modified Model Respectively :





(c) (d)

Figure 9: Illustrating the **(a)** Thermal of steady state, **(b)** Temperature, **(c)** Total heat flux, and **(d)** Directional heat flux respectively

2.5: CFD Analysis of Original Turbine Model :

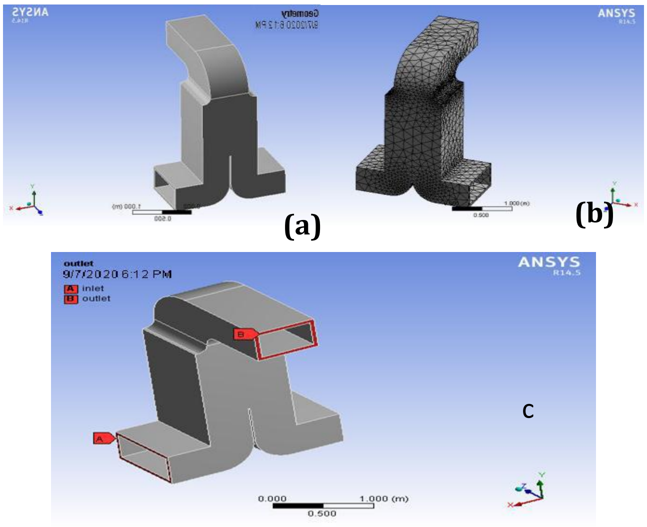


Figure 10: Illustrating the **(a)** Geometry, Mesh and, **(b)** Input data of the Original Turbine Model Respectively.

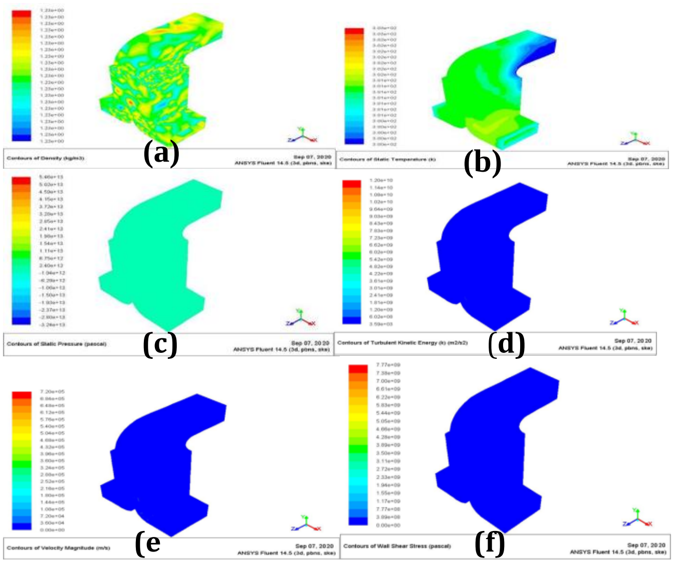
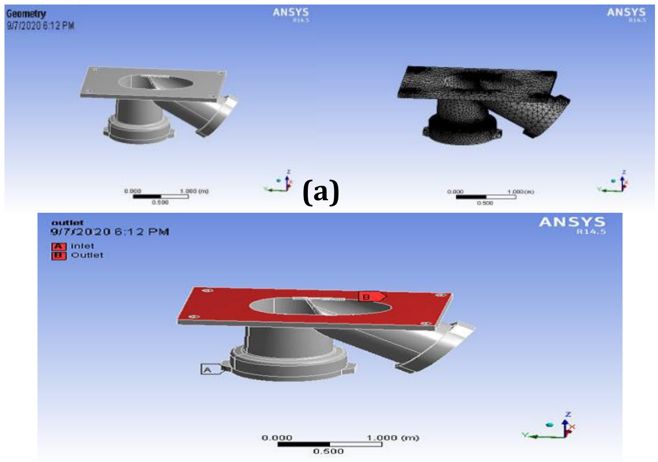


Figure 11: Illustrating the (a) Density, (b) Temperature, (c) static pressure, (d) Turbulent kinetic energy, (e) Velocity magnitude, and (f) Wall shear stress, of the Original Turbine Model Respectively

2.6: CFD-Analysis of Modified Turbine Model



(b)

Figure 12: Illustrating the **(a)** Geometry, Mesh and **(b)** Input data of the Modified Turbine Model Respectively

