BUILDING A LOW SPEED RESEARCH COMPRESOR AT SEOUL NATIONAL UNIVERSITY

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ABSTRACT

A low speed research compressor at Seoul National University (SNU) has been built to measure aerodynamic performance of axial compressors. The SNU compressor is a vertical four-stage low speed axial compressor rig with IGV and is based on the design of the GE Aviation. Air passes through the upstream bellmouth with a circular filter, compressor, and a downstream throttle. It is powered by a DC motor, and a gearbox is installed to transfer the power. For steady measurements, the SNU compressor uses Kiel and 5-hole probes. For unsteady measurements, hot-wire probes and Kulites are used. Radial and circumferential traverse systems are installed to enable pitchwise and spanwise movements of sensors. Pitot probes and RTD sensors are installed to measure inlet flow qualities, and a torquemeter, and an encoder have also been installed.

NOMENCLATURE

Symbols

C	Chord length of rotor
S	Span
R	Rotor
S	Stator
M	Measuring Plane
U_t	Blade tip speed
C_x	Axial velocity
$\dot{\theta}$	Angular velocity
C_p	Heat capacity of air
$\dot{m}$	Mass flow rate
τ	Torque
γ	Heat capacity ratio
ρ	Density
P	Pressure
T	Temperature
υ	Kinematic viscosity of air
Φ	Flow coefficient
Ψ	Pressure Coefficient
η	Efficiency

Subscripts

$_s$	Static
$_t$	Total

INTRODUCTION

To improve efficiency, maximize pressure rise, and extend operating range, understanding the detailed flow structure inside the compressor is required. Measuring the flow structure inside of axial compressors is difficult, therefore to elaborate these efforts, many researchers studied on cascades [1-3], or adopted the computational fluid dynamics (CFD) [2-10]. However, for cascade experiments the nature of flow structure is inherently different from axial compressors [11], and CFD requires experimental validation [12]. Therefore, it is necessary to measure the flow structure inside the actual axial compressors to understand the flow field.

Various institutes have large scale, subsonic axial compressors [13-17] to investigate aerodynamic performance of axial compressors. Seoul National University recently has built its research compressor; it is composed of four identical stages with IGV with Reynolds number up to 261,800. It is an open-type compressor with upstream bellmouth and downstream throttle. Instrumentations to measure the flow properties are installed. Steady and unsteady sensors are also equipped to enable radial and circumferential measurements. Detailed introduction of each components will be followed.

DESIGN PARAMETERS

The SNU compressor is an axial compressor, having four identical stages with IGV,

Table 1 : SNU Compressor FACILITY DATA

Parameters	Numbers
Design mass flow rate	5 kg/s
Diameter	1,000 mm
Hub to tip ratio	0.85
Rotor Chord	75 mm
Tip claearance (% S)	1.4 %
Motor power	55 kW
Design RPM	1,000
Reynolds number	261,800

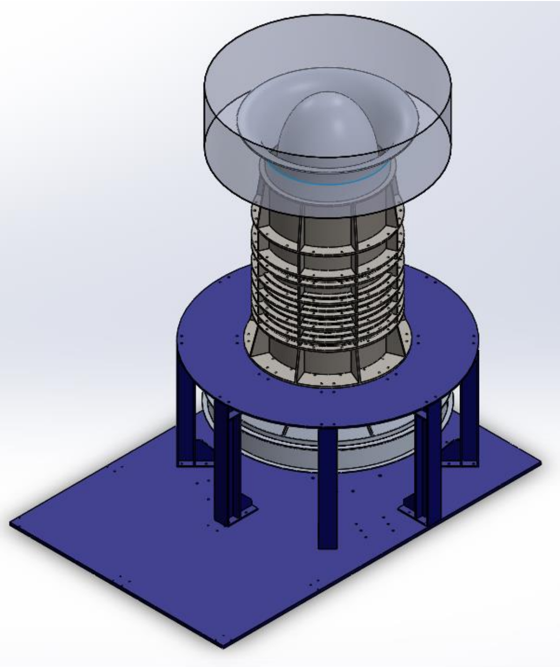

Figure 1. The Overview of SNU Compressor

and the blades have been designed by Doosan Heavy Industries. Reynolds number of SNU compressor based on chord length and rotor tip speed (CU_t/ν) is 261,800. Its basic configurations follow that of the GE LSRC [4], having been scaled down to 2/3 of the original size.
Table 1 demonstrates the design parameters of SNU compressor.

