SIMULATION OF GAS TURBINE AT OFF DESIGN CONDITION

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ABSTRACT

The gas turbine engine is a complex assembly of a variety of components that are designed on the basis of aero-thermodynamic laws. The design and operation theories of these individual components are complicated. The complexity of aero-thermodynamic analysis makes it impossible to mathematically solve the optimization equations involved in various gas turbine cycles. Manufacturers and designers of gas turbine engines became aware that some tools were needed to predict the performance of gas turbine engines especially at off design conditions where its performance was significantly affected by the load and the operating conditions. Also it was expected that these tools would help in predicting the performance of individual components, such as compressors, turbines, combustion chambers, etc. A mathematical modeling using computational technique was considered to be the most economical solution. The first part of this work presents a discussion about the gas turbine modeling approach. The second part includes the gas turbine component matching between the compressor and the turbine which can be met by superimposing the turbine performance characteristics on the compressor performance characteristics with suitable transformation of the coordinates. The last part includes the gas turbine computer simulation program and its philosophy.

Keywords: *Gas Turbine, Engine Performance, Design*

1. INTRODUCTION

A turbine is any kind of spinning device that uses the action of a fluid to produce work. Typical fluids are: air, wind, water, steam and helium. Windmills and hydroelectric dams have used turbine action for decades to turn the core of an electrical generator to produce power for both industrial and residential consumption. Simpler turbines are much older, with the first known appearance dating to the time of ancient Greece.

The name "gas turbine" is somewhat misleading, because to many it implies a turbine engine that uses gas as its fuel. Actually a gas turbine has a compressor to draw in and compress gas (most usually air); a combustor (or burner) to add fuel to heat the compressed air; and a turbine to extract power from the hot air flow. The gas turbine is an internal combustion (IC) engine employing a continuous combustion process. This differs from the intermittent combustion occurring in Diesel and automotive IC engines. Because the origin of the gas turbine lies simultaneously in the electric power field and in aviation, there have been a profusion of "other names" for the gas turbine. For electrical power generation and marine applications it is generally called a gas turbine, also a combustion turbine (CT), a turbo-shaft engine, and sometimes a gas turbine engine. For aviation applications it is usually called a jet engine, and various other names depending on the particular engine configuration or application, such as: jet turbine engine; turbojet; turbofan; fanjet; and turboprop or prop jet (if it is used to drive a propeller).

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2. BACKGROUND

In an aircraft gas turbine the output of the turbine is used to turn the compressor (which may also have an associated fan or propeller). The hot air flow leaving the turbine is then speeded into the atmosphere through an exhaust nozzle to provide thrust or propulsion power.

The smallest jets are used for devices such as the cruise missile, the largest for future generations of commercial aircraft. The jet engine is a turbofan engine, with a large diameter compressor-mounted fan. Thrust is generated both by air passing through the fan (bypass air) and through the gas generator itself. With a large front area, the turbofan generates peak thrust at low (takeoff) speeds making it most suitable for commercial aircraft. A turbojet does not have a fan and generates all of its thrust from air that passes through the gas generator. Turbojets have smaller front areas and generate peak thrusts at high speeds, making them most suitable for warrior aircraft.

In non-aviation gas turbines, part of the turbine power is used to drive the compressor. The remainder, the "useful power", is used as output shaft power to turn an energy conversion device such as an electrical generator or a ship's propeller.

Such units can range in power output from 0.05 MW (Megawatts) to as high as 240 MW. Heavier weight units designed specifically for land use are called industrial or frame machines. Although aero derivative gas turbines are being increasingly used for base load electrical power generation, they are most frequently used to drive compressors for natural gas pipelines, power ships and provide peaking and intermittent power for electric utility applications. Peaking power supplements a utility's normal steam turbine or hydroelectric power output during high demand periods .Such as the summer demand for air conditioning in many major cities.

2. RESULTS AND DISCUSSION

The output of the new methodology presented in this work is illustrated graphically in Fig.1 and 2, which show complete typical performance characteristics of a centrifugal compressor and complete typical performance characteristics of a radial turbine, respectively.

In order to match the turbine with the compressor, Fig. 1 and 2 have to be reproduced by introducing the matching parameter [m˙ N/d2cPo1]. The transformation is shown in Fig. 3 and 4. For the compressor it is worth noting that the constant speed lines were shifted apart, nevertheless the trends stay the same. For the turbine, the trend of the constant speed lines has changed. The reason is because the turbine inlet temperature T03 is not constant along any constant speed line while for the compressor case; the compressor inlet temperature T01 is constant. The graphs between Pressure ratio and Mass flow rates is shown in Fig. 5 and 6.

