Optimization of Axial Compressor for the instability measurement of Fluid

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Abstract—Control and Modeling for stall and surge phenomenon in axial flow compressors have received great importance in recent times. In power generation plant and aerospace propulsion compression system are prone to the aerodynamic instabilities of stall and surge. In aero engine compressors higher pressure ratio has always been a growing stipulates which has over involved by diverse rotating stall and surge of aerodynamic instability. Due to interrupted mass flow variation in compressor, plenum, throttle i.e. in whole pumping system, surge may occur. Stall can be described by a wave travelling about the boundary of the machine. Blades become overheated due to decrease of pressure rise in the compressor, which is being caused by fluid instabilities i.e. stall and surge. These instabilities of fluid result mechanical damage to the compressor. The objectives of this research are to restrain stall and surge, to enlarge steady working of the axial flow compressors and to expand the stable fluid flow. This review report surveys the most recent optimization research literature on stall and surge effects in axial compressor. Success of this research field will significantly improve the efficiency of the axial compressor and aero-engine performance in future.

Index Terms—Bifurcation analysis, FDM, Compressor Flow chart , Centrifugal Compressor, Axial Flow compressor, FDM, Moore-Greitzer Model (MGM), Multiple Time Scale (MTS)

1 Introduction

Compressor is a mechanical instrument which employs high pressure of compressible fluid during the channel of the fluid through the compressor by decreasing the fluid specific volume. Compressor fundamental objective is to transport fluid at higher pressure by compressing the fluid than its original pressure. Compressor is classified as positive displacement and dynamic compressor. A rise in pressure prior to discharge occurred in positive displacement compressor in such a way when specified amount of fluid is allowed to enter in a compressor for compression and volume is mechanically decreased. The air flow remains fundamentally stable with variation in discharge pressure at steady speed e.g. reciprocating compressor, vane compressors and rotary compressors [3]

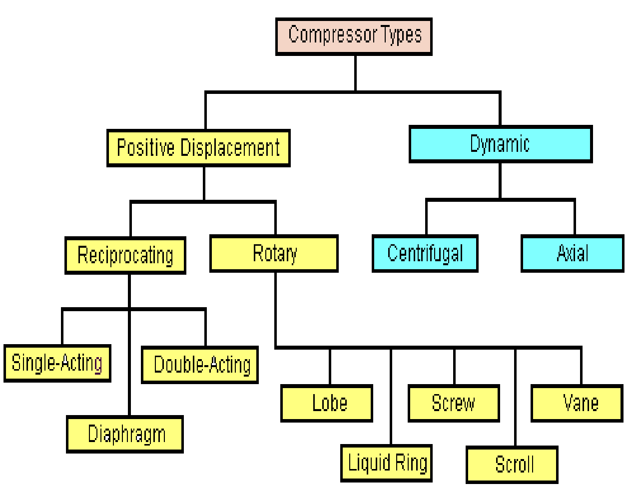

Figure 1(Compressor flow char)

When the impellers rotate at very high speeds velocity energy is being imparted to continuously flowing fluid in dynamic compressors. Impellers and discharge diffusers changes velocity energy into pressure energy. Dynamic compressor consists of centrifugal compressors and axial compressors. Compression is achieved in centrifugal compressor by applying inertial forces to the gas by means of rotating impellers. A centrifugal compressor consists of one of more stages. Each stage consists of rotating element and stationary element i.e. impeller and diffusers respectively. In centrifugal compressor, fluid enters the impellor axially and discharges radially at right angle to the axis of rotation. Centrifugal compressors are used in helicopter and small aircraft applications because it has higher single-stage pressure ratio than axial compressors [4]

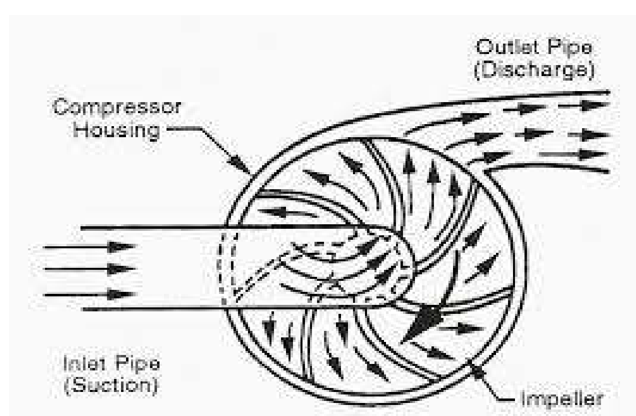

Figure 2 (Centrifugal Compressor)

