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INVESTIGATION OF TURBULENT FLOW CHARACTERISTICS WITHIN SCREW COMPRESSOR

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ABSRACT

The material presented in this paper is part of a research project dedicated to measure the fluid mean velocity distribution and the corresponding turbulence fluctuations at various cross-sections across the working and discharge chambers to characterise the flow development through the port of the compressor at different phase angles. Axial mean flow measurements and the corresponding turbulent fluctuation were measured inside of a screw compressor both upstream and downstream of the discharge port with high spatial and temporal resolution using laser Doppler Velocimetry (LDV) at a rotational speed of 1000 rpm and a pressure ratio of 1.0.

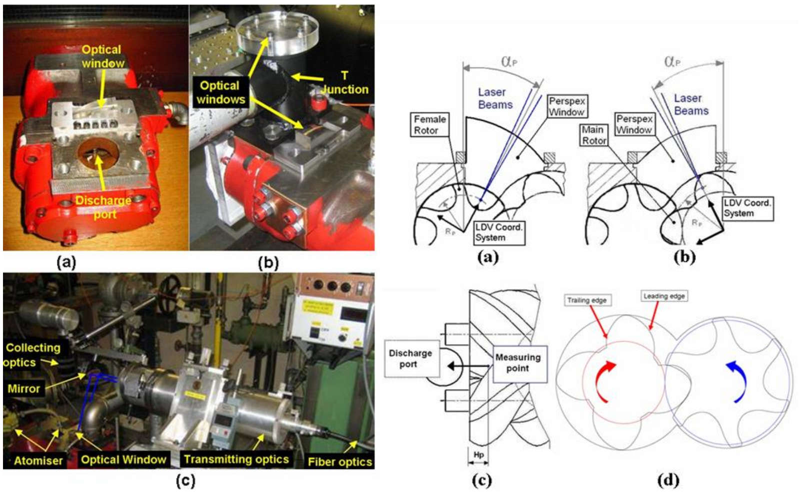


Figure 1 Left : Optical compressor set up: (a) modified compressor with transparent window near the discharge; (b) modified discharge pipe with transparent lid on the top; (c) LDV optical set up of transmitting and collecting optics and Right : Coordinate system adopted for the rotor chamber: (a) female; (b) male; (c) axial plane; (d) view, of male and female lobes, right.

Flow in screw compressors is complex, three-dimensional and strongly time-dependent that the measuring instrumentation must be robust to withstand the unsteady aerodynamic forces, have high spatial and temporal resolution and not disturb the flow. A dual beam Laser-Doppler Velocimeter (LDV) fulfils these requirements, as demonstrated by the authors in previous research [1, 2 and 3]. It will characterise the fluid mean velocity and turbulence fluctuations. This was made possible through transparent windows made of plexiglass, which provided optical access for the laser beams and backscatter signal acquisition. Separate windows were fitted for the male, and female interlobe regions with a third for the outlet port, as shown in Figures 1 (a) and (b).

The flow was seeded by a silicone oil atomiser that produces droplet sizes in the range of 1 to 2 μm. A low viscosity silicone oil of 5 cSt was used. A computer program was written in which the shaft angular position from the shaft encoder was used to resolve the velocity with respect to the rotor, the so-called ‘gated’ measurements. This was done by collecting the sum of all the instantaneous velocities over a given time-window and then calculating the ensemble mean and RMS values. This method of gated measurements proved to be efficient since the data was collected continuously as the rotor turned and provided ensemble averages for every 1.0° over the entire 360˚ cycle in a time interval of up to 25 minutes.

