Technical Notes

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Effects of Compound-Lean Stator Clocking in a Low-Speed Axial Compressor

Fu Chen,* Zhonghua Gu,† Haiyi Xie,‡ and Zhongqi Wang§
Harbin Institute of Technology, 150001 Harbin, People's Republic of China

DOI: 10.2514/1.17591

I. Introduction

AIRFOIL clocking, consisting of adjusting the relative circumferential position of stators (or rotors) in adjacent stages, has the potential for affecting the compressor performance by means of changing the circumferential position of the upstream wake entering the downstream blade passage [1,2]. The numerical study performed by Gundy-Burlet and Dorney [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. Leaning the blade stacking line in the circumferential direction, that is, aerodynamic effects of compound lean (bowing or dihedral) are used to reduce endwall loss in the compressor [4]. Weingold et al. [5] investigated 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 dihedral on both endwalls.

A bowed wake unique to the compound-lean compressor blade will lead to a different mechanism of wake–wake and wake–airfoil interactions and, thus, different effects of airfoil clocking. 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. Table 1 describes the key parameters for the compressor. The clocking positions of the first-stage stators, shown as θ in the following figures, were established by rotating the stator row of the first stage relative to that of the second stage, $1/18$ of the pitch each time in the direction opposite to the rotor rotation. Consequently, 18 relative positions between the stators of the two stages were selected from $\theta = 0/18$ to $\theta = 17/18$.

Received 9 May 2005; revision received 27 July 2006; accepted for publication 28 July 2006.

*Professor, School of Energy Science and Engineering, P.O. Box 458.
†Assistant Professor, School of Energy Science and Engineering, P.O. Box 458.
‡Graduate Student, School of Energy Science and Engineering, P.O. Box 458.
§Professor, School of Energy Science and Engineering, P.O. Box 458.

II. Results and Discussion

Figure 1 gives the compressor efficiency of the baseline (STR) and the compressor with compound-lean stators (BOW) at different clocking positions. The design flow coefficient is 0.51. Efficiency is defined as the ratio of the isentropic compression work to the consumed work calculated from measured torque. The stator clocking has different levels of effect on compressor efficiency as the compressor operating condition varies. The maximum variations of efficiency due to stator clocking effect at the maximum flow coefficient condition tested are 2.7% and 3.0% for the baseline and the compressor with compound-lean stators, respectively, and 0.6% for both of them at design condition (see Fig. 2). With decreasing flow coefficient, the effect of stator clocking on compressor efficiency diminishes.

Figure 2 illustrates the variation of compressor efficiency with the stator clocking positions at design condition. There exists distinct clocking position corresponding to the maximum and the minimum compressor efficiency, respectively. For the compressor with compound-lean stators, the minimum efficiency occurs when θ is $4/18$ and the maximum efficiency occurs when θ is $12/18$. For the baseline, $1/18$ and $12/18$ correspond to the minimum and maximum efficiencies, respectively. A 1.22% increase in efficiency, at most, can be obtained in this case by the combined effects of blade compound lean and stator clocking in comparison with that of the baseline. The observed improvement in compressor performance with the application of clocking effect to the compressor with compound-lean stators indicates a potential way to enhance compressor performance. Thus, it is suggested that clocking be considered as a design method for compressors with compound-lean stators.

Figure 3 illustrates the contours of total pressure coefficient at the exit of the compressor at different clocking positions. Total pressure coefficient is the ratio of the total pressure (gauge) to the inlet dynamic pressure. It can be seen that as the stator clocking positions alter, the high-loss region (indicated by the dashed/dotted line) changes its location. At $\theta = 12/18$, corresponding to the maximum efficiency, no dashed/dotted line is drawn, due to the dense contour lines of the total pressure coefficient near the suction surface where the high-loss regions are located. As the clocking positions vary, the high-loss regions decrease in size and move toward the suction surface. At $\theta = 12/18$, the high-loss regions at the hub and tip region become marginally small, but the wake region enlarges. At

Table 1 Key parameters for the low-speed axial compressor

Rotating speed	3000 rpm	Axial velocity	48 m/s
Mass flow rate	8.7 kg/s	Pressure ratio	1.05
Tip radius	0.3 m	Hub radius	0.2 m
Axial blade row gap at midspan		0.03 m	
		Rotor	Stator
Aspect ratio (span/chord)		1.25	1.27
Inlet metal angle at midspan		53.59 deg	28.21 deg
Outlet metal angle at midspan		49.02 deg	−8.64 deg
Number of blade		20	20
		Rotor tip	Stator hub
Clearance		0.0007 m	0.0008 m