INLET SYSTEM

A circular filter with flow straightening plates is installed upstream of inlet bellmouth and bullet nose. Porous material made of fabric is used as the circular filter, which is supported by a circular frame to prevent foreign objects from entering the compressor.

COMPRESSOR SECTION

The compressor consists of four identical stages plus an IGV row, which have been designed by Doosan Heavy Industries. IGV and rotor rows are cantilevered, and stator rows are shrouded. All blade rows including the IGV, rotor and stator are designed to allow the stagger angle and the solidity variation.

The blade tips have additional 0.5 mm clearance to enable stagger angle changes up to ± 20 °. All blades are machine-fabricated to obtain a dimensional accuracy of less than ± 0.05 mm, and the surface roughness is less than Ra 3.2 μm, is equivalent to nondimensionalized roughness parameter k+ [18] of 3.36. Typical standard for aerodynamically smooth surface is k+ < 10.

CASINGS

The compressor casings have several physical access ports for measuring aerodynamic properties. Casings are designed to be modulized such that they can be replaced for different research purposes.

POWERTRAIN

The SNU LSRC is powered by a horizontally aligned 55-kW DC motor. A bevel-type gear box transfers power to the vertically aligned main shaft.

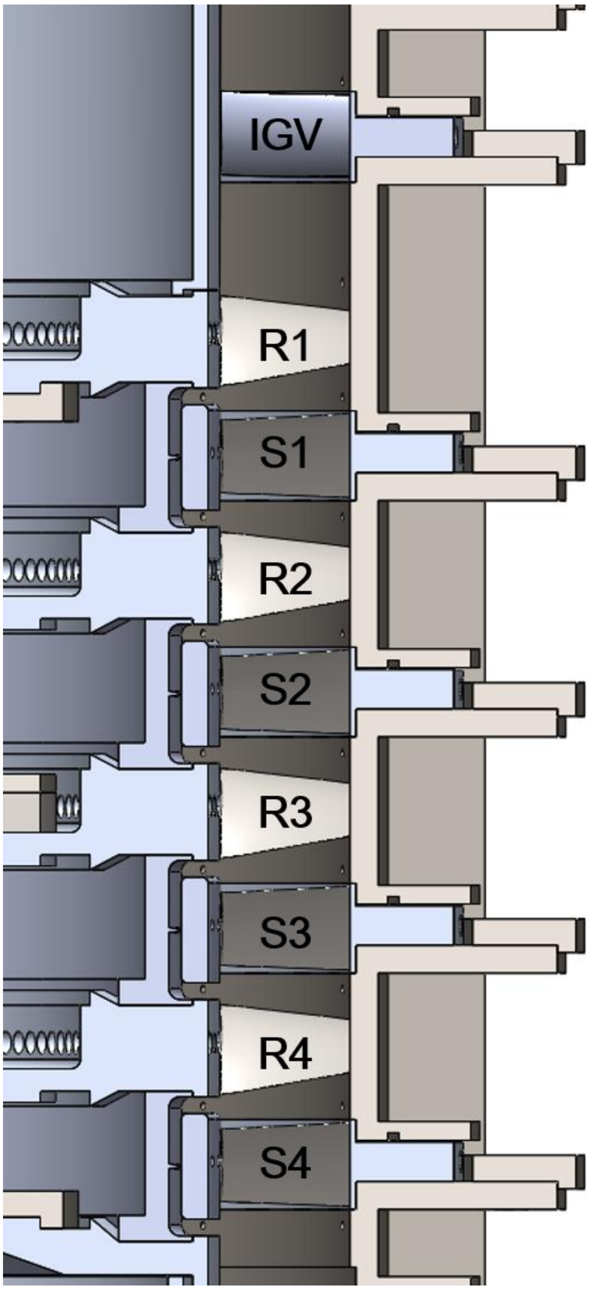

Figure 2. The Compressor Section

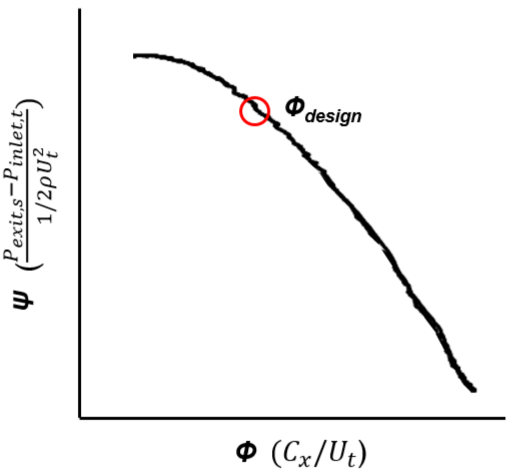

Figure 3. A Compressor Map

Two torque limiting couplings have been installed - between the main shaft and the gearbox.

INSTRUMENTATIONS

