PIV Messungen in einer Taylor-Couette Strömung mit weitem Spalt

PIV Measurements in a Wide Gap Taylor-Couette Flow

Andreas Froitzheim[1], Sebastian Merbold[1], Christoph Egbers[1]
[1] Lehrstuhl Aerodynamik und Strömungslehre, Brandenburgisch Technische Universität Cottbus-Senftenberg, Siemens-Halske-Ring 14, 03046-Cottbus, Germany

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Summery

The angular momentum transport inside Taylor-Couette flow has been intensively investigated in the last years. Special attention was paid to the found maximum transport, which coincides with a maximum torque needed to keep the rotating cylinders at constant speed. To get a better understanding of this phenomenon in this paper the velocity field is measured using PIV in a wide gap Taylor-Couette flow with a radius ratio of $\eta = 0.5$.

Introduction

The flow in the gap enclosed by two independently rotating cylinders und a bottom and top plate is called Taylor-Couette flow (TC). Due to the rich dynamic behavior of this system many different flow states can be realized by adjusting the control parameters radius ratio $\eta = R_1 / R_2$, aspect ratio $\Gamma = L/(R_2 - R_1)$ and the ratio of the angular velocities $\mu = \Omega_2 / \Omega_1$ with the indices 1 and 2 for the inner and outer cylinder respectively. Further instead of two Reynolds Numbers $\mathrm{Re}_{1,2} = (R_{1,2}\Omega_{1,2}d)/\nu$ for each cylinder the Shear Reynolds Number $\mathrm{Re}_S = 2R_1R_2d|\Omega_2 - \Omega_1|/(\nu(R_1 + R_2))$ introduced by Dubrulle et al. (2005) with the kinematic viscosity ν and the gap width $d = R_2 - R_1$ is used.

According to Eckhardt et al. (2007) in TC flow the flux of angular velocity $J^{\omega} = r^3\left(\{u_r\Omega\}_{A,t} - \nu\partial_r\{\Omega\}_{A,t}\right)$ is conserved and directly related to the torque T acting either on the inner or outer cylinder. The correlation is given by $J^{\omega} = \nu^2 G$ with the dimensionless torque $G = T/(2\pi L\rho\nu^2)$. This torque has been investigated experimentally by Merbold et al. (2013) for co- and counter rotation and $\eta = 0.5$ over a wide range of Shear Reynolds Numbers finding a torque maximum at $\mu_{\max} = -0.2$. Ostilla-Monico et al. (2014) proceeded these investigations by changing the radius ratio leading to an also shifted value of $\mu_{\max}$. To get a better understanding of the torque maximum Merbold et al. (2014) performed flow visualizations in a TC flow with $\eta = 0.5$ in the maximum regime. They found out that at $\mu_{\max}$ the neutral surface of the azimuthal velocity is still close to the outer cylinder wall which suppresses the stabilizing effect of the outer cylinder rotation. A deeper look inside the flow was enabled by numerical simulations of Ostilla-Monico et al. (2014) with $\eta = 0.714$ analyzing the Ω-profile over the gap. At the maximum torque the profile is flat in the center and steep in the cylinder wall regions so that plumes can detach strongly into the bulk flow and amplify the large scale circulation. The purpose of this work is to further investigate experimentally the torque maximum in Taylor flow with Particle Image Velocimetry (PIV).

Experimental Setup

The Taylor-Couette facility used in here has the geometrical dimensions $R_1 = 35mm$, $R_2 = 70mm$ and $L = 700mm$ leading to a radius ratio of $\eta = 0.5$ and an aspect ratio of $\Gamma = 20$. Shear Reynolds Numbers up to $2 \cdot 10^5$ can be reached. The gap is filled with distilled water with a dynamic viscosity of $\nu = 1 \cdot 10^{-6} m^2 s^{-1}$ and hollow glass microspheres are added as tracer particles with a mean diameter of $10 - 20\mu m$. The top plate and the outer cylinder are made of acrylic glass and thus transparent. To illuminate the radial azimuthal plane a laser light sheet of $2mm$ thickness is generated at mid height with a Neodym-YAG-Laser at a wavelength of $532nm$. Above the top plate the scattered light from the particles inside the flow is captured with a PIVCam 10-30 CCD camera with a resolution of $1016 \times 1016 px$. The set-up is pictured in Fig. 1. The light sheet enters the flow from the right hand side and the camera is mounted on the top of the experiment.