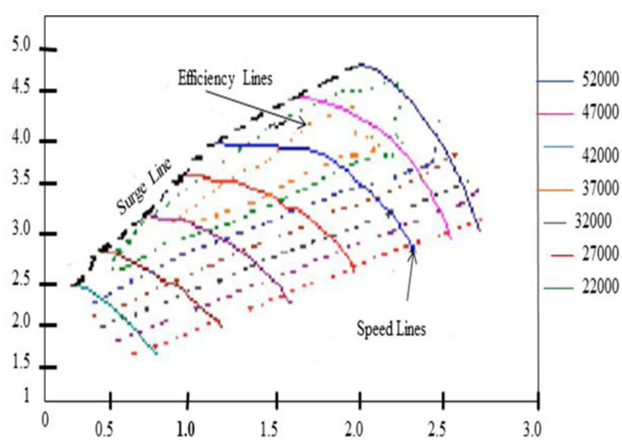

Fig.1: Centrifugal compressor performance

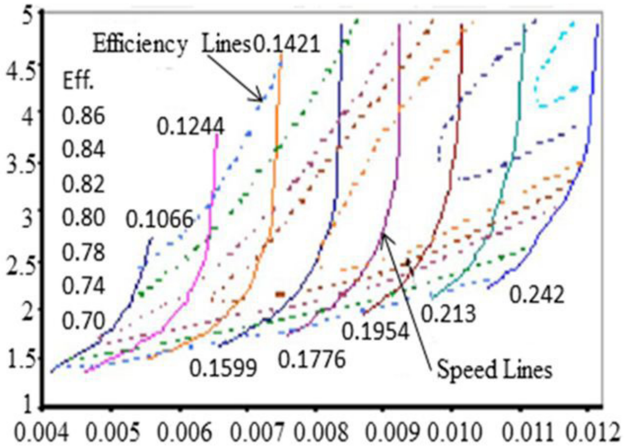

Fig.2: Radial turbine performance

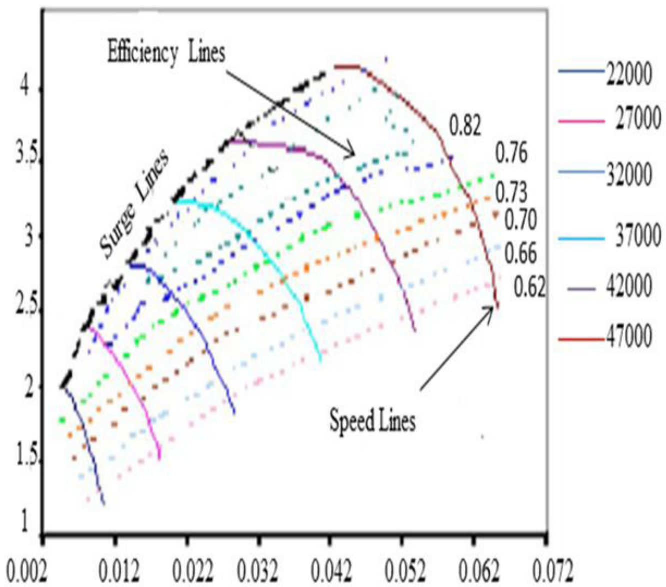

Fig.3: Transformation of Centrifugal compressor

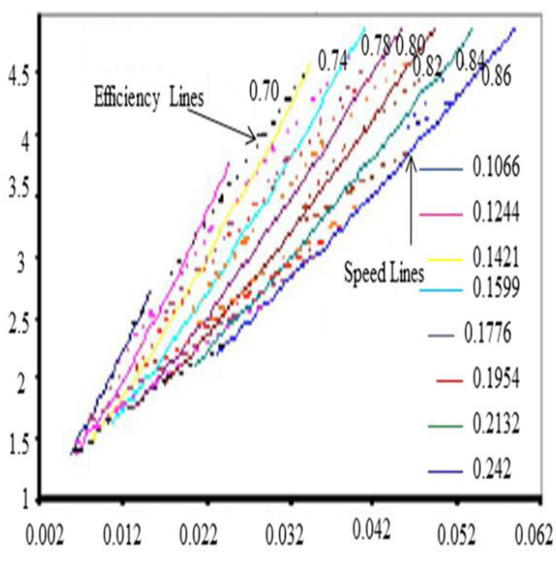

Fig.4: Transformation of Radial turbine

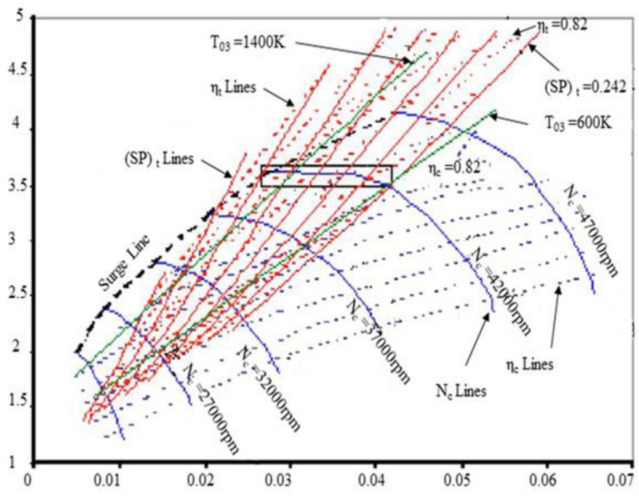

Fig.5: Pressure ratio

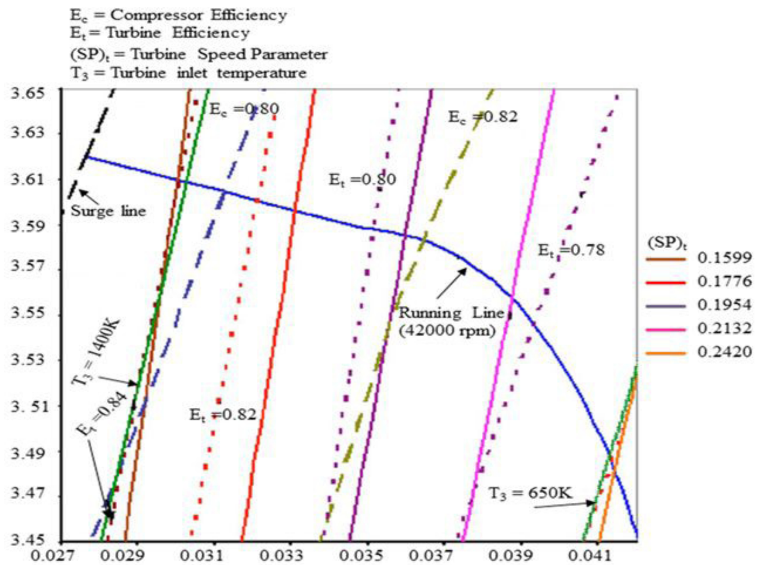

Fig.6: Mass flow

4. CONCLUSION

It can be concluded from the output whether the gas turbine engine is operating in a region of adequate compressor and turbine efficiency. Matching technique proposed in the current work used to develop a computer simulation program, which can be served as a valuable tool for investigating the performance of the gas turbine at off-design conditions. Also, this investigation can help in designing an efficient control system for the gas turbine engine of a particular application including being a part of power generation plant.

Modeling, matching, and simulation of a gas turbine engine for power generation have been presented. A computer program for simulating a gas turbine engine has been developed that can satisfy the necessary matching conditions analytically and, thus, achieve matching between the various components in order to produce the equilibrium running line. Representing the