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Analysis and Simulation of Surge Phenomena in the First Stage of Axial Compressor of GE-frame 6 Gas Turbine

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ABSTRACT: One of the important subjects in the analysis of compressor performance is estimating the surge limit. If the angle of attack changes for any reason, air jets separate from the blades and the cross-section area of the passing air becomes small and causes the alteration of the angle of attack in the next stage blades; this phenomenon is known as stall. When stall completed on a row, a pressure drop occurs at the rearward of that row. So, high-pressure air goes from the next row to the lower pressure area, which associated with a lot of noise and can cause the failure of the blades which is called surge. In this paper, the numerical simulation of surge in the first stage blades of the axial compressor of GE-Frame 6 gas turbine has been done. Simulations are done with a 34 degree angle of attack and k-□ SST turbulence model has been used. Obtained velocity vectors indicate that during the surge, the reverse flow which is the most important characteristic of surge occurs and the flow returns backward. Also, in this paper, the coupled ordinary differential equations of pressure and flow changes for different values of the stability parameter B has been solved. It was found that for B = 0.6, which is less than the critical value, rotating stall occurs and the pressure fluctuations damp after several fluctuations. While for B = 1.6, which is more than its critical value, a deep surge occurs and the pressure and flow disturbances fluctuate with constant amplitudes.

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1- Introduction

In high mass flow, getting of fluid velocity to the speed of sound and choking is one of the limiting factors. However, in low mass flow, the presence of surge and stall instability cause to limit the compressor performance area. Bontempo et al. [1] presented an innovative information processing technique for analyzing the surge in a compressor. They said Since the Surge cycle has no fixed characteristics, it can only be described through the statistical method. For this reason, they used statistical methods and empirical experiments for centrifugal and axial compressors to describe the surge phenomenon. Kabral and Abom [2] stated that surge is one of the most important compressor limiting factors and for this reason, they used a new laboratory acoustic two-port model for study surge and stall in a centrifugal compressor. Munari et al. [3] showed that surge is the most important instability in the compressor, which greatly affects the operation of the compressor. They experimentally investigated the response obtained during the surge event for a multistage compressor and were able to set up a nonlinear model for simulating the dynamic behavior of the compression system. In recent years Pakle and Jiang [4] and Wang et al. [5] have investigated surge phenomena in centrifugal compressors and were able to demonstrate the characteristics and effects of the surge on the performance of centrifugal compressors. In this paper, it is attempted to study the characteristics of the surge in the GE Frame 6 gas turbine axial compressor. Therefore, numerical simulations of the first stage of the compressor have been performed in the Ansys Fluent software to show the characteristics of the surge in this special compressor. Also, with the coding of nonlinear dynamical equations in the unsteady state in MATLAB software, the rate of changes in pressure and current during the surge event has been examined.

2- Methodology

2- 1- Governing equations

Navier Stokes equations are the governing equations for this simulation, which is solved by the method of the univariate Unsteady Reynolds-averaged Navier-Stokes (URANS) Reynolds equations for the unsteady state. Those equations for solving the behavior of the meantime flow and the amount of turbulent fluctuations are solved. The k-ω (SST) model performs better in currents that involve the reduction of speed and separation caused by the inverse pressure gradient.

The Eq. (1) is related to the B parameter that is defined by Gritzer [6] and Eqs. (2) and (3) are the rates of flow and pressure variations for surge mode that are derived by Moore-Gritzer. The advantage of these equations is that the pressure and flow equations are solved in coupling form and can show fluctuations with a large amplitude.

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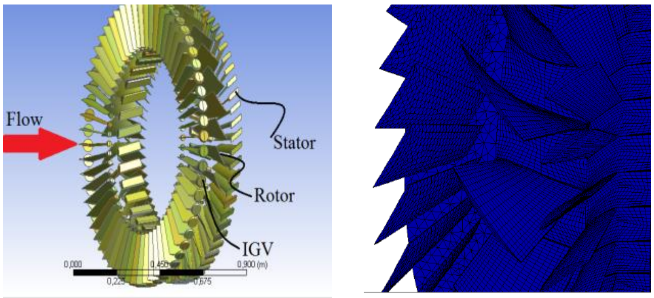

Fig. 1. (a) The blades of ½ axial first-stage GE-frame 6 compressor, (b) The mesh structure: hexahedron mesh for rotor and tetrahedron mesh for IGV

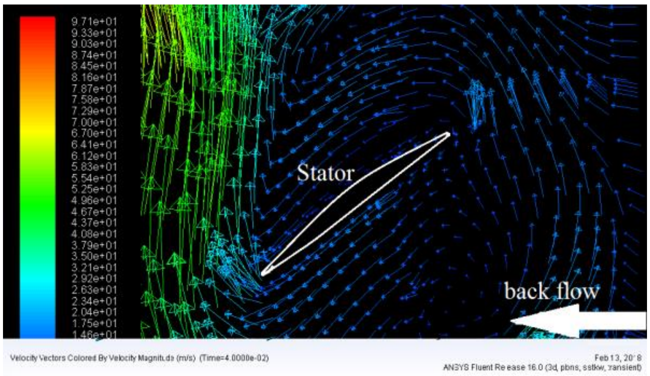

Fig. 2. The existence of a reverse flow phenomenon and the occurrence of surge

$$B = \frac{U}{2\omega_H L_c} = \frac{U}{2a}\sqrt{\frac{V_p}{A_c L_c}} \tag{1}$$

$$\dot{\psi} = \frac{\omega / H}{4B^2}\left(\frac{\Phi}{\omega} - \frac{1}{\omega}\Phi_T(\psi)\right)\frac{H}{l_c} \tag{2}$$

$$\dot{\Phi} = \frac{H}{l_c}\begin{pmatrix} -\frac{\psi - \psi_{c0}}{H} - \frac{1}{2}\left(\frac{\Phi}{\omega} - 1\right)^3 + 1 \\ +\frac{3}{2}\left(\frac{\Phi}{\omega} - 1\right)\left(1 - \frac{J}{2}\right) \end{pmatrix} \tag{3}$$

2- 2- Mesh and geometry

The first step in analyzing the computational fluid dynamics is creating a computational model. The model of the blade rows of GE-frame 6 compressor consists of 64 Inlet Guide Vane (IGV) blades, 32 rotor blades and 60 stator blades. Fig.