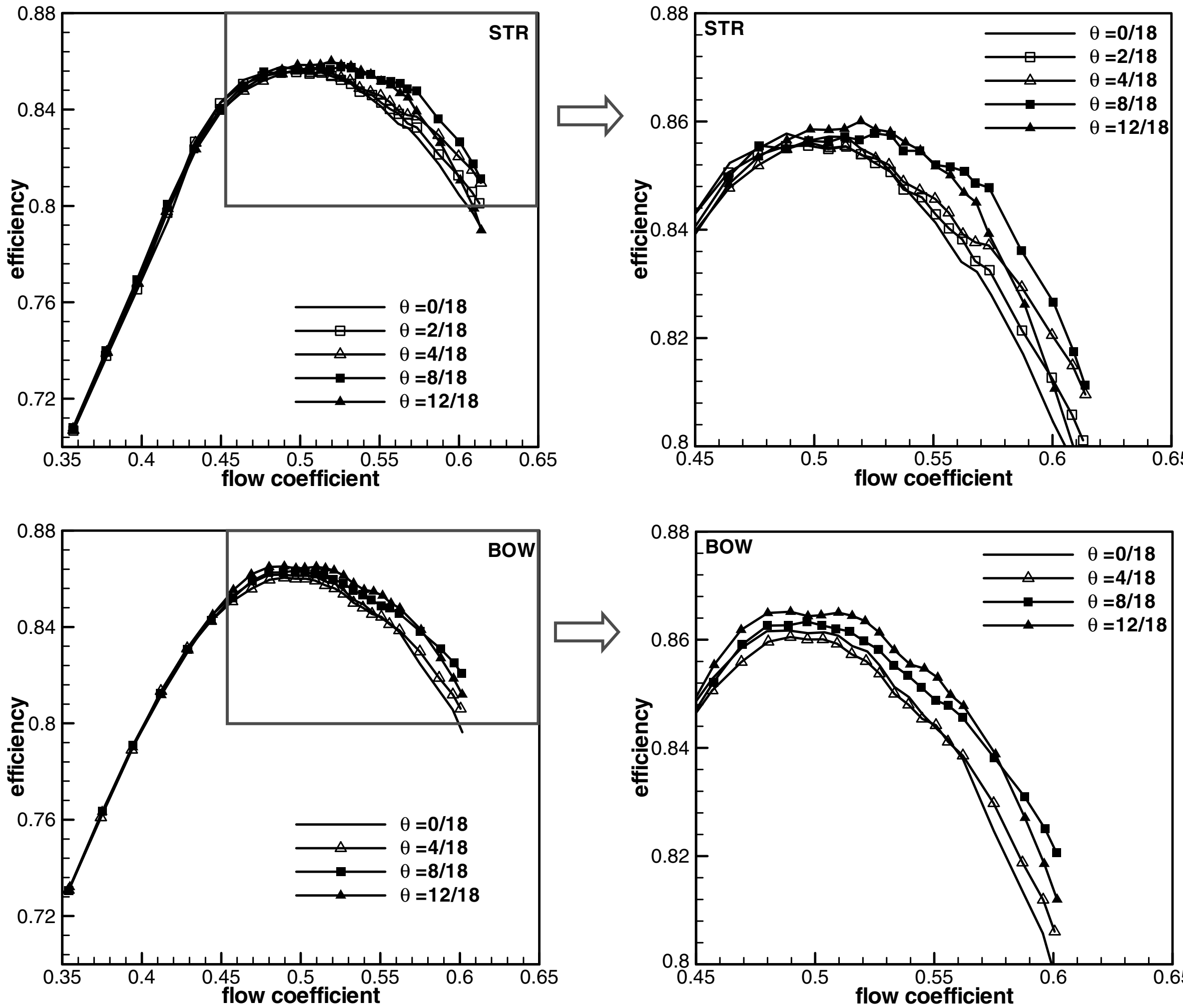

Fig. 1 Compressor efficiency at different clocking positions.

$\theta = 16/18$, the high-loss regions occur in the midflow passage close to the pressure surface. For the baseline, similar results can be inferred from the distribution of total pressure coefficient at different clocking positions.

A hypothetical explanation for the observations is put forward in the following discussion. The pitchwise variations in midspan total pressure coefficient at the exit of the compressor with compound-lean stators at design condition are shown in Fig. 4; the results are in accord with the observations inferred from Fig. 3. With upstream stators clocked at $\theta = 4/18$ for the minimum efficiency, there is a

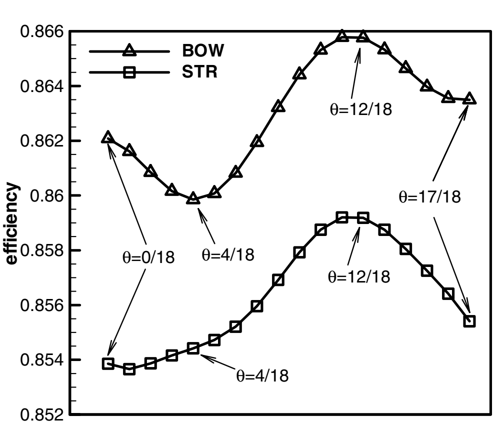

Fig. 2 Variations of compressor efficiency with different stator clocking positions.