data for this line either in the form of lookup tables or an equation is known as modeling; solving that equation with the help of a computer is computer simulation. Thus, modeling and simulation together satisfy all energy and mass balances, all equations of state of the working fluids, and the performance characteristics of all components.

Table1. Calculated parameters within the specified working range of 42000 rpm

Sl. No.	Matching Parameter	r (pressure ratio)	Turbine Speed	η_c
1	0.0413	3.483	0.242	83
2	0.0387	3.58	0.2132	83.2
3	0.0359	3.585	0.1954	81.8
4	0.0331	3.597	0.1776	80.8
5	0.03	3.61	0.1599	79.5
Sl. No.	W_t	W_{net}	**Fuel/Air Ratio**	$\dot{m}_f$
1	296.79	28.55	0.00611	0.01095
2	374.59	118.74	0.01143	0.01921
3	415.78	172.66	0.01596	0.02488
4	45.72	228.08	0.02205	0.03169
5	493.48	283.08	0.03036	0.0395

Table 2. Calculated parameters within the specified working range of 42000 rpm

Sl. No.	η_t	T_{02}	T_{03}	T_{04}	W_c
1	82	436.82	651.97	508.69	268.24
2	84.5	439.48	840	647.02	255.85
3	84.7	443.17	1000	769.1	243.12
4	82.8	445.58	1210.52	936.02	227.64
5	80	448.7	1493.34	1165.4	210.4
Sl. No.	η_{gt}	**SFC**	τ_c	τ_t	τ_{net}
1	6.37	0.7699	203.39	225.04	21.65
2	15.1	0.3464	194	284.04	90.04
3	16.95	0.3327	184.35	315.27	130.92
4	17.57	0.3481	172.61	345.55	172.94
5	17.48	0.3861	159.54	374.19	214.65

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