土木学会第50回年次学術講演会（平成７年９月）

# II -278 Velocity Measurements in an Impeller-Generated Swirling Jet

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## INTRODUCTION AND PROCEDURE

In many environmental and technical/industrial applications there is a need to artificially induce flows in fluids and fluid mixtures. The purpose of flow generation could be to transport substances, keep solids in suspension, homogenize fluids with different properties, dissolve matter in liquids, enhance biological and chemical reactions, or modify the thermal conditions in a fluid. A submersible mixer is a flexible and efficient device for inducing such artificial flows. The mixer is a compact unit that consists of an impeller (a propeller operating at static conditions) and a motor. The rotating impeller generates a swirling jet with an initial size, velocity, and direction that depends on the characteristics and orientation of the impeller. The swirling jet penetrates through the fluid and grows in size as it entrains ambient fluid; simultaneously, a large-scale motion is induced in the fluid that largely depends upon the flow geometry. Most mixer applications involve complex fluid dynamics regarding both the impeller flow and the large-scale motion that must be understood in detail to maximize the efficiency of the mixing operation. However, only a limited number of experimental investigations exist of the velocity field downstream an impeller or propeller; these studies derive mainly from the fields of aerodynamics, naval architecture, and turbomachinery (Lepicovsky 1988, Hyun and Patel 1991).

In this study, the velocity field downstream an impeller operating in water was measured using a two-component LDV (Petersson et al. 1995). The focus of the investigation was on the spatial development of the mean velocity in the axial, radial, and circumferential direction, although simultaneous measurements were performed of the velocity unsteadiness from which turbulence characteristics were inferred. The measurements extended up to 12 impeller diameters from the impeller blades displaying the properties of the swirling jet both in the zone of flow establishment (ZFE) and the zone of established flow (ZEF). Integral properties of the flow such as volume and momentum flux were computed from the measured velocity profiles. The transverse spreading of the impeller jet and its development towards self-similarity were examined and compared with non-swirling jets and swirling jets generated by other means.

## LABORATORY MEASUREMENTS

A 1:10 model of the impeller from a Flygt 4501 mixer was used in the experiments. The three-blade model impeller had an overall diameter of $D$=0.078 m and a hub diameter of 0.015 m, and it was operated at a constant speed $N$ throughout a specific experiment. The impeller was initially placed in a plexiglass tank with an inside bottom area of 0.98 x 0.98 $m^2$ and a water depth of 0.65 m. However, this setup only allowed velocity measurements to be performed relatively undisturbed by the circulation up to a distance of 5$D$ from the impeller and for lower values on $N$. Thus, a different experimental setup was employed in most of the measurements that involved a larger fluid body, which was obtained by closing of a section in a large glass-walled flume. The enclosed section was 2.5 m long with a rectangular cross section of 0.9 x 0.9 $m^2$, permitting relatively undisturbed measurements up to a distance of 12$D$ downstream of the impeller. The water depth in the flume was 0.81 m during all experiments. A two-component TSI LDV system was used for the velocity measurements and an automatic traversing system was developed to allow efficient and accurate measurements at arbitrary cross sections downstream of the impeller. The velocity components $U$ (axial), $V$ (radial), and $W$ (tangential) were measured at selected downstream locations for $N$=600, 1200, and 1800 rpm. Measurements were performed at the following locations for respective $N$: 0.5$D$, 1$D$, 2$D$, 3$D$, 4$D$, 5$D$ (600 rpm); 0.064$D$, 0.128$D$, 0.256$D$, 0.5$D$, 1$D$, 1.5$D$, 2$D$, 3$D$, 4$D$, 5$D$, 6$D$, 10$D$, 12$D$ (1200 rpm); and 0.128$D$, 2$D$, 4$D$, 6$D$, 8$D$, 10$D$, 12$D$ (1800 rpm).