Various instrumentations have been installed to decide the operating conditions of SNU compressor. Table 2 illustrates parameters and their definitions required to fix the operating conditions on a compressor map (Figure 5) - flow coefficient, pressure coefficient, and efficiency.

Two Pitot probes (United Sensors PAA-8-KL) located downstream of bellmouth, and the compressor section measure the inlet and outlet P_t, P_s. A RTD sensor positioned inside of an upstream strut measures the inlet T_t, having an accuracy of ± 0.01 °C, and a Humlog 20 barometer having an accuracy of ± 0.05 kPa measures barometric pressure P_{atm} to identify the inlet air conditions. Two and between the gearbox and the DC motor - to protect components from mechanical failures. MKS 220DD differential pressure transducers having an accuracy of ± 0.15 % readings read the pressure difference from the two Pitot probes to measure the pressure and flow coefficients.

Table 2 : VARIABLES AND ITS DEFINITIONS REQUIRED FOR SNU COMPRESSOR OPERATIONS

Variables	Definitions
Flow Coefficient (Φ)	$\frac{C_x}{U_t}$
Pressure Coefficient (Ψ)	$\frac{P_{s,out}-P_{t,in}}{1/2\rho U_t^2}$
Isentropic Efficiency (η)	$\frac{\dot{m}C_pT_{in}\left\{\left(\frac{P_{t,out}}{P_{t,in}}\right)^{\frac{\gamma-1}{\gamma}}-1\right\}}{\tau\dot{\theta}}$

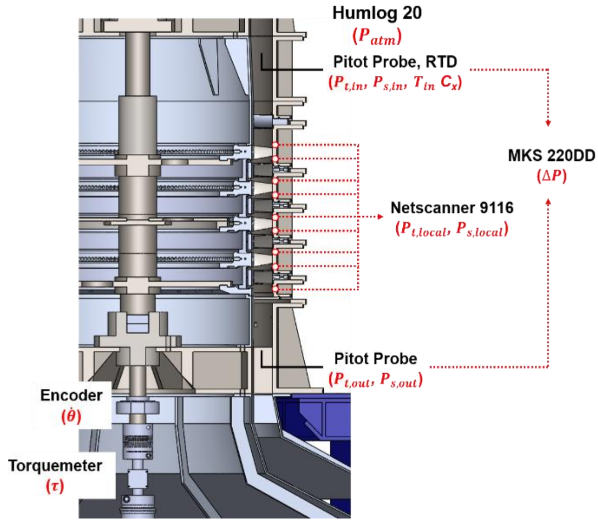

Figure 4. Instrumentations for LSRC Operation

To measure the mass flow rate, a bellmouth and a bullet nose are calibrated using a 1/16" diameter Pitot probe at 12 different circumferential directions, and these data are compared with the casing P_s to correlate mass flow rate and the P_s. A Netscanner 9116 16-channel pressure transducer having an accuracy of ± 0.15% of full scale (2.5 kPa/7 kPa) is used to measure the local P from Pitot probes, casing pressure taps, Kiel and 5-hole probes.