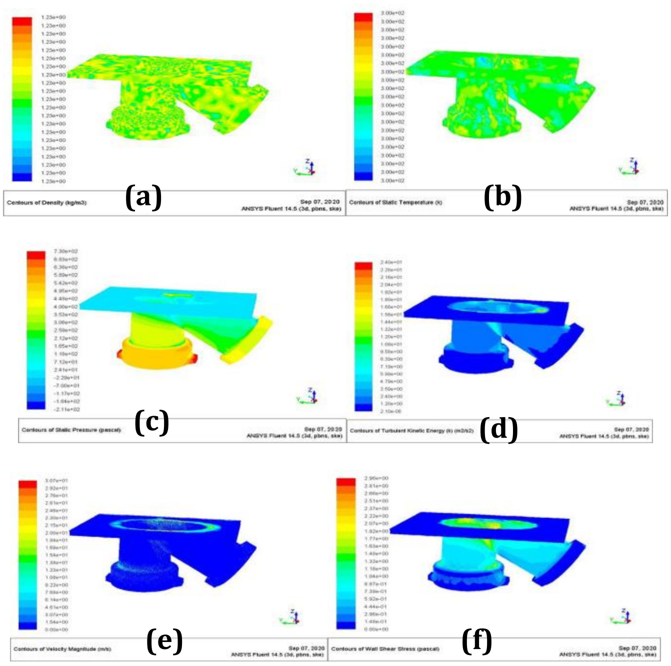


Figure 13: Illustrating the (a) Density, (b) Temperature, (c) static pressure, (d) Turbulent kinetic energy, (e) Velocity magnitude, and (f) Wall shear stress, of the Modified Turbine Model Respectively

3: Result and discussions :

We can conclude from the results of the comparison result tables that the modified turbine model is the better material because it contains heat flux is very low and also has directional heat-flux is low, as shown in table (1). As can be seen, the outcomes are presented in tabular and graph form, and the modified-model turbine is recognized as the better model in all variants because the stress, velocity, and temperature are significantly different, as shown in table (2).

Table 1: Thermal Analysis of Original Turbine Model (OTM) and Modified Turbine Model (MTM):

Materials of OTM	Temperature, ⁰C		Total-heat-flux, W/m²		Directional-heat-flux", W/m²	
	Min	Max	Min	Max	Min	Max
Cast Iron	339.59	1005.4	1.1563e -11	3.5817e⁵	-1.9679e⁵	1.4576e⁵
Stainless steel	116.9	1013.4	0	1.6695e⁵	-1.6447e⁵	1.0558e⁵

Materials of MTM	Temperature, ⁰C		Total-heat-flux, W/m²		Directional-heat -flux, W/m²	
	Min	Max	Min	Max	Min	Max
Cast Iron	425.8	1001.4	0.012485	1.1592 e⁵	-1.0716e⁵	1.0755e⁵
Stainless steel	142.71	1002.8	0.012201	76574	-70475	71585

Table 2: CFD Analysis of Original Turbine Model (OTM) and Modified Turbine Model (MTM):

Model Type	Pressure, Pa		(Density, Kg/m³)		Temperature, ⁰C	
	Min	Max	Min	Max	Min	Max
OTM	-3.24e+13	5.46e+00	1.23e+00	1.23e+00	3.00e+02	3.03e+03
	Turbulent-kinetic-energy K. m²/s²		(Velocity magnitude)" m/s		Wall-shear-stress Pa	
	Min	Max	Min	Max	Min	Max
	3.59e+03	1.20e+10	00e+00	7.20e+05	00e+00	7.77e+09

	Pressure, Pa		Density, Kg/m³		Temperature, ⁰C	
	Min	Max	Min	Max	Min	Max
MTM	- 2.11e+02	7.3e+03	1.23e+00	1.23e+00	3.00e+02	3.00e+03
	Turbulent-kinetic-energy K. m²/s²		Velocity-magnitude m/s		Wall-shear-stress Pa	
	Min	Max	Min	Max	Min	Max
	2.10e-06	2.40e+01	00e+00	3.07e+01	00e+00	2.96e+00

Conclusions:

This study looks at how the manifold inlet air intake system of the liquid hydrogen turbines is designed. Due to variances of turbine outputs and implementations, several intake-air manifolds designs are required to achieve optimum volumetric efficiency, as a result, the highest performance of the turbine is selected. This research will look at the flow properties of liquid-hydrogen flowing via several types of air-intake-manifolds. 3D simulations of airflow by two models of the turbine air intake manifold are performed by using the commercial Computational fluid dynamics (CFD & ANSYS) software. We performed thermal analysis on the original turbine model (OTM) and also to the modified turbine model (MTM) using two different of materials are cast-iron and stainless-steel, and plotted the findings in a tabular format to compare the results. Based on these findings, can infer that the stainless steel modified turbine model is the better material because it contains heat flux is low and also has directional heat-flux is low, as indicated in the characteristics table (1). All of the data are presented in tabular and graph form, and the modified turbine model is regarded as the better model in all variants because there is a considerable difference in temperature, velocity, and stress, as shown in characteristics table 2

Future Scope:

The liquid hydrogen turbine intake manifold is thermally and computationally analyzed using two models manufactured of two different materials, cast-iron, and stainless-steel. The research can be furthered by examining various models of the intake manifold that are already available. It's possible to extend forward this study, materials such as composites and functionally graded materials can be used. A lot of other components of the turbine, such as the turbine housing, propeller blades, hub, shaft, and so on, can be analyzed in addition to the intake manifold

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BIOGRAPHIES

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