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Research Paper

One-dimensional model analysis and performance assessment of Tesla turbine

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HIGHLIGHTS

- Nozzle limit expansion ratio is introduced in the nozzle analysis.
- The flow is regarded as turbulence and friction factor is determined by Moody Figure.
- Rotor radial pressure gradient is considered in the model.
- In the current model, there is no experienced parameter.
- Tesla turbine performance is analyzed using the 1-D model.

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ABSTRACT

Tesla turbine is characterized by the bladeless design that makes it easy to be manufactured and operated. It offers an attractive option for power output in small and micro scale systems if an efficient design can be achieved. One-dimensional model is useful as it can adequately represent the flow characteristics in the Tesla turbine and allow parametric exploration for early design analysis. This paper improves the one-dimensional model for Tesla turbine. The limit expansion ratio of the nozzle is introduced, which is related to the geometry angle and the working fluid properties. The flow loss in the nozzle is evaluated instead of assuming an empirical velocity coefficient. The flow is regarded as turbulence rather than laminar, and friction factor is determined by the Reynolds number based on Moody Figure. In the rotor, the governing equations for compressible flow between adjacent discs are used. In addition, the radial pressure gradient effect in the rotor gap spacing is considered. The improved model show better agreement with the experimental data than the original model. The flow characteristics in the Tesla turbine is analyzed and the streamline of the bulk flow in the rotor is derived based on the one-dimensional model. Tesla turbine can yield considerable efficiency and it can be regarded as a potential choice to be applied in small and micro scale systems.

1. Introduction

Tesla turbine was invented and patented by the famous scientist Nikola Tesla in the early 20th century [1]. This bladeless design makes use of the viscous effect in the boundary layer flow between the rotating discs. The nozzles are located at the outside edge of the discs, through which the working fluid flows nearly tangentially into the rotor. A series of flat discs distribute parallelly and co-axially along a shaft hence small gaps are formed between any two adjacent discs. The working fluid flows spirally from the disc outer part to the inner part, converting the angular momentum into shaft torque by virtue of coupling of the fluid and the discs. The exhaust working fluid flows out through the outlet ports in the discs near the shaft.

Tesla turbine is characterized by the particularly simple and bladeless rotor design. However, in the year leading up to this novel invention, it received only limited attention [2,3]. The initial interest in Tesla turbine began in the 1950s. Rice [4] conducted both analytical and experimental explorations on Tesla turbines, which provided considerable insight into the operating characteristics. Beans [5] investigated a Tesla turbine theoretically by using the differential forms of the equation of motion, and the qualitative agreement between calculated and experimental performance was satisfactory. Armstrong [6] implemented analysis of friction turbine to determine ways to improve upon Tesla's original design and offer suggestions for further

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Nomenclature

$\dot{m}$	mass flow rate, kg/s
h	specific enthalpy, kJ/kg
T	temperature, K
p	pressure, kPa
W	power, kW
v	velocity, m/s
c	sonic speed, m/s
U	rotor surface tangential velocity, m/s
r	radius, mm
b	gap distance, mm
f	friction force
V	volume, m^3
A	area, m^2
l	length, m
d	diameter, m
k	specific heat ratio
Re	Reynolds number
Ma	Mach number
n	rotation speed, rpm

Greek symbols

η	efficiency
φ	nozzle velocity coefficient
ρ	density, kg/m^3
μ	viscosity coefficient, Pa s
α	nozzle geometry angle, deg
δ	deviation angle, deg
ε	Nozzle expansion ratio
ζ	flow loss in the nozzle

Subscripts

T	turbine
1	outer circumference of the rotor
2	inner circumference of the rotor
1′	front part of the nozzle (before throat area)
1″	latter part of the nozzle (after throat area)

Superscript

*	total parameter

Acronyms

CFD	Computational Fluid Dynamics

investigations; in addition, possible commercial applications was also discussed.