## SELECTED RESULTS

**1.** Mean axial velocity ($\bar{U}$) profiles measured at different streamwise locations in the ZFE are shown in Fig. 1 for $N$=1200 rpm (only half of the jet is shown; $U_p$ is the peripheral blade velocity). Close to the impeller the profile has a marked trough in the jet center characteristic for strong swirl flows. The trough is caused by the centrifugal forces in the rotating jet and the blocking effect of the impeller hub. Immediately downstream the impeller, the maximum of the mean axial velocity $U_{max}$ occurs around $r/R_o$=0.5 ($r$ is the radial distance and $R_o$ the impeller radius), which approximately corresponds to the position where the blades produce maximum thrust. Two distinct peaks are noticeable in the mean tangential velocity ($\bar{W}$) profile close to the impeller (Fig. 2). The first peak occurs around 0.15$r/R_o$, which corresponds to the impeller hub radius, whereas the second peak is located at about 0.65$r/R_o$; thus, the inner peak is produced by the rotating hub and the outer peak is created by the blades.

**2.** In order to investigate the approach towards self-similarity in the jet, $\bar{U}/\bar{U}_{max}$ was plotted against $r/(x+a)$, where $a$ is the distance from a virtual origin to the impeller blades. The measurements indicated that $\bar{U}$ was approximately self-similar from a location where $\bar{U}_{max}$ occurred on the jet centerline. A Gaussian profile fitted the data quite well from about 3-4$D$ downstream of the impeller, as shown in Fig. 3.

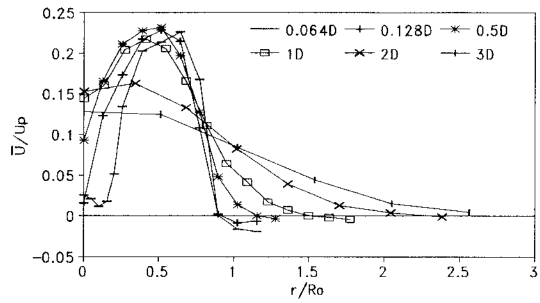



Fig. 1 Mean axial velocity profiles

**3.** A jet width was defined to characterize the spread of the jet based on the radial distance where $\bar{U}=\bar{U}_{max}/2$. The impeller jet was observed to spread linearly at a half angle of 7.1 deg, and the angle was nearly the same for the three impeller speeds investigated. The virtual origin $a$ was found for the impeller jet by extrapolating the line describing the radial spread backwards, which gave $a$=2$D$.

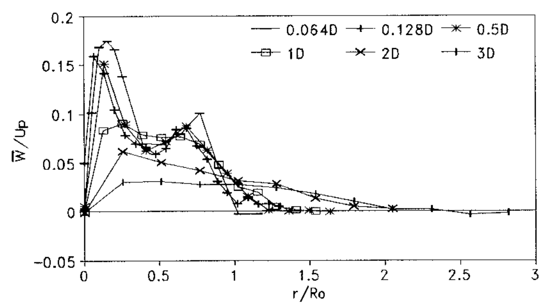
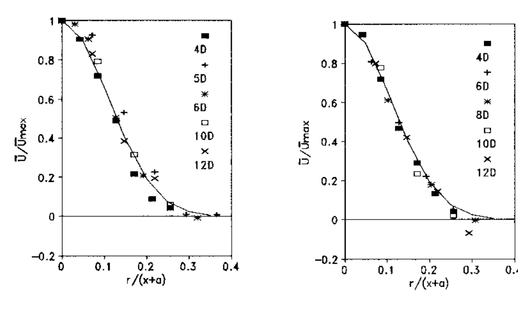



Fig. 2 Mean tangential velocity profiles

**4.** The volume flux was determined at downstream cross-sections by integrating the measured $\bar{U}$-profiles across the jet, and a linear growth with distance from the impeller was observed. The momentum fluxes (linear and angular) were also determined through integration. To obtain conservation of the axial flux of linear momentum the velocity unsteadiness had to be taken into account, as well as the effect of the return flow outside the jet in the experimental container.




N=1200 rpm N=1800 rpm

Fig. 3 Self-similar mean axial profiles

## REFERENCES

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