2 Axial Flow Compressor

Particularly above 5 Megawatt axial compressors are mostly used in gas turbine purpose. In axial flow compressor fluid enters the compressor and also exits from the gas turbine in

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axial direction. The axial flow compressors have higher cross sectional flow area per mass flow rate and also possess lower frontal areas i.e. diameter. The efficiency of axial flow compressor is quite higher than the centrifugal compressor thus it is generally being given more preference over centrifugal compressors. When high intake volume of flow is required and also when head required is low than axial compressors are ideal under these circumstances [5]. Gases or fluid are being continuously pressurized in an axial flow compressor. Axial flow is airfoil rotating based compressor where fluid enters and leaves axially in the compressor. Therefore it is different from centrifugal and mixed flow compressors where fluid flows radially to the compressor. In axial compressors rotor blades wield torque on the fluid which amplifies the velocity of the fluid as it flows through the compressor. To achieve a large pressure rise several rows of airfoils are required in axial compressor that also make them more complex [6]. Fluid is compressed in axial flow compressor to obtain high pressure ratio by first accelerating and then diffusing the fluid. Fluid is initially accelerated in rotor which is a row of rotating blades. This accelerated fluid is than diffused into the stator where velocity increase gained is being converted into pressure increase. There are numerous stages of compressor. Stage is the combination of rotor followed by stator. IGV (Inlet Guide Vanes) are further rows of stationary blades that are used in compressor inlet. IGV are used to ensure that at desired flow angles fluid penetrates in the first stage rotor [7]. For the fluctuating flow requirement of the engine, Inlet Guided Vanes are also pitching variable so that it can be adjusted. At the exit of the compressor EGV's is another diffuser. The basic purpose of the EGV is to control fluid velocity entering the combustors [8]. There are two parameters in which gas turbine depends. First is increase in pressure ratio as well as second is raise in firing temperature [9]

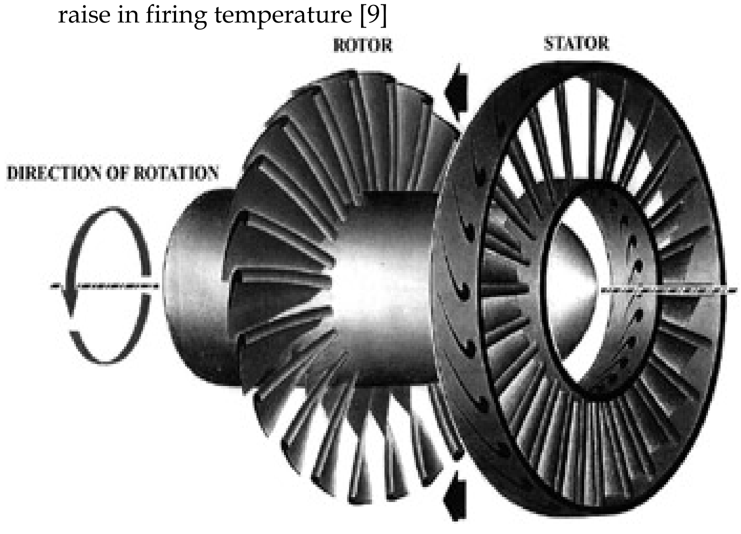

Figure 3 (Axial Flow Compressor)

As by foundation of thrust by weight ratio the performance of aerospace engine has been delivered [10]. High engine thrust ratio can be achieved for the maximum work output per unit flow by increasing of maximum aspects of ratio blades in the compressor furthermore by optimizing the firing temperature and the pressure ratio of the turbine [11]

2.1 Blade Cascade Nomenclature

Nomenclature and methods of concerning compressor blade shapes are nearly the same as aircraft wings. All blades has an inter effect with each other in axial compressors, therefore to stimulate compressor rotor and stator several blades are usually placed in a row. Such combination of blades in a row is known as cascade. The shapes of airfoils are bowed that shows concave on one side and convex on other side with the rotor rotating toward the concave side. Suction side and pressure side of the blade are called as convex and concave side respectively [12]

2.2 Factors that causes Surge and Compressor Stall

Gas turbine works at optimum operating speed and it is detained steady and very small deviation takes place. Axial compressors blades are designed in such a way to achieve the optimum efficiency of the gas turbine at the synchronous speed. The rotor and stator are set in its place and also their shapes are precisely machined so that compression of fluid through the compressor remains smooth and efficient, to achieve good performance of the compressor. The separation of flow at the airfoil will occur if the speed of blades are less, thus the air is not smoothly compressed because the nomenclature of the blades are not designed and suitable to low speed and low flow condition [13] Thus, fluid separated and become unstable, whereas compressor will instigate to surge. This will cause high sporadic bending stresses in the compressor due to rapid fluctuation of the compressor [14]. In axial flow compressor system operates as close as possible to the critical value but it will have instability when a minute transform in the stream occurs. As soon as the mass flow rate in an axial compression system is decreased the pressure will rise till a position is arrived where stable axisymmetric stream does not remain stable.

