



Fig. 14 Total pressure at the outlet of the impulse-type and shock-rotor stage

within the stator passage in the whole operation range. This can be realized by stators with variable geometry.

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DISCUSSION

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The authors present a very interesting paper on an important field of compressor research activity. Three different supersonic stages have been examined (Fig. 2) using fixed and variable geometry stators. It would be very interesting to compare these different types of stage, especially to see the payoff by the variable stator stage configuration.

The authors give some hints in Section 4.1 on a considerable improvement of stage performance by combining the impulse-type rotor with the variable single-row stator. In order to verify this, a presentation and comparison of the different performance maps would be very valuable. Of course, the per-

formance map of the variable geometry stage is more complex due to the additional stagger angle parameter. But it is not easy to evaluate the different stage results from the diagrams in the paper. Using performance maps not only off-design comparisons would be possible, but also design performance comparisons, which are of great interest too.

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We would like to point out that in the bottom diagram of Fig. 3 the stagger angle α_{st} of the turnable stator is measured toward the blade pressure side, whereas in Fig. 11 α_{st} is measured toward the suction side. That results in a difference of 7 deg [22]. In the definition of Fig. 11 the design value of α_{st} is 47 deg.

The results presented in Fig. 11 extend from $\alpha_{st} = 61$ to 53 deg. Therefore the lowest value of α_{st} is still 6 deg above design. Are there any results close to the design value of $\alpha_{st} = 47$ deg? Also results for the rotor/stator combination of Fig. 11 taken at higher than the starting rotor speed would be of great interest.

From Fig. 13, where the fixed and the turnable stator stages are compared at design speed, the question arises as to whether the results of the turnable stator are taken at the design stagger angle. From the shock system on the stator cascade sketch given in this diagram, this seems not to be the case. The flow case shown in Fig. 13 with no suction surface leading edge oblique shock wave [22] belongs to a stator blade stagger position of 7 deg or more above design.

Similar questions arise for Fig. 14 (upper part): Have the compared results been obtained at design speed, design stator blade stagger angle position of $\alpha_{st} = 47$ deg and, as in the lower part of this diagram for the fixed tandem stator blade stage, at maximum back pressure? The maximum back pressure presented for the turnable stator blade stage seems to be quite low.

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Authors' Closure

The authors thank Dr. Fuchs and Dr. Starcken for their detailed discussion.

The following closure is arranged systematically with respect to the main topics of the discussion.

1 Influence of the Stator Setting on the Starting Process (Impulse-Type Rotor/Variable Geometry Stator). The definition of the stagger angle in Fig. 3 representing blade geometry

data is correct. In Fig. 11, explaining mainly the velocity triangle at stator inlet, the stagger angle should also be measured with respect to the pressure side. This inaccuracy in the preprint is already corrected in the printed version. Thus $\alpha_{st} = 53$ deg corresponds to the closest stator setting (Design 54 deg).

2 Lack of Results Regarding the Impulse-Type Rotor/Variable Geometry Stator at Speeds Higher Than the Starting Speed (Fig. 11). As can be seen from the axial Mach number distribution versus speed ratio in Fig. 11, the axial flow is clearly supersonic if the starting speed is exceeded. For this case the rotor exit average data coincide with the data for rotor-alone operation and are omitted for clearness reasons.

3 Design Performance Comparison of the Different Supersonic Compressor Stages. The main features of the flow at design speed and increased back pressure are described in Section 4.2.

"Regarding the *impulse-type rotor and tandem stator*, the close vicinity of starting and design speed . . . did not allow a throttling" (Section 4.2). Consequently no data for design back pressure can be presented.

The design-speed line of the *shock-rotor/tandem stator* combination is given in Figs. 13 and 14. Stable operation and the design data (see introduction) have been achieved with satisfying efficiency.

Regarding the *impulse-type rotor and variable geometry stator* the corresponding data are also shown in Figs. 13 and 14. The results at maximum back pressure refer to the closest throttle position with stable operation corresponding to the surge margin of the compressor stage. Contrary to design condition the interaction of shocks with wall boundary layers at hub and casing prevents a deceleration of the flow to subsonic exit conditions. In the real compressor a pseudoshock system is achieved, generating nearly sonic speed at the stator exit (see section 4.2).

For these reasons further investigation of supersonic compressors at the Technical University Aachen is mainly focused on the development of shock rotors in combination with tandem stators [23].

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