VISUALIZATION OF FLOW IN A TRANSONIC CENTRIFUGAL COMPRESSOR

Hiroshi Hayami*, Masahiro Hojo and Shinichiro Aramaki***

** Institute of Advanced Material Study, Kyushu University, Fukuoka 816-8580, Japan*
*** Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Japan*

Two kinds of measurement techniques by image processing were applied to visualize a flow in a transonic centrifugal compressor. One was a velocity field measurement at the inducer of the impeller using Particle Image Velocimetry (PIV) and the other was a pressure field measurement at the cascade diffuser using a Pressure Sensitive Paint (PSP) measurement technique. A shock wave in the impeller was clearly visualized by using PIV. And a violent change in pressure was visualized using a PSP measurement during a surge condition. Both results are discussed in comparison with those of Laser-2-Focus (L2F) velocimetry and those of semiconductor pressure sensors.

EXPERIMENTAL APPARATUS AND PROCEDURE

A high-pressure-ratio centrifugal compressor was tested in a closed loop with HFC134a gas at 18,000 rpm. The open shroud impeller had 15 main blades and 15 splitter blades. The impeller diameter was 280 mm and the inducer diameter was 172 mm. The diffuser consisted of a low solidity cascade with eleven vanes and two parallel walls 9.4 mm apart from each other[1].

A velocity field in the inducer of impeller was visualized using PIV. Figure 1 shows the measurement system based on a double-frame PIV with a double-pulsed Nd:YAG laser with 25 mJ. Dioctylpthalate (DOP) particles of about 0.6 μm in mean diameter were used as tracer particles. The time interval between double pulses was 2 μs. And a delay pulse generator was used so that measurements could be performed at arbitrary specified impeller blade phases. The sampling rate of a pair of images was about 3 Hz or every 300 revolutions using a non-contact displacement sensor and a preset counter.

A pressure field in the cascade diffuser were visualized using a PSP measurement technique. The measurement system[2] is shown in Fig. 2. Ru(bath-phen) was used as a PSP.

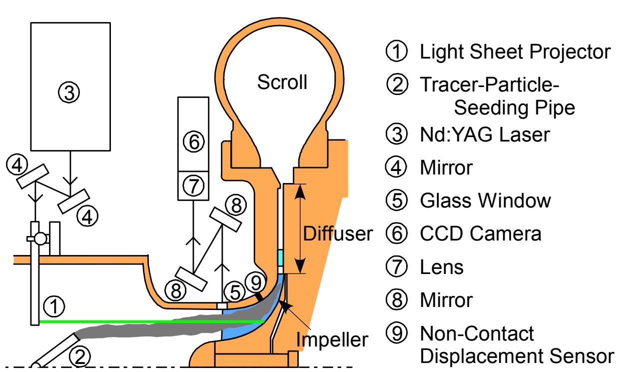


Fig. 1 PIV measurement system.

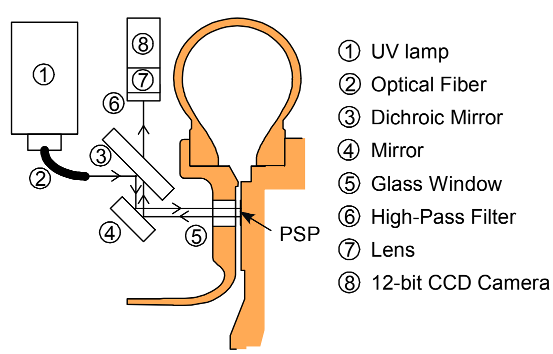


Fig. 2 PSP measurement system

VELOCITY FIELD IN IMPELLER BY A PIV MEASUREMENT

Figure 3 shows the relative velocity vector field and the contour map of Mach number based on an inlet stagnation temperature between a blade-to-blade passage at RMS radius of the inducer. The relative velocity vectors were calculated by vectorial subtraction of the peripheral velocity of the impeller and absolute velocity vectors averaged by 100 instantaneous velocity vectors, which were evaluated a cross-correlation method with sub-pixel processing and the average correlation method[3]. The measured maximum absolute velocity was 117 m/s, where the particle displacement was 8.1 pixel. The flow along the blade suction surface is once accelerated with an expansion wave, and then a shock wave was generated. These closely resemble the result of L2F measurements[4] shown in Fig. 4. Since the similar result could be obtained for a shorter measurement time than L2F, the PIV is very attractive for a flow measurement in a rotating impeller.