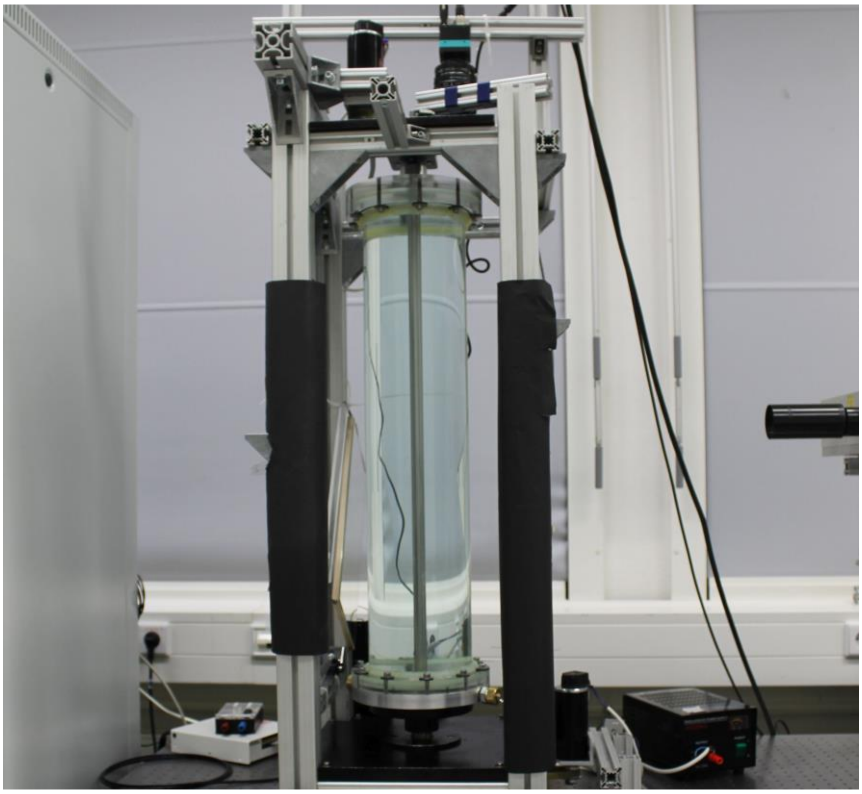

Fig. 1: Photograph of the Taylor-Couette facility with the PIV set-up

For the experiments presented in the next chapter PIV images were generated in the double frame mode on mid height, which means in an outflow region. During each run 50 double images were taken with a frame rate of $15Hz$. From these particle images the azimuthal and radial velocity components can be analyzed. On this basis velocity profiles and the radial position of the neutral surface (turning point of the azimuthal velocity) can be determined to generate a better understanding of the torque maximum.

Results

From the double frame picture series the flow field inside the Taylor-Couette gap can be calculated by an adaptive cross correlation method. An example of an averaged flow field over the 50 double frame images at a Shear Reynolds Number of $Re_S = 40000$ and a rotation rate of $\mu = -0.2$ (ratio of maximum transport) is shown in Fig. 2. The positions of the inner and outer cylinder are represented by the red lines. In between the direction and the magnitude of the flow field velocity is expressed by the blue arrows. In the region of the cylinders the flow is parallel to the walls. Due to counter rotation of the cylinders the flow changes its azimuthal direction giving a location of the 'neutral surface'. It is obvious that the outer cylinder can influence the flow only in a near wall area, in which his stabilizing effect comes into account.

