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Use of Synchronous Motors for improving rpm control and start-up of Axial Compressors

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Abstract

The underlying paper deals with mode of operation of axial flow air compressors. Unlike the conventional axial compressors design that are driven by a motor or a turbine (in case of heavy machinery), the proposed model of the compressor uses synchronous motor arrangement for rotation and initial start-up. Blades will be made of magnetic materials or would be given magnetic coatings so that, blades can react to the induced magnetic field. This new model is expected to perform better and would have better speed control as that of conventional ones. The paper does not deal with any new design or configuration of the blades or blade profile. Magnetic materials and coatings would be discussed in later sections and also better ones based on various properties such as magnetic field strength, tensile strength etc. have been discovered as the fields of further research and development.

Key Words: Axial, Compressors, Synchronous, magnetic

Introduction

Axial flow compressors are the most efficient compressors as far as heavy duty applications are concerned. These compressors provide best stage efficiency i.e. 80%-90% per stage [1]. These compressors provide compression ratio as high as 20:1 and even upto 40:1. Due to the heavy shaft load and weight of the rotor, the shaft becomes too heavy that requires a highly efficient turbine mounted at the same shaft either directly or by gear train. But, initial start-up is still an issue to deal with heavy duty compressors. As far as aircraft turbine engines are concerned, the initial start-up is provided by starter-motor-generator, cartridge starters etc. Various disturbances in flow such as rotating stall, surge etc. causes vibrations and instability of the shaft [2].

Various improvements in blade materials have been done so as to increase performance characteristics and delay fatigue. New alloys such as INCONEL® alloy 718 [3], has high tensile strength and corrosion resistance.

Most of the axial compressors use cascade aerofoil [1]. Cascade airfoils are NACA 65 series airfoils [1]. These airfoils efficiently drive the airflow backwards with less aerodynamic losses as compared to other airfoil shapes.

The design of axial compressor as proposed in this paper uses synchronous motor arrangement for promising compressor performance. The synchronous motors are

those motors that are driven by AC current. The magnetic field produced by the stator is rotator in nature and hence induces the torque in the armature. The speed of the rotor is in synchronization with the frequency of the flowing AC current through the stator windings [4]. One of the greatest advantages of these motors is that, the speed of rotation is independent of the load [5]. Different classes of synchronous motors are there, but for this specific application, permanent-magnet motors have been considered. These motor have electronically controlled variable frequency stator drive [6].

Design and Working

The proposed design of axial compressor is an integration of conventional axial compressor and synchronous motor. The conventional compressor setup i.e. relative arrangement of guide vanes, stators and rotor blades is kept same.

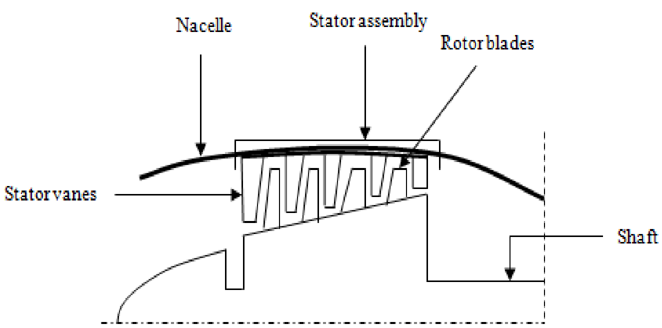

Fig. 1: Rotor-Stator assembly in Compressor

But, slight modifications are introduced on the surface of the stator assembly that is just above the rotor blades as shown in Fig. 2. Also, the blades will have their independent north and south poles that can be generated by using magnetic material coating. This surface acts as the stator of the synchronous motor, through which AC current will flow hence inducing the rotating magnetic field.

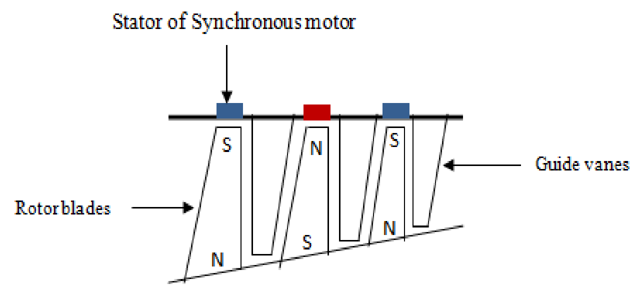

Fig. 2: Synchronous motor's stator and rotor arrangement (side view)

So, at each compressor stage a synchronous motor is present. Hence, total number of compressor stages will be equal to the number of synchronous stators present.