2.3 Description of Surge and Stall

At the working point at which compressor maximum head capability and minimum flow limit are reached in axial compressor, it is known as surge. At this point the compressor become unstable and loss its capability to maintain maximum head. When the fluctuation in flow rate occurs than compressor move towards the surge line whereas, normally compressor works to the right of the surge line. The fluctuation in flow happened when flow is reduced under startup and shutdown of the system. If operating point approaches the surge line

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than the impeller instigate to work in stall and recirculation of flow begins. [15]. Operational changes should be made by using control system to operate the compressor out of the surge line. Otherwise surge cycle will keep on repeating itself [16]. The flows can be on the whole categorized as stable rotating stall, deep surge & classic surge. Part of the compressor annulus operates in stalled flow when the machine experiences rotating stall [17]. This is also referred as stall cell. Almost half of the wheel speed stall cell rotates around the annulus. If the pressure rises, average mass flow remains constant and flow also remains steady than there will have steady rotating stall whereas flow moves in a context with the stall cell [18]. Steady rotating stall has lower pressure ascend than the design point [19]. Surge is a variation of mass flow & pressure rise along the length of axial compressor [20], with a frequency inferior to related by channel of a stall cell.

3 Fluid Dynamic model

Numerous considerations have been dedicated for the research of airflow & turbo-machine combustion because when a turbo machines works close to optimal working value and parameter the flow became unstable. Large stress on the engine has been developed due to these instabilities. To facilitate recuperate the original operations from these instabilities sometimes engine needs to be turned off. Thus to avoid these circumstances presently jet engines are being run away from optimal operating values. But, when they are run away from optimal parameter values they consume more fuel and engine weight [21]. The performance of axial flow compressors is being limited due to fluid dynamic instabilities such as rotating stall and surge. Consider the schematic of the axial compression system. It consists of a compressor, a pipe leading the free stream flow into a plenum, a plenum, throttle and its exit duct. In this model for the description of pressure rise the compressor is replaced by the combination of actuator disk and a constant area duct having length "Lc". Similarly throttle is also replaced by the combination of actuator disk and a constant area duct having length "Lt" [22]

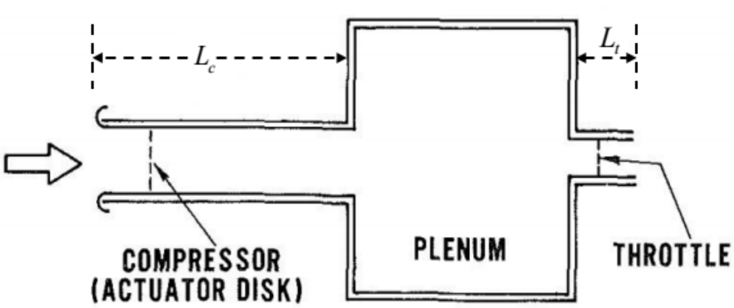

Figure 4 (FDM "\control volume for the compression system")

The following hypotheses are taken in considerations before going on the derivation of the model. A situation, in which any of these assumptions is no more valid, can bring the results from the model in question.

The oscillations happening in the structure have been modeled to those of a Helmholtz resonator. It describes as all the K.E of oscillation is possessed by the fluid motion in the compressor and throttle ducts whereas all the P.E is possessed in the plenum by the compression of the gas.

Low Inlet Mach number is being subjected to the compression system. Thus as compare to the ambient pressure, pressure rises are minute. As the oscillation related to surge is usually associated as reasonably low frequency, thus the flow in the duct is incompressible having density taken as equal to the ambient value. Thus at any instant all the fluid particles will have the same axial velocity in one of these ducts. It means it will have fully developed flow.

Area of the plenum is larger than the compressor duct, thus velocities and fluid accelerations in the plenum are insignificant [23] Whereas pressure in the plenum is assume to be uniform spatially, but changing with time.

The flow field is considered as irrotational

The effects of viscosity have not been taken into account.

Body forces acting on the control volume have not been considered.

The inertia in the throttle duct has been neglected. This is generally a good assumption since throttle curves are usually steep and the fluctuations in mass flow rate of throttle are smaller than those through the compressor.

The flow is considered to be one-dimensional, and only the axial component of velocity is responsible for the transport processe.