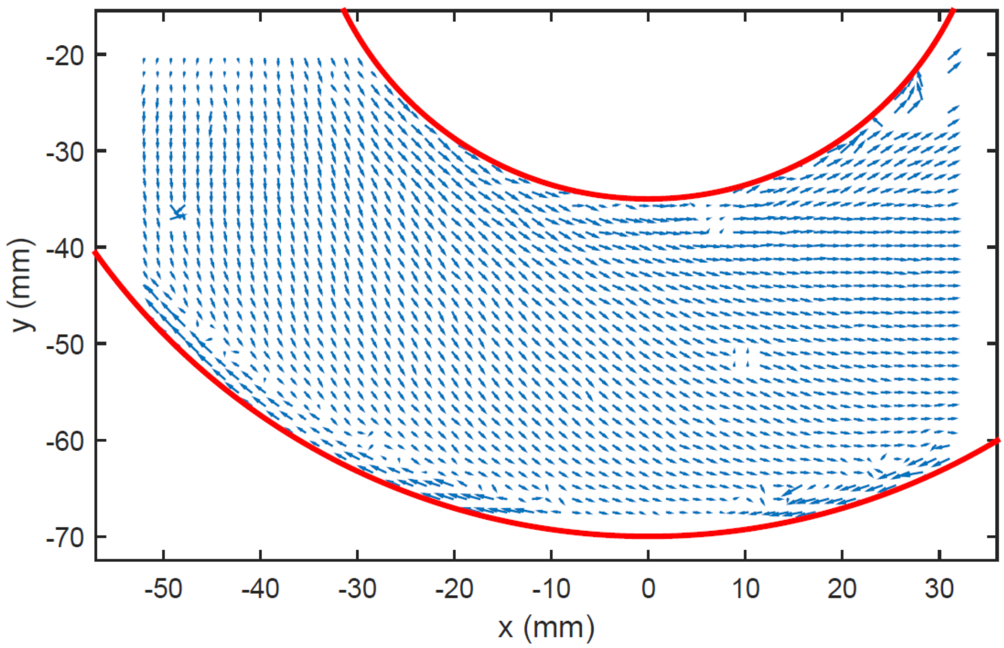

Fig. 2: Averaged flow field for $Re_S = 40000$ and $\mu = -0.2$

Based on these flow fields radial velocity profiles can be analyzed by averaging the interesting component in the azimuthal direction. In this paper we concentrated on the angular velocity profile because this is also the main variable in the conserved transport quantity J^{ω}. The angular velocity Ω and the Radius r are non-dimensionalized by $\overline{\Omega} = (\Omega - \Omega_2)/(\Omega_1 - \Omega_2)$ and $\bar{r} = (r - r_1)/(r_2 - r_1)$.

In Fig. 3 angular velocity profiles are shown for different Shear Reynolds Numbers and the outer cylinder at rest. All Ω-profiles are really close together except the one for the lowest Re_S with a value of 6840. In this case the profile lies below the other ones and the transition between the bulk and the boundary layer flow is much smoother. It indicates a less developed boundary layer for lower cylinder speeds. The slope of the profiles in the bulk is similar for all Re_S, while about the boundary layers no more information are available because in the vicinity of the cylinders the flow could not be resolved. However the asymmetry between the inner and outer cylinder boundary layer thickness, which is typical for wide gap TC flow, is clearly visible.