Recently, there has been a resurgence of interest in Tesla turbine since it can allow a low cost, reliable design to generate power at small and micro scales and act as the prime movers that drive generators for applications of varying sizes. A lot of analytical and experimental investigations have been conducted to explore the performance characteristics of Tesla turbine. Lemma et al. [7] presented experimental and numerical study to explore the performance characteristics of viscous flow turbines and the results indicated that the adiabatic efficiency of this kind of turbomachinery was around 25%. Lampart et al. [8] presented results of the design analysis of a Tesla turbine intended for a co-generating micro-power plant, which exhibited features in the distribution of flow parameters within the interdisc space. Hoya and Guha [9,10] presented a simple theory that described the three-dimensional fields of velocity and pressure in the Tesla disc turbine and designed a flexible test rig. Carey [11] developed a model of momentum transport in the Tesla turbine rotor; the model was used to evaluate the Tesla turbine performance used in Rankine cycle solar thermal power generation systems. Romanin et al. [12] investigated the parametric trends in performance using analytical models and compared the simulation results to the test data for a micro-scale Tesla turbine with water as the working fluids, which showed that the predicted performance trends matched the experimental results. Pandy et al. [13] carried out design and CFD analysis of a 1 kW Tesla turbine, which indicated that Tesla turbine could be an attractive option for practical applications. Schooser et al. [14] focused on the flow phenomena and momentum transport inside the rotor and developed the numerical and theoretical study of Tesla turbine. Okamoto et al. conducted both numerical and experimental researches on Tesla turbine performance [15–18]; in addition, the Tesla pump was also studied [19–21], in which the shear force and the loss mechanism were focused.

Assessment of the Tesla turbine performance requires a model that could adequately represent the flow characteristics and allows parametric exploration. Of course one can use CFD to analyze the performance of a Tesla turbine. One-dimensional model is still useful to be used in the earlier investigation. The one-dimensional model for Tesla turbine presented in [11] is focused and regarded as the original. In the authors' previous research [22], an improvement on the nozzle analysis is implemented, in which the nozzle velocity coefficient is taken into consideration and the nozzle could allow supersonic flow. But there are still some critical issues of the model that should be considered. In this paper, further improvements are conducted on the original model. The limit expansion ratio of the nozzle is introduced, which is related to the geometry angle and the working fluid properties. The flow loss in the nozzle is evaluated instead of assuming an empirical velocity coefficient. The flow is regarded as turbulence rather than laminar, and friction factor is determined by the Reynolds number based on Moody Figure. In the rotor, the governing equations for compressible flow between adjacent discs are used. In addition, the radial pressure gradient effect in the rotor gap spacing is considered. The improved model is verified with some experimental results in the previous research [4] and compared with the original model. One-dimensional analysis is conducted for a Tesla turbine using the improved model and the flow characteristics in the turbine is investigated.

2. Previous experimental results of Tesla turbine

Rice [4] conducted experimental and analytical investigation of Tesla turbines, which indicated that this kind of multiple-disc turbine might be attractive in the low-power part of the turbine spectrum. Several turbines were constructed and tested, of which the original one was the most interesting and was detailedly described in the previous research. The turbine was designed and constructed from the inventor's descriptions, which operated on compressed air and exhausting to the atmosphere. The rotor was stated to have 9 discs with an outer radius of 88.9 mm and a disc spacing distance of 1.59 mm. Each space between discs was supplied individually with air through a single nozzle directed at an angle of 15-deg from the tangential direction. The nozzle consisted of drilled holes and were placed in two groups at opposite sides of the rotor to produce the effect of a pure couple on the rotor, with no axial or radial load imposed on the bearing due to the flow. The turbine was built entirely of mild steel, using ball bearings with no provision for continuous lubrication. The air exhausting from the rotor was collected from the bearing housing into a single exhaust pipe. Some of the results obtained from the testing of this turbine are given in Table 1, in which