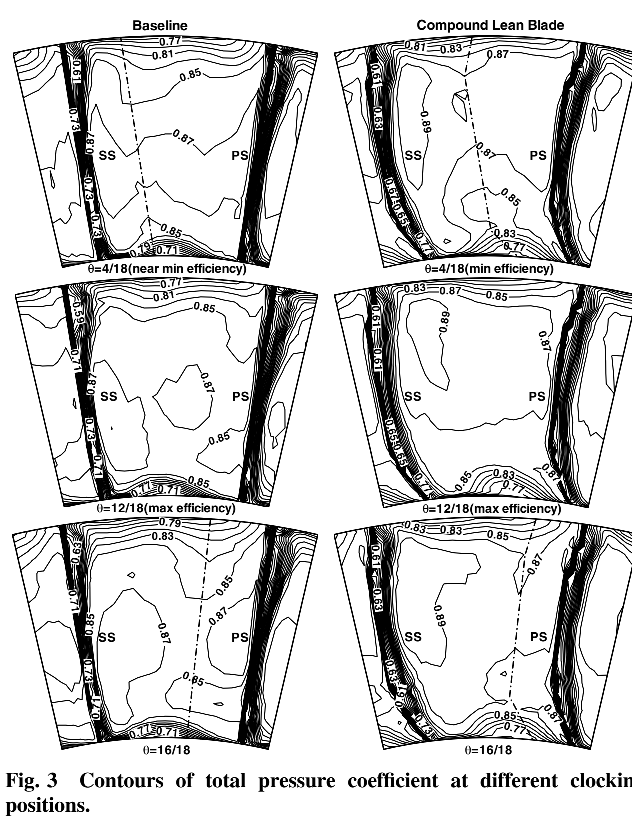

Fig. 3 Contours of total pressure coefficient at different clocking positions.

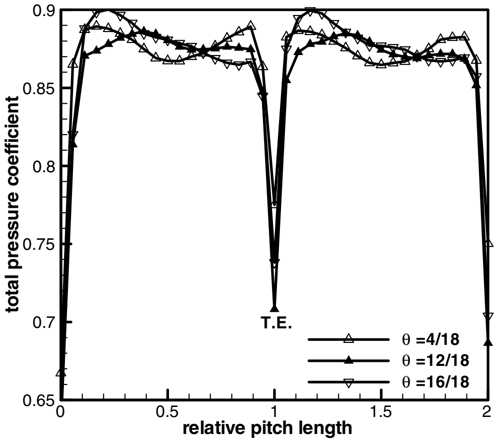

Fig. 4 Variations of total pressure coefficient at the midspan with the clocking positions.

trough in the distribution of the total pressure coefficient in the midflow passage at the exit of the downstream stators. The trough indicates the migration of the upstream stator wake to the middle of the downstream stator row to mix with the main flow. The mixing process increases the loss and deteriorates the flow behavior in the main flow region. The upstream wake (i.e., the trough in the distribution of total pressure coefficient) moves toward the suction surface as the clocking positions vary continuously and impinges on the leading edge of the downstream stator at $\theta = 12/18$. The upstream wake redistributes near the blade surfaces and thus enlarges the width of the wake leading to additional loss within the wake. The total pressure, however, retains a high value in the main flow region, so that maximum efficiency is obtained. The trough in the distribution of total pressure coefficient occurs close to the pressure surface when the clocking position changes to $\theta = 16/18$. Another plausible source for the present observation is in the response of the endwall flow.

III. Conclusions

The maximum 1.22% increase in efficiency at design condition is obtained through the combined effect of the compound lean and stator clocking in this case. It is thus suggested that the design of compound-lean stators should include clocking as a design parameter.

The maximum efficiency of the compressor with compound-lean stators occurs when the upstream wake impinges on the leading edge of the downstream stator.

Acknowledgments

The authors would like to acknowledge the support of the National Natural Science Foundation of China, grant no. 50236020. The authors also would like to thank reviewers and C. S. Tan and Y. Gong of the Massachusetts Institute of Technology for their comments, which helped us improve the quality of this Technical Note.

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C. Tan
Associate Editor