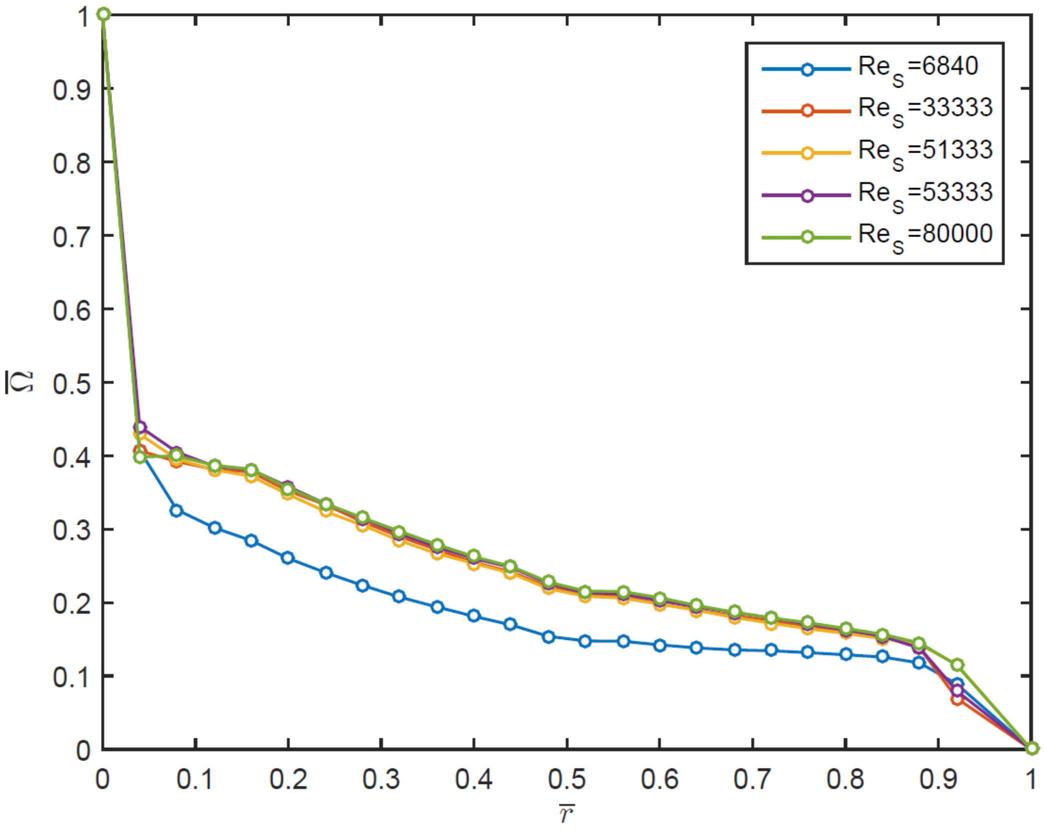

Fig. 3: Angular velocity profiles for different Re_S and outer cylinder at rest ($\mu = 0$).

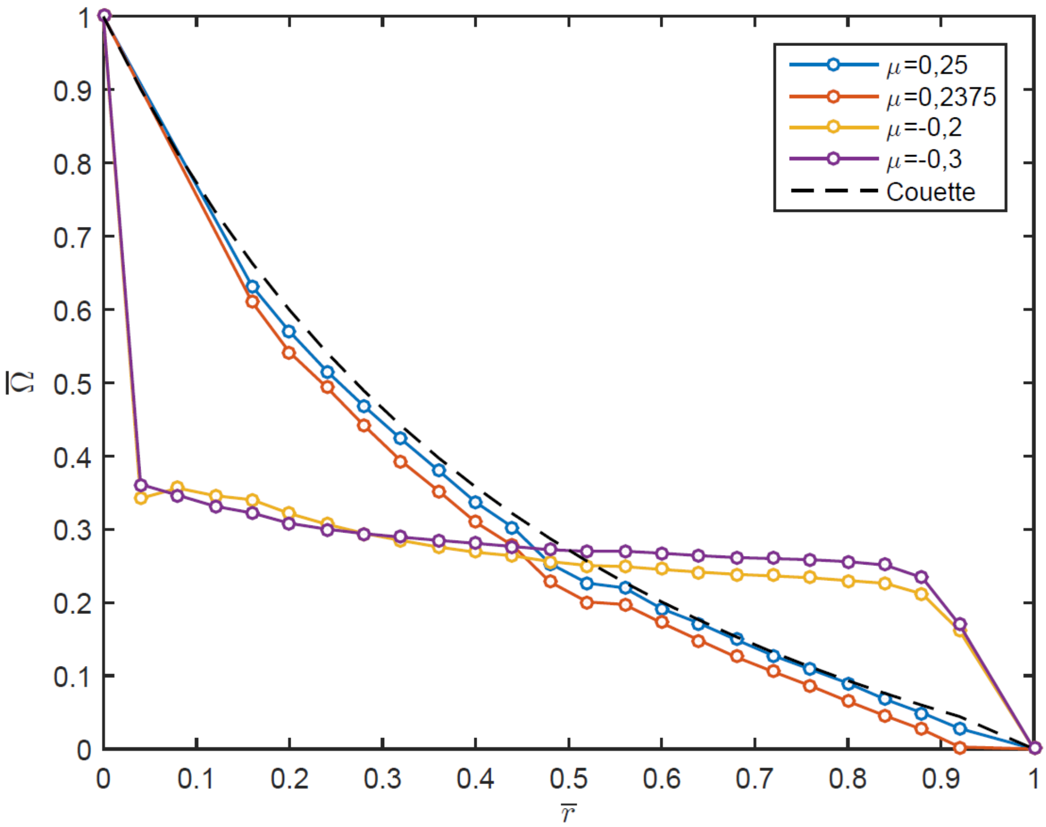

Fig. 4: Angular velocity profiles depending on μ for a constant $\mathrm{Re}_S = 40000$.