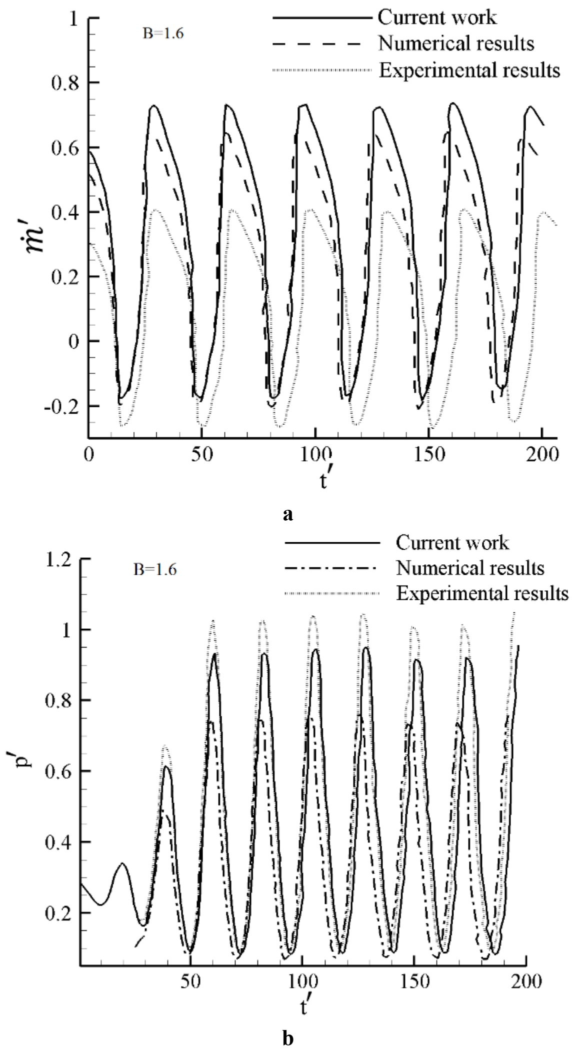

Fig. 3. Dimensionless pressure and flow rates during the occurrence of surge (a) dimensionless flow rates (b) dimensionless pressure rates

1 (a) demonstrates the geometry of the problem consisting of a perfect 360-degree stage of rotor and stator alongside the IGV blades in the entrance section of the compressor. For meshing the geometry, hexahedron mesh is used for rotor and tetrahedron is used for IGV (Fig. 1(b)).

2- 3- Simulation procedure

In this article, Fluid Structure Interaction (FSI) is employed in a fully coupled fashion. The flow simulation is executed in an unstable manner. Time step independence for 0.1, 0.06, 0.04 and 0.01s time steps was investigated, in which for 0.01s and 0.04s due to the close results the 0.04s time step is used. The flow is considered to be turbulent and the turbulence model is of k-ω(SST) type. For solving the Navier-Stokes equations the finite volume method is employed. The Semi-Implicit Method for Pressure-Linked Equations (SIMPLE) algorithm is considered for coupling the pressure and velocity equations. In order to reach convergence, the residual of continuity and momentum equations is set to be 10-6.

3- Results and Discussion

As already mentioned, the deep surge is generally found in the unstable region of the surge line and its signs are oscillations of pressure and flow. The most important characteristic of the deep surge is back flow. In previous papers [8,9], fluctuations in the flow have been shown as fluctuating graphs but now, in the present paper, the back flow is shown in the form of a vector. As it is evident in Fig. 2, due to the occurrence of a deep surge, the direction of flow is reversed and the flow from the stator to the rotor returns.

Also, other work done in this paper is the coding of Eqs. (2) and (3) for different values of parameter B and obtaining the dimensionless pressure and flow rates during the occurrence of Surge. The results of Fig. 3 show that for values more than B_crit surge occurs and the flow and pressure fluctuates with constant amplitude and the results are in good a agreement with previous work [6, 8].

4- Conclusions

It can be easily seen that the performance of the system at a point far from the surge line can prevent the occurrence of the surge, but due to the high pressure and efficiency ratio near the surge line, it is better to operate the compressor near the surge line. In this paper, the full recognition of this instability, its

On the basis of numerical investigations, the following conclusions are drawn:

• Obtained velocity vectors indicate that during the surge, the reverse flow which is the most important characteristic of surge occurs and the flow returns backward.

• The observations indicate a deep surge occurs on the left side of the surge line and unstable state and when the surge occurs, the flow returns back.

• It was found that for B = 0.6, which is less than the critical value, rotating stall occurs and the pressure fluctuations damp after several fluctuations.

• For B = 1.6, which is more than its critical value, a deep surge occurs and the pressure and flow disturbances fluctuate with constant amplitudes.

• Other results in this article are the surge cycle. surge's cycle shows that both the flow and pressure fluctuate at steady-state intervals.

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