A Unipulse UTMII-500 torquemeter and a Baumer EIL 580 encoder having an accuracy of ± 0.15 Nm and ± 0.02% of the measured value, respectively, are installed at the main shaft to measure the efficiency and the rotation speed, and to synchronize the unsteady sensor signals with the relative position of rotors.

Using these sensors, parameters for determining operating conditions - flow coefficient, pressure coefficient, and efficiency - can be measured with uncertainties less than 0.19 %.

THROTTLE

A throttle is installed downstream of the compressor to control the flow rate. Four Parker ETH032 linear actuators having an accuracy of ± 0.05 mm actuates the throttle to control the flow rate precisely. Using this equipment, the flow coefficient of SNU LSRC can be controlled to be within 0.001.

STEADY MEASUREMENTS

To measure steady flow properties inside the blade passage, a United Sensors KAA-8 Kiel probe having a diameter of 1/16 inch is used for P_t measurements of three-dimensional flow to calculate the loss components, and a custom-made L-shaped 5-hole probe is used for P_t, P_s and $\vec{v}$ of three-dimensional flow. The 5-hole probe is 2 mm

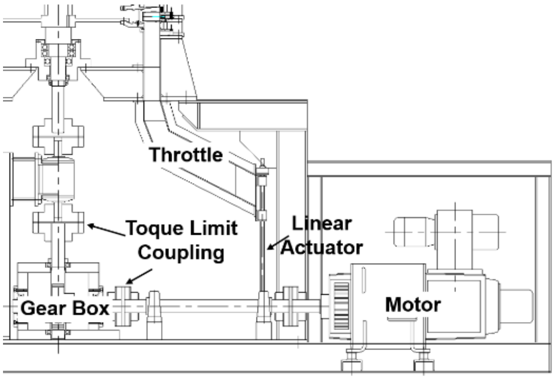

Figure 5. The Powertrain and the Throttle Sections

diameter, and calibrated within the range of ± 25° with 5° grid.

UNSTEADY MEASUREMENTS

To measure the unsteady flow properties inside of the blade passage, circumferentially and radially distributed XCQ-062 miniature Kulite sensors diameter of 1.7 mm is used for casing P_s measurements. Also, Dantec dynamics 55P11 miniature hot-wire anemometry sensors are used for measuring three-dimensional flow $\vec{v}$.

CIRCUMFERENTIAL AND RADIAL TRAVERSING OF SENSORS

To traverse the sensors in the circumferential and radial directions, three Velmex Bislide linear traverses having an accuracy of ± 0.01 mm are used.

The three linear traverses are installed perpendicular to the casing circumferences, and traverse the sensor circumferentially and axially to align the sensor at the exact locations. A Velmex B59 rotary table is installed on the traverse system to align the direction of sensors to meet the flow angle within the probe measuring range.

The stator and IGV casings rotate circumferentially. Connectors are installed at each stator and IGV rows, and the step motor circumferentially rotates the connector using a gear system, which can rotate the stator and IGV rows 22.5° circumferentially.

SUMMARY

The low speed research compressor at Seoul National University has been rebuilt to measure the aerodynamic properties of axial compressors. It is an open-type compressor, having four identical stages including IGV. Air passes through an upstream bellmouth with a circular filter, compressor, and a downstream throttle. It is powered by a DC motor, and a gearbox is installed to transfer the power. Two torque limit couplings are installed to prevent mechanical damage.

Instrumentations to operate the SNU LSRC have been selected to measure the operating parameters to be within the uncertainties of 0.19%. A throttle is located at the downstream of the compressor section, and it is actuated by four linear actuators to control the flow rate precisely. Steady and unsteady sensors are equipped, and can be traversed circumferential and radial by linear traverses, connectors and a step motor.

ACKNOWLEDGMENTS

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