The change of the flow for $\mathrm{Re}_S = 40000$ and different rotation rates can be seen in Fig. 4. The Ω-profiles for co- and counter rotation have a completely different shape. In the co-rotating regime, the profiles are in good agreement with the laminar Couette-solution. For $\mu = 0.25$ the profile is closer to the fully laminar flow than the one for $\mu = 0.242$. According to the Rayleigh stability criterion the TC flow with a viscous fluid is linear stable if $\Omega_1 > 0$ and $\mu > \eta^2$. Therefore the flow with $\mu = 0.25$ is in the parameter space located on the stability line while the flow with $\mu = 0.242$ is linear unstable. In contrast for low negative rotation rates in the region of the maximum transport the flow can be divided into bulk and boundary layer. In the bulk the slope of the Ω-profile is flat while in the boundary layer the slope is steep. This means that for low counter rotation the bulk flow is turbulent leading to an enhanced impulse exchange and so a homogenized velocity profile. Furthermore as explained in Ostilla-Monico et al. (2014) such profiles enable that plumes can detach from the cylinder walls into the bulk flow and strengthen the large scale circulation which could be a reason for the torque maximum.

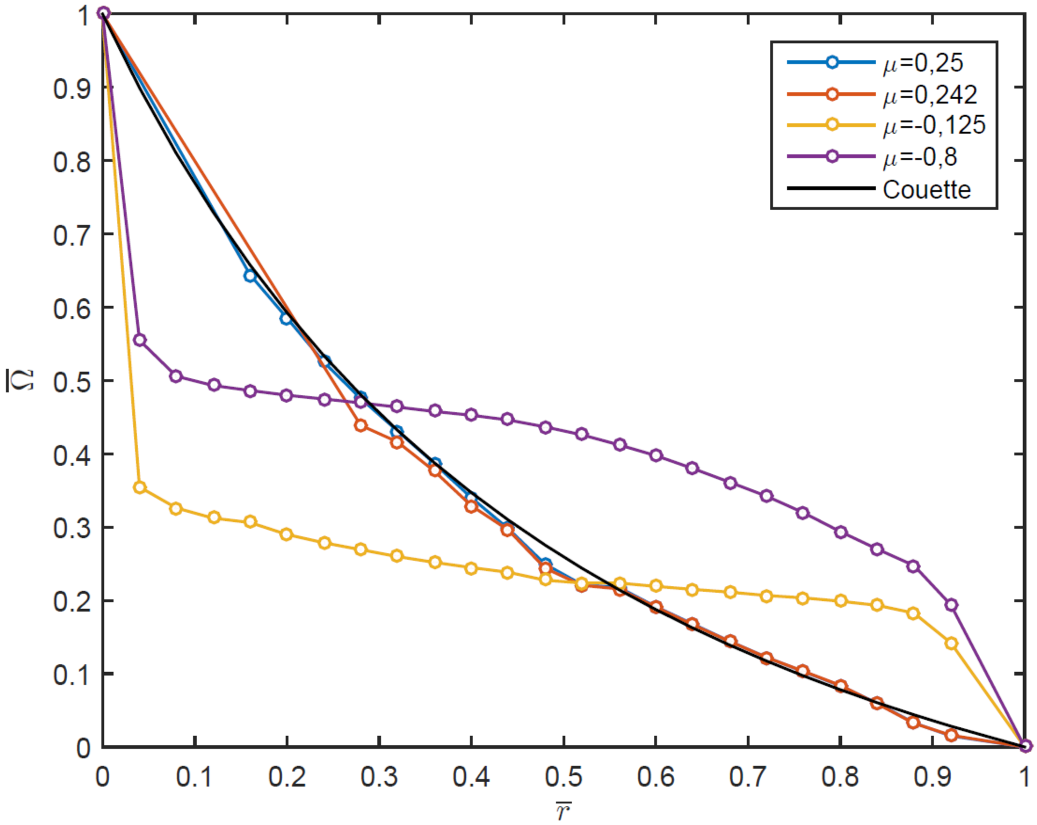

Fig. 5: Angular velocity profiles depending on μ for a constant $\mathrm{Re}_S = 60000$

The Ω-profiles for $\mathrm{Re}_S = 60000$ are analog to these of $\mathrm{Re}_S = 40000$. However in Fig. 5 it is shown that in the higher counter rotating regime ($\mu = -0.8$), the slope in the bulk flow increases and the slope in the boundary layer decreases again compared to the profile in the vicinity of the maximum transport. Therefore the plume ejection from the cylinders and the enhancement of the large scale circulation is not pronounced like in the maximum regime.

The preliminary results presented before show a good agreement with experimental and numerical investigations from the literature.

Acknowledgements

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