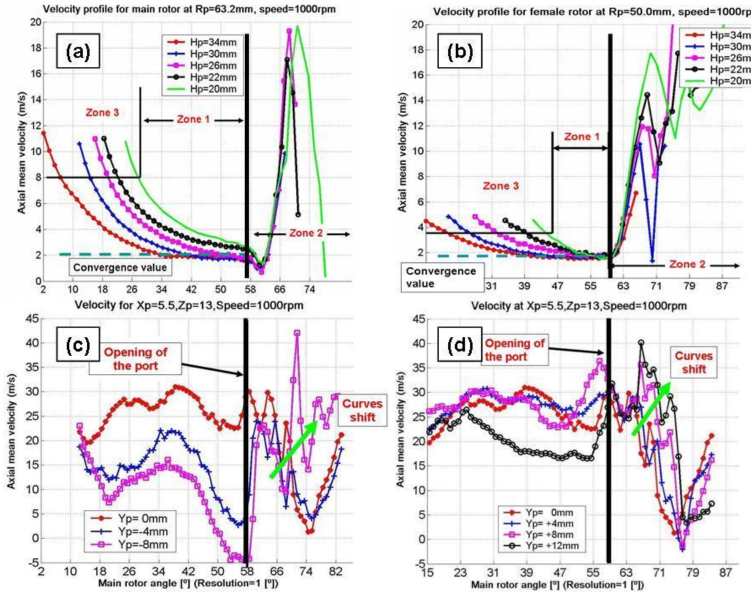
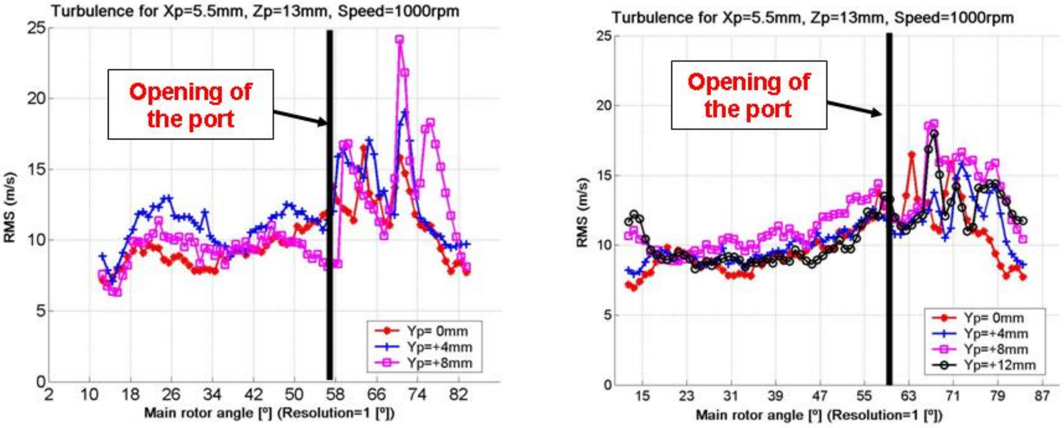


Figure 2 Comparison between discharge axial mean velocity component at the inlet (rotor side) and outlet (cavity side) of the discharge port: (a) Inlet main rotor curves (b) Inlet female rotor curves; (c) Outlet curves of the port region close to the main rotor (d) Outlet curves of the port region close to the female rotor.

The post processing technique and the choice of the most suitable resolved angle-window has already been defined in [1], as well as the overlapping procedure involved in the generation of the velocity profiles. The results presented in this paper show the behaviour of the axial component of velocity and the corresponding turbulence (RMS) as a function of the shaft rotational position.

Since the air is moving in a screw compressor mainly in axial direction from one chamber to the next, only the axial velocity component was considered. The results are presented in Figures 2(a) and (b) refer to the main and female rotors, respectively while (c) and (d) refer to the discharge port flow. These locations were chosen because it was found that the air flow is more sensitive to the discharge process as was discussed in [1]. These three regions with respect to Figure 2(a) and (b) are: Zone 1 where the velocity decreases towards a defined value around the middle of the working chamber for all the curves. This common value was similar for all axial locations and was mainly influenced by the rotor motion. Zone 2 is in which all velocities exhibit a sudden high and consistent acceleration that reached its peak and then decelerate. This trend was similar at all measured locations. A similar pattern was observed for turbulence with relatively very high compared with that of zone 1. Here, the flow is influenced mainly by the pressure difference between the rotor and the discharge chamber and also by the opening area at the discharge port, rather than by other parameters such as the working chamber motion. Zone 3 is near the trailing edge. This is influenced mainly by the leakages through the gaps between the rotors and the casing.

No doubts that flow in Zone 2 influences the flow development in the discharge port cavity. Diagrams (c) and (d) in Figure 2 illustrate the velocity behaviour at the outlet of the discharge chamber in V section for the same angular position of zone 2 on the main and female sides, respectively. The black vertical lines were drawn on the graphs to identify the exact angular position of the discharge port opening.



(a) (b)

Figure 3 represents axial RMS velocity variation at the outlet of the discharge port: (a) at the port region close to the main rotor and (b) at the port region close to the female rotor.

The velocity values obtained at the discharge presented in Figure 5, are considerably higher than the velocity in the rotor vicinity. This difference can be explained by noticing a rather large flow contraction which causes fluid acceleration. In addition, once the compressed air at the roeor end is exposed to the lower discharge chamber pressure, the flow momentum will increase and become very changeable. This trend is evident for all velocity curves. The flow structure was discovered to be very complex and at least three distinct peaks are recognisable. Also, there is a tendency for the peaks to shift to higher velocities as soon as the control volumes move away from the centre of V-section towards its edges on both sides. On the left hand side of diagrams, before the opening line, the flow motion is smoother with higher variations at the main rotor side.

Figures 3(a) and (b) represent the axial RMS velocity variation at the outlet of the discharge port and correspond to those at Figure 2 (c) and (d). In general the RMS velocity profiles follow those of the mean velocity but with large fluctuations immediately after the port opening. They become smoother later on when the port is more open to the incoming flow from the rotor chambers.

To explain the observed changes in the mean flow, the absolute pressure and the mean velocities are presented together in Figure 4 at the axial control volume location of Hp=20mm.