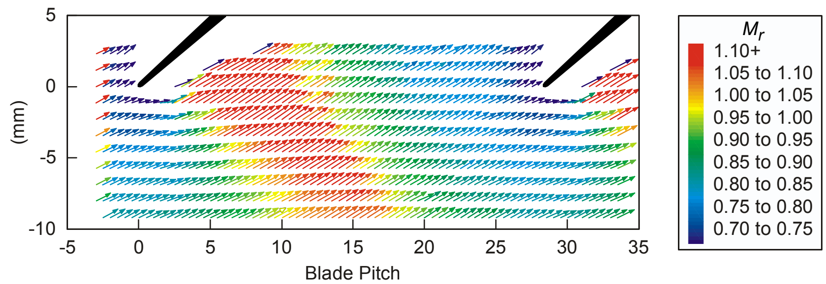


Fig. 3 Relative velocity vector field and contour map of relative flow Mach number.

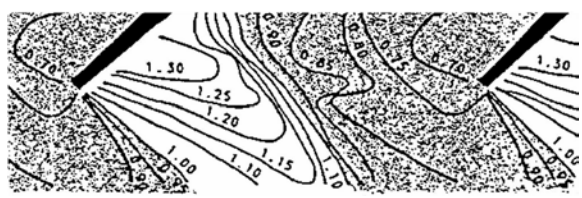


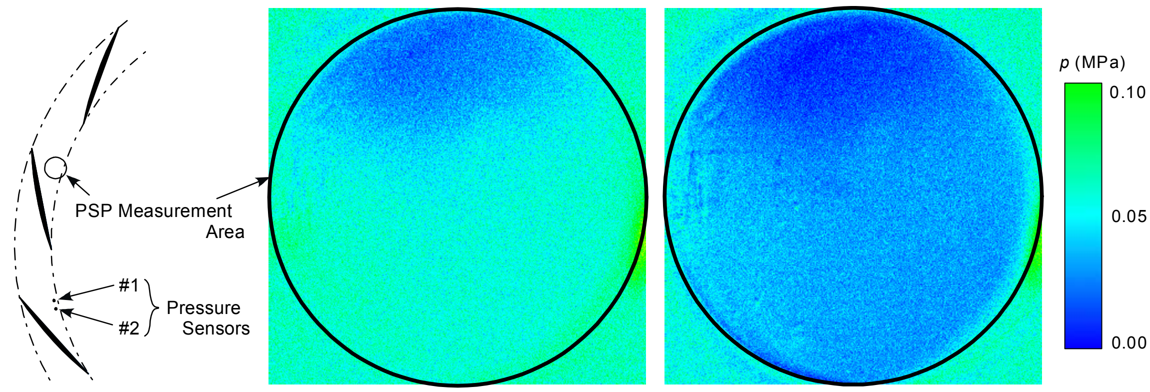
Fig.4 Contour map of relative flow Mach number by L2F measurement[4].

PRESSURE FIELD IN CASCADE DIFFUSER BY A PSP MEASUREMENT

Figure 5 shows two typical visualized unsteady pressure fields in a cascade at a stall condition and a non-stall condition during a surge[5]. Here colors indicate pressure levels based on the luminescent intensity. A drastic change in pressure was recognized. However, pressure at the top in the measurement area was not changed due to no illumination light. Any strong pressure gradient was not observed clearly in the area to show the existence of a shock wave. Figure 6 shows histories of PSP pressure compared with those of two semiconductor pressure sensors shown in Fig. 5a. Both pressure variations agreed well with each other.

CONCLUSION

The flow measurement techniques by image processing were successfully applied to a flow measurement in a transonic centrifugal compressor. The existence of a shock wave can be recognized by a contour map of the relative flow Mach number measured using PIV and unsteady pressure fields at a surge condition were visualized using PSP measurements.



(a) Test Cascade (b) at stall condition (c) at non-stall condition

Fig. 5 Visualized pressure field.

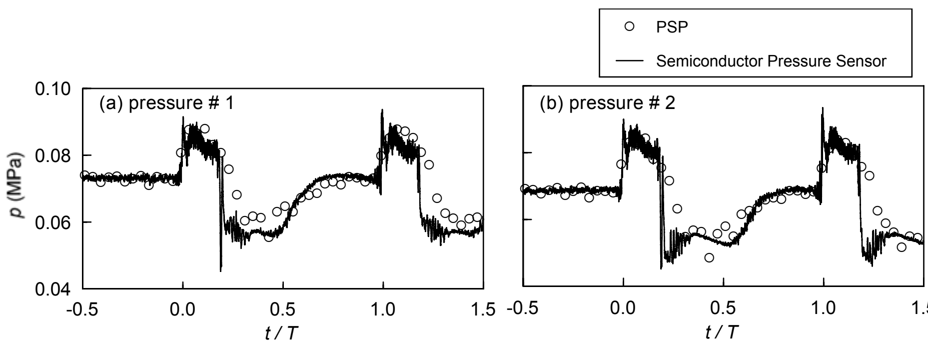


Fig. 6 History of pressure

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