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Experimental Evaluation of the Partially-Admitted Supersonic Turbine Characteristic Curves in Turbine Test-Rig

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1- Introduction

In order to prevent the horseshoe vortex and secondary flow losses in small supersonic turbines, the partial-admission technique is used. It is obvious that the partially injection of flow creates a new type of loss which is called partial-admission loss. Therefore, in the design process, the partial-admission degree and flow injection configuration should be evaluated accurately. To that end, it is necessary to produce the characteristic curves of the turbine in this condition. These curves are provided in the form of turbine performance parameters and represent the turbine behavior in different operational conditions.

In this paper, a relatively complete process of supersonic turbine test rig based on gas-dynamic similarity method is presented. Some examples of the turbine characteristic curves that are produced in this test rig are evaluated and compared with the other works that is an example of the innovations presented in this work.

2- The Similarity Conditions and Related Calculations

The simulated design parameters of the turbine are temperature, inlet and outlet pressure, mass flow rate, rotational speed and the shaft power.

In order to establish the similarity between the model and the actual turbine flow, the following requirements must be provided:

Geometric similarity, equality of Mach numbers (absolute, relative and blade tip speed) and Reynolds number.

These conditions can be achieved through the similarity of the velocity-triangles.

In this work, the turbine geometry is preserved and the gas dynamic similarity is achieved.

3-The Test Rig Components

Compressors are feed the high pressure tanks. The air is heated in the heat exchanger, enters the turbine and after producing the shaft power, discharges into the atmosphere. A dynamometer absorbs the turbine power. The flow temperature and pressure is measured before and after each component. The mass flow is measured at the upstream of the heat exchanger. In Fig.1 a schematic view of the test rig components are shown.

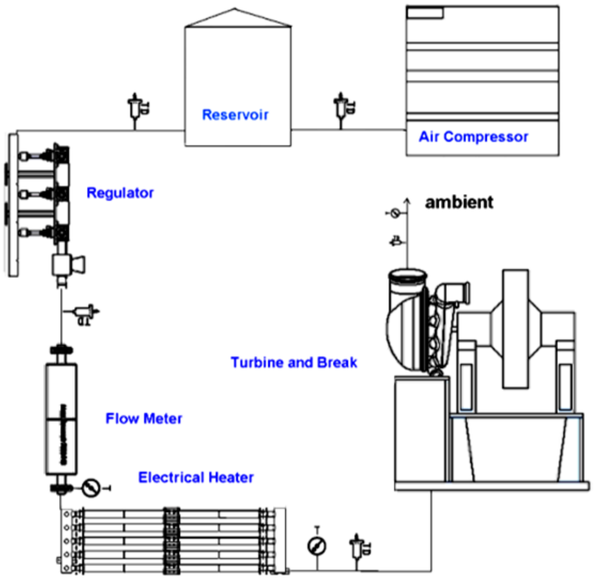

Fig. 1. Schematic diagram of turbine test rig

Fig. 2 shows the ice formed on the external surface of the regulator pipe caused by the drastic reduction of temperature due to flow expansion.

Fig. 2. Ice formed on the pipe after pressure regulation

Pressures and temperatures are measured in different locations in the test rig. Fig. 3 shows how to install the sensors.

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Fig. 3: How to install sensors

4-The Partially-Admitted Turbine Characteristic Curves

Fig. 4 shows the turbine characteristic curve in terms of efficiency changes according to the turbine pressure ratio in different rotational speeds.

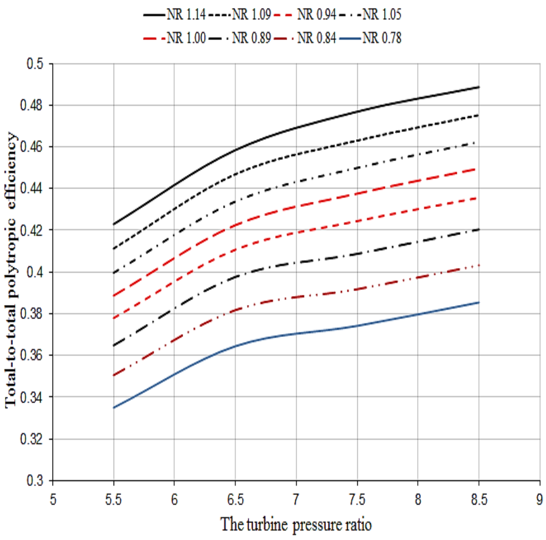

Fig. 4: The turbine characteristic curve in different rotational speeds

Fig. 5 is represents another characteristic curve for the turbine. This figure indicates that the nozzle pressure ratio is decreased slightly due to the increased rotational speed. The interesting point in this graph is that when the turbine pressure ratio exceeds the design value, the nozzle pressure is reduced. Reduced nozzle pressure ratio is due to further expansion of flow in the stator-rotor axial gap, which leads to the stagnation pressure recovery. This conditions lead to improvement of the turbine efficiency.

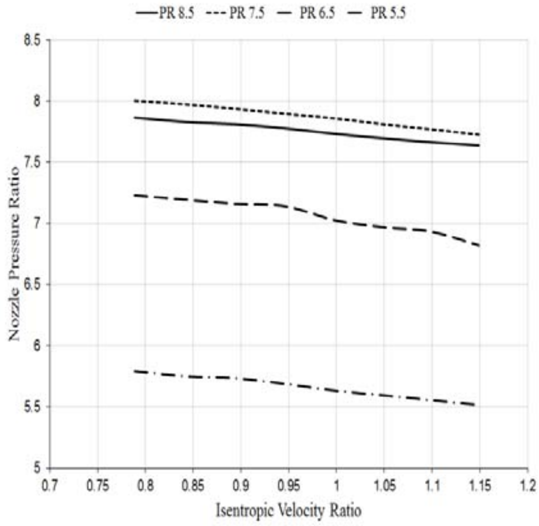

Fig. 5: The nozzle pressure ratio via isentropic velocity ratio in different turbine pressure ratios

According to Fig. 4, in the turbine pressure ratio of 5.5, both the turbine and the nozzle pressure ratios are nearly the same at high velocity ratios.

5-Error Analysis and Uncertainty in Measurements

In this section an example of error and uncertainty in the analysis presented for rpm of 5000. According to the mean value obtained for efficiency, absolute error for turbine efficiency is about 0.87%.

The overall uncertainty in efficiency works out to a maximum of ±1.16% for the worst combinations of pressures and temperatures measured in the entire test range.

6-Conclusion

Any review and evaluation of partial admission effects on the turbine performance, requires the characteristic curves of the turbine. This curve is produced in the turbine test rig. The similarity conditions will facilitate the testing conditions, for example, reducing the power, frequency, working temperatures, simplifying the stand design, inexpensive tests, and, etc.