ABSTRACT

This paper reports on an examination of rotating stall in a low speed three stage axial flow compressor operating with various degrees of stage mis-match. The objective of this study was to simulate the mis-matching which occurs in high speed multistage compressors when operating near surge. The study of the stall zones involved the use of fast response measurement techniques.

The study clearly shows how stages can operate in an axi-symmetric fashion even when heavily stalled, rotating stall inception requiring the stall of more than one stage. The study also compares conditions required for full span and part span stall and suggests that the part span stall structure is the more relevant to high speed multistage compressors.

NOMENCLATURE

U	Mean rotor speed
Va	Axial velocity
V	Absolute velocity
Vw	Whirl velocity
Va/U	Flow coefficient
$DPtt/1/2\rho U^2$, ψtt	Non dimensional total to total pressure rise coefficient
$DPts/1/2\rho U^2$, ψts	Non dimensional inlet total to exit static pressure rise coefficient
$DPss/1/2\rho U^2$, ψss	Non dimensional static to static pressure rise coefficient.

INTRODUCTION

Multistage compressors need to be capable of operating over a wide range of conditions and inevitably incur stall at low flow rates which eventually provides a limit to the operating range. It is well known that when a multistage compressor operates at low speeds (and low flow rates) the front stages will tend to stall first. The reason for this is that at low speeds the operating density ratio is lower than the design value causing the axial flow coefficients in the rear stages to increase above the design value, eventually causing high negative incidence losses. These losses restrict the axial velocity in the inlet stages eventually causing stall.

At high speeds, surge usually occurs due to the rear stages stalling. This is because, at high speed and low flow rates, the front stages operate at a density ratio above the design value causing a reduction in axial velocity in the rear stages. This reduced axial velocity will eventually cause an increase of positive incidence and stage stall in the rear stages.

The objective of this study has been to investigate the stall process of multistage compressors operating with mismatched stages. In this case the stage mismatch has been simulated by varying (from design) the blade stagger in a three stage, low speed (parallel annulus) compressor. It is clear that conventional compressor mismatch occurs due to the occurrence of different flow coefficients in adjacent (usually similar) stages whereas in the present study the same flow coefficient is imposed on all stages and the stages are arranged to have different stall points. It is also clear that the present tests involved an exaggeration of the actual mismatch conditions prevailing in a three stage compressor operating at off design conditions.

TEST RIG AND INSTRUMENTATION

The Compressor

The compressor used for the present investigation was a low speed constant annulus three stage machine which could be configured in a variety of different builds. The design speed was 3,000 rpm with a mean blade speed of 50m/s.

The blades were of free vortex design with the degree of reaction varying from 0.66 at the tip to 0.31 at the hub and with 0.5 at the midheight. The blades could be set to any stagger angle desired. In order that the blade rows in the compressor should be fully interchangeable, the width of each rotor and stator ring (in which the blades were mounted) was identical. This simply means that the axial distance between the centre lines of each blade row was fixed. When the blades were set at design stagger, the axial gap between blade rows could be either 40% or 70% of axial chord lengths (depending on the spacers used). When the stagger was altered, however, the spacing between the trailing edges of adjacent blade rows was clearly a function of the stagger setting.

The flow rate was controlled by a manually operated throttle. The mass flow through the compressor was measured by a venturi flow meter some distance downstream. Details of the compressor geometry are given in fig. 1 and Table I. Details of the builds tested are given in Table II where the variation from the design stagger of 36 degrees is shown (0 degrees indicates the design stagger).

Slow Response Instrumentation

The rig was equipped with conventional (time average) wall static tappings at inlet, the interrow gaps, and the outlet of the compressor. At each measuring station there were four static tappings at 90 degree intervals connected to a common manometer tube.

The data acquired from the wall static tappings was used to obtain the steady state overall and individual stage characteristics of the compressor as well as the time unsteady average rotating stall characteristics.

The mass flow rate through the machine was measured using the calibrated downstream venturi. The flow through the venturi was straightened using an upstream honeycomb mesh. The venturi had four static tappings at 90 intervals at both the 406mm diameter inlet and at the 256mm throat.

Instantaneous (Real Time) Instrumentation For The Unsteady Measurements

The instantaneous or real time instrumentation is shown schematically in fig. 2 consisting of cylindrical yaw probes with closely coupled fast response pressure transducers, a bank of amplifiers, low pass filters, a sample and hold unit with a trigger circuit, an oscilloscope, an analogue to digital converter, and a BBC computer with a floppy disk drive.

The flow measurements in the rotating stall regime were performed using the cylindrical three hole type yaw probe which was 4mm in diameter, and a wall static probe (to be described later). The three hole probe had been used earlier for the rotating stall investigation by Das and Jiang [1] and was found to be suitable for the present investigation. Each of the