Having in mind that pressure on the discharge chamber is equal to 1 bar; the shorter dashed line shows the pressure difference Δp between rotors and discharge chamber. The pressure data, in the diagrams (c) and (d) of figure 4, can be divided into three zones: Zones a and c where the pressure difference between the chambers is quite small and air flow is simply due to the rotor motion. After the discharge port is open, rotors, like a piston, push the air out of the chamber and force it to accelerate to pass through the small V-section causin strong axial mean velocity gradients, peaks and turbulence variation.

The flow structure displayed in zone (b) can be interpreted by focusing to two considerations: the first is that once the discharge process starts, at the extreme left and right side of the port, flow passages are narrow and the pressure difference is high. In such a situation, the air rushes towards the low pressure chamber forming jets at very high speed. Once one of these jets reaches the control volume, it creates a peak like profile as the observed In Figure 3. Secondly, as the rotors rotate further, the ports will be open more causing the air jet stream to move towards the centre of the V-section and reduce its velocity. This explains why the velocity peaks in Figures 3(c) and (d) move up and to the right.

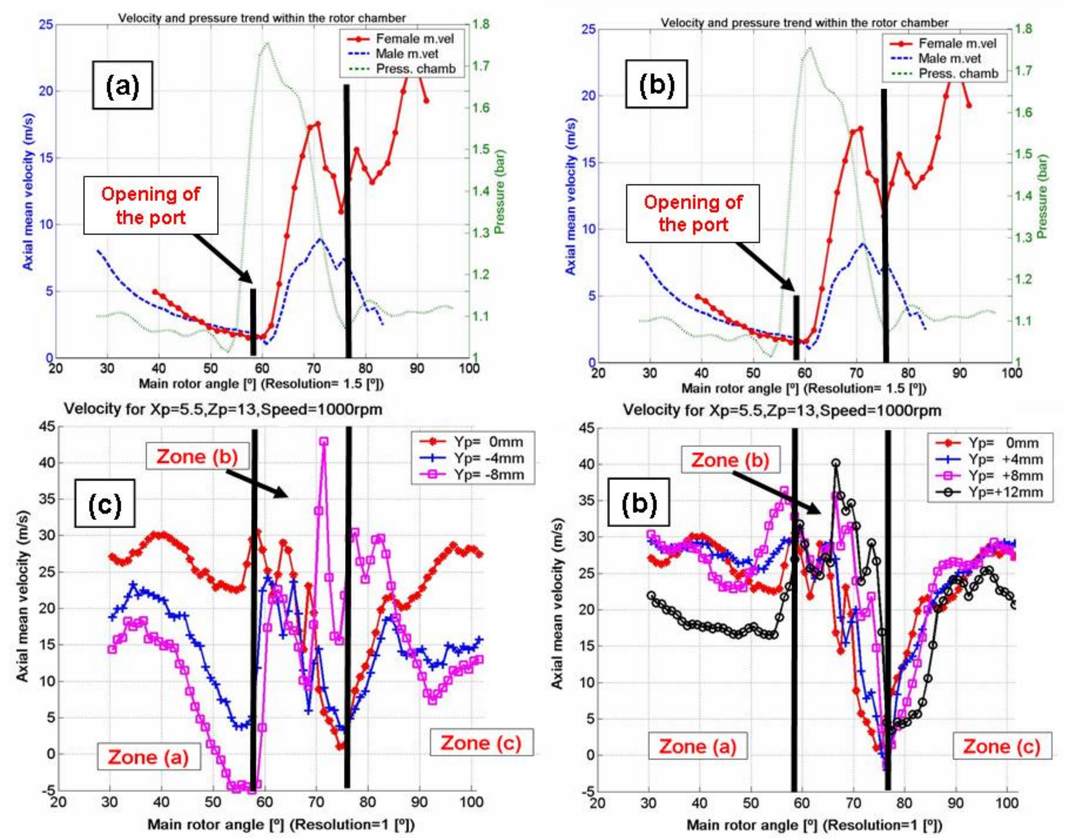


Figure 4 Effects of pressure difference upon velocity fields: (a) Main rotor curves (b); Female rotor curves; (c) Outlet curves of the port region close to the main rotor, (d) Outlet curves of the port region close to the female rotor.

The most important findings of this investigation can be summarised as: A temporal resolution of 0.1° of the rotor angle can be achieved, but the results of the axial mean and RMS velocities showed that the flow structure remained unchanged for an angular resolution of up to 1.5° in the rotor chambers and 1.0° in the discharge chamber. A high data rate pressure transducer was employed within the working chamber to provide an additional set of data to characterise not only the axial velocity field but also the instantaneous pressure. The axial velocity distribution within the discharge chamber can be described by dividing it into three different zones: In zone (a) and (c), the velocity is mainly influenced by the rotor motion while in zone (b), the velocity is influenced mainly by the pressure difference between the chambers at the opening of the discharge port. As the high pressure port starts to be exposed, the high pressure difference causes jet like flow into the discharge chamber. These jets create peaks in the mean velocities and high turbulence flow.

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