4 Bifurcation of the Surge and Rotating Stall

During the research of axial compressors a very significant dilemma arises while flow instability that either it will experience rotating stalls or surge. To analyze this dilemma linear compression system model was being investigated by Greitzer. He accomplished that for a specified compressor system there is a non dimensional parameter. The system response is depended on this NDP. This parameter is denoted by "B" [24]

$$B = (U/2a)\,[V_p/(A_c\,L_c)]^{1/2}$$

The value of B" is the compressor characteristics which verify the mode of instability. If the value of B lies above than the critical value than it will exhibit surge oscillation. If the value of B lies lower than the critical value than it will reveal initial transient to the steady flow [25]

Here,

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a = speed of sound

U = rotor speed

Lc = effective length of compressor duct

Ac = compressor flow area

Vp = Plenum Volume

5 Brief of post Stall:

To explain post stall, Greitzer developed two dimensional theories in axial compression system that elaborate the development of rotating stall amplitude, mass flow and pressure rise during compression. He investigated that both surge and rotating stall exit in equilibrium form. This concluded that amplitude of rotating stall during steady state is dissimilar from unsteady flow. Thus in both cases performance of the compressor differs instantaneously. Furthermore it was also analyzed that surge and rotating stall of the system not only depends upon the parameter of "B" but also depends upon the length to radius of the radius of the compressor. Higher the value of B, higher will be the surge and vice versa.

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6 Moore- Greitzer Model:

For the understanding the mechanism of fluid instabilities numerous models and methods have been proposed. Moore-Greitzer model is one of the renowned and universally accepted models to understand the mechanism of fluid instabilities. It comprises of compressor working in a channel & discharging to a downstream plenum [26]. The dimension of plenum is larger than compressor and its duct so that in plenum velocity and fluid acceleration is negligible considered. The pressure in the plenum is uniform at probably changeable in instance. At the plenum exit the flow is constrained by the throttle.

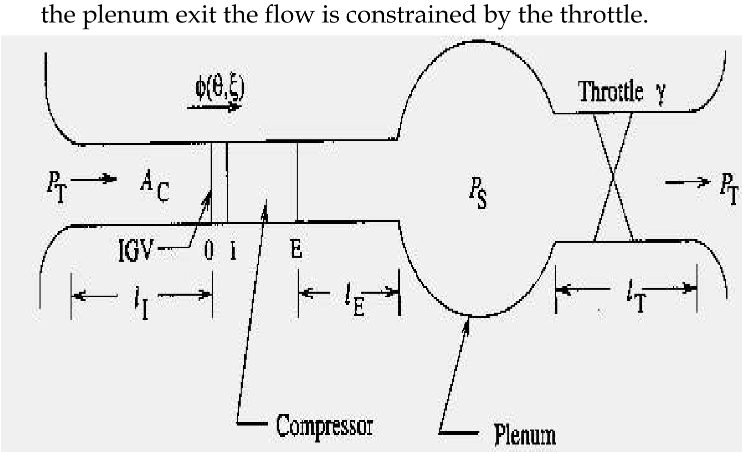

Figure 5Moore-Greitzer Model)

7 Stability of Axial Flow Compressor

Various techniques have been examined and introduced for axial compressor fluid stability and rotor casing treatment such as passive control techniques (PCT) and active control of rotating stall (ACRS). PCT by using screen is being carried out to manage the flow disorder ingoing in the compressor. By using this technique, it has increased stable flow range as well as peak pressure rise up to 15% to 20%. In Axial compressor for rotor casing treatment, over the tips of rotors consist of groves. ACRS consist of two approaches. 1st approach is based on the control of model wave, whereas 2nd approach is based on simulating the flow directly into the rising stall cell. Greitzer introduced an air injection system by developing a range of separately controlled valves. These controlled valves are installed near the tips of the first rotor where stall cells generally first appears and all these controlled valves are equally spaced from each other.

8 Conclusions

This work is deduced, after studying and analysed different authors/ researchers work on the axial compressor instability. The generalized effect of compressor characteristic under cubic nonlinearity on the behavior of Limit Cycle Oscillations has been measured. By means of MTS method, estimated solutions are obtained. From these solutions, stability criterion and the necessary condition for sustained limit cycle oscillations is derived. Salient results concluded from this research are listed as under

The behavior of surge oscillations is significantly dependent on the choice of compressor characteristic. By treating the compressor characteristic used in the MGM in a generic manner, it has been found that a small change in $\propto$ and β effects the dynamics of the system significantly. The amplitude of surge oscillations exhibits supercritical bifurcation for the stable limit cycle.

Method of Multiple Time Scales has successfully captured the qualitative and quantitative aspects of the surge phenomena. The analytical solution obtained via MTS method is well in agreement with the numerical solution.

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