Experimental Study of Stator Clocking Effects in an Axial Compressor

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Abstract: This paper is focused on the experimental study of the effects of stator clocking on the performance of a low-speed repeating stage axial compressor with compound-lean stators as well as the one with conventional stators (the baseline) for comparison. The experimental results show that as the clocking positions vary, the upstream stator wake enters the following passage at different circumferential positions, and then mixes with the local fluid in the following passage. This is the main reason for the variation of the compressor performance resulted from the stator clocking effects. The variation of the compressor performance due to the clocking effect is less pronounced for the compressor with compound-lean stators than with the baseline. At a certain clocking position, the efficiency of the compressor with compound-lean stators is increased in comparison with that of the baseline，especially on small mass flow rate conditions, e.g., 0.7% at design condition and 3.5% at near-surge condition in this case. The maximum 1.22% and the minimum 0.07% increases in efficiency on design condition are obtained through the combined effects of the stator compound-lean and the stator clocking in this case.

Key words: compressor performance；stator clocking；compound-lean stator；wake interaction

压气机直、弯静叶 Clocking 效应实验研究. 陈 浮，顾忠华，陆华伟，王仲奇. 中国航空学报(英文版), 2006, 19(4)：278-285.

摘 要：实验研究静叶 Clocking 效应对采用直、弯静叶的某低速双级轴流压气机气动性能影响。结果表明，随 Clocking 位置不同，上游静叶尾迹被输运到下游叶列流道中不同周向位置并与该列叶栅不同区域流体掺混是导致压气机性能变化的主要原因，且采用弯曲静叶的压气机性能随 Clocking 位置不同而变化的幅度要小一些。静叶 Clocking 位置固定时，采用弯静叶时压气机效率比直静叶时明显提高，且随流量减小而趋势显著，设计工况和近喘振点处分别约提高 0.7%、3.5%。针对本文研究的压气机，综合静叶造型和 Clocking 效应影响，采用弯曲静叶的压气机设计点处效率最高可提高 1.22%，最低提高为 0.07%。

关键词：压气机性能；Clocking 效应；弯曲静叶；尾迹干涉

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Airfoil clocking, consisting of adjusting the relative circumferential positions of stators (or rotors) in adjacent stages, has the potential for weakening the negative effects of the inherently unsteady flow in turbomachines due to the relative motion between rotating and stationary airfoil rows, thus improving the multistage performance[1]. The numerical studies performed by Gundy-Burlet and Dorney[2,3] showed changes in efficiency on the order of 0.5% to 0.8% in a 2-1/2 stage compressor as stators were clocked. Saren et al[4] proved that the airfoil clocking could be used to increase the performance and reduce the unsteady aerodynamic load on airfoils, while in another experimental investigation Layachi and Bolcs[5] showed that the flow at the stator inlet was characterized by the presence of IGV wake, and by a zone of loss coming from the interaction between the IGV wake and the rotor tip clearance; and that

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the circumferential positions of these low-energy zones would determine the structure of the flow in the stator passage and hence the performance of the compressor stage.

Leaning the blade stacking line in the circumferential direction, i.e., the aerodynamic effects of compound-lean (bowing, or dihedral) are used to reduce the endwall loss in compressor[6]. Weingold et al[7] investigated the bowed stators in a three stage compressor, and reported a 2% increase in overall efficiency and a delay of the corner stall due to the radial blade force caused by the dihedrals on both endwalls. Sasaki and Breugelmans[8] also observed this phenomenon in the experimental study of a compressor cascade with dihedral blades.

A bowed wake unique to the compound-lean blade will lead to different mechanisms of wake-wake and wake-airfoil interactions, and thus different effects of airfoil clocking, compared to those in a conventional compressor previously studied since airfoil clocking affects the compressor performance by changing the circumferential position of the upstream wake entering the downstream blade passage. The goal of this work is to assess experimentally the effects of stator clocking on improving the performance of a low-speed repeating stage compressor with compound-lean stators. For the purpose of comparison, the stator clocking effect in the compressor with conventional stators (the baseline) is also investigated experimentally.

1 Test Compressor and Instrumentation

The low-speed axial compressor at Harbin Institute of Technology consists of two geometrically identical stages[1]. The airfoils of both rotor and stator are NACA65-24A_{10}-10. Table 1 contains the design parameters of the facility. An electric motor is installed to drive the rotors to change the velocity from 0 to 3 300 r/min, while the design rotating speed is 3 000 r/min. Off-design conditions can be obtained by adjusting the discharge area at the exit of the compressor.

Traverse measurements at the exit of stators of the two stages (see Fig.1) are performed with a conventional five-hole probe (2.1 mm tip diameter), which is able to move along the radial direction and rotate around its own axis. The circumferential movement of the probe is attained by rotating the outer rings of the stators of the two stages simultaneously. As the stators are assembled in their own outer rings respectively, the circumferential rotations of the outer rings are used to obtain the desired clocking positions of stators. Two five-hole probes located at the 32% of the axial chord length downstream the stators of the two stages respectively are employed to measure the static pressure, the total pressure and the flow direction. The circumferential probe traverses occupy one and a half pitches, totally 38 measuring points, which are denser near the stator trailing edge with a spacing of 0.5° each，and coarser in the mid-passage, 1° one spacing because the flow parameters at each point within the wake vary significantly from each other. The radial probe

Table 1 Design parameters for the axial compressor

Rotating speed/ $(r \cdot min^{-1})$	3000	Axial velocity/$(m \cdot s^{-1})$	48
Mass flow rate/$(kg \cdot s^{-1})$	8.7	Pressure ratio	1.05
Tip radius/m	0.3	Hub radius/m	0.2
Axial blade row gap at midspan/m	0.03		

	Rotor	Stator
Aspect ratio (span/chord)	1.25	1.27
Inlet metal angle at midspan/(°)	53.59	28.21
Outlet metal angle at midspan/(°)	49.02	-8.64
Number of blades	20	20
Clearance/m	0.000 7	0.000 8

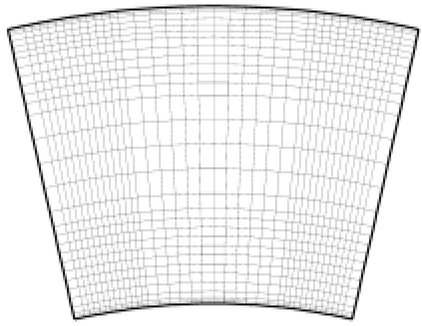

Fig.1 Traverse positions at the exit of stator