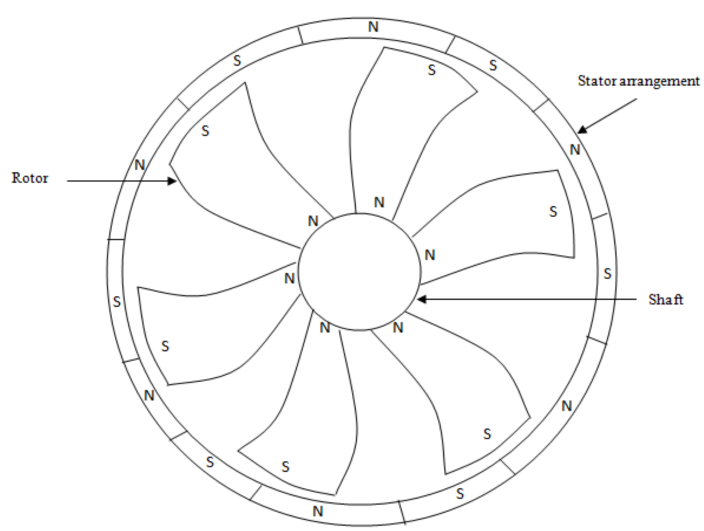

Fig. 3: Rotor-Stator arrangement (front view)

The blades of compressor rotor are also magnetic in nature that requires a material investigation. The blade can be given strong bonded coatings of strong natural magnets such as neodymium magnets that have better magnetic properties, good corrosion resistance and other mechanical properties [7]. The synchronous motor used is a three phase synchronous motor. As the AC current will flow through the stator windings it will produce a magnetic field that will traverse along the circumference of the stator hence producing an induced torque in the rotor. Due to constant attraction and repulsion between the unlike and like poles the rotor continues to rotate.

As stated earlier, speed controlling (regulation), shaft vibrations and compressor start-up are the major issues to deal with, for compressor. This mechanism addresses these issues closely.

As far as initial start-up is concerned, this mechanism provides a faster start-up because of more number of synchronous motors. This technique will reduce the load on the starting system hence increasing its service duration. Due to heavy weight of the rotor assembly, the shaft requires an initial rotating force from an external agency, after which the motor will take-over.

After some time the rotor will reach a constant speed i.e. the synchronous speed that is provided to the rotor as a property of synchronous motor which is independent of the shaft load. This provides compressor a stable and controlled rotational speed. Due to this the load over the compressor driving system i.e. turbines (in heavy duty applications) is also reduced, hence increasing the total efficiency of the system. This will reduce turbine stages; as a result, the weight reduction of the system is also possible. This point is very vital as far the design of aircraft engines is concerned.

The magnetic forces induced from all the directions around the rotor are constant and uniform. This keeps the rotor balanced in central position hence decreasing chances of any possible vibration.

Theory

To avoid surge and keep compressor safe from stalling that can make the flow violent inside the compressor the operation range i.e. Surge Margin (SM) is defined as the safe operating range for the compressor. Surge Margin (SM) is given by:

$$SM = \frac{PR(surge) - PR(working)}{PR(working)}$$

where, PR- pressure ratio.

For synchronous machines, torque produced by two magnetic fields attempting to align is given by:

$$T = F_s F_r \sin(\alpha)$$

where, F_s- stationary magnetic field

F_r- rotating magnetic field

α- torque angle

The mechanical output power which is three times the average per-phase electrical power is given by:

$$T_\omega = P = 3R_e(\boldsymbol{EI_s^*})$$

where, I_s*- complex conjugate of stator current.

$R_e(\boldsymbol{EI_s^*})$- average power flowing into the voltage source **E**.

Synchronous speed (n_s) is given by:

$$n_s = \frac{120 \times f}{p}$$

where, f- frequency of AC current

p - Magnetic poles per phase

Maximum torque (T_{max}) is given by:

$$T_{max} = \frac{P(\max)}{\omega}$$

The equations used are the standard equations that are stated in for synchronous motors.[1], [8] and [9].

Advantages

1) The mechanism stated is more efficient as compared to conventional axial compressors.
2) There will be less wear and tear in proposed operation technique of axial compressors.
3) Due to regeneration property of synchronous motor, current stored can be reused for other cycles and also for other onboard operations.
4) Proposed mechanism of axial compressors has wide industrial applications from aircraft jet engines to industrial turbines.
5) Less maintenance is required in proposed operation of axial compressors.

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