PIV-Messungen in horizontaler Rohrströmung bei hohen Re-Zahlen

PIV Measurements in a Horizontal Pipe Flow at High Re-Numbers

Emir Öngüner[1], Mirko Dittmar[2], Peter Meyer[2], Christoph Egbers[1]
[1] Department of Aerodynamics and Fluid Mechanics, Brandenburg University of Technology, Siemens-Halske-Ring 14, 03046, Cottbus, Germany
[2] LaVision GmbH, Anna-Vandenhoek-Ring 19, 37081, Göttingen, Germany

Schlagworte: PIV, Rohrströmung, Turbulenz, hohe Reynolds-Zahlen
Keywords: PIV, Pipe flow, turbulence, high Reynolds-numbers

Summary

Recent studies about coherent structures incl. large-scale and very large-scale motions with intrusive measurement techniques show that the streamwise extension of these structures is highly dependent on the Re-number. They are usually represented in wave length (λ) or wave number (*k*). It can be observed that the sizes of these coherent structures can reach even couple of meters along the pipe axis. This phenomenon is going to be investigated with Particle Image Velocimetry (PIV) as a non-intrusive measurement technique to validate and compare the results of Hot-Wire Anemometry (HWA).

At the Department of Aerodynamics and Fluid Mechanics, Brandenburg University of Technology Cottbus-Senftenberg, the unique pipe facility "CoLa-Pipe" (Cottbus Large Pipe) is designed and built to investigate fully developed pipe flow at high Reynolds numbers ($Re_m \leq 1.5 \times 10^6$). The type of this facility is closed-return with two available test sections providing a length-to-diameter ratio of L/D = 148 and L/D = 79 (Figure 1). This paper will give a general overview about the Particle Image Velocimetry (PIV) measurements in CoLa-Pipe.

Introduction

Recent studies about coherent structures incl. large-scale and very large-scale motions with intrusive measurement techniques show that the streamwise extension of these structures is highly dependent on the Re-number. They are usually represented in wave length (λ) or wave number (k). It can be observed that the sizes of these coherent structures can reach even couple of meters along the pipe axis. This phenomenon is going to be investigated with Particle Image Velocimetry (PIV) as a non-intrusive measurement technique to validate and compare the results of Hot-Wire Anemometry (HWA).

The so called CoLa-Pipe (Cottbus Large Pipe) (König et al. (2014)) is a high Reynolds number test facility ($60x10^3 < Re_b < 10^6$) for various purposes ranging from basic to applied researches, which is used to investigate these mentioned structures. The large-scale and very-large-scale structures are quite important with respect to the turbulent kinetic energy and Reynolds stresses.

According to Kim & Adrian (1999), Guala et al. (2006), Vallikivi (2014) and Öngüner et al (2014) some open questions remain unsettled for identifying accurate sizes of the large-scale motions (LSM) and very large-scale motions (VLSM). The theory of Kim & Adrian (1999) claims sizes of LSM (λ_{LSM}=2R-3R) and VLSM (λ_{VLSM}=8R-16R), but that does not estimate precisely magnitudes of the larger streamwise structures in turbulent pipe flow. The reason is that the experimental studies of Kim & Adrian (1999) had been carried out for lower Re-numbers. The CoLa-Pipe is providing an opportunity to approach higher Re-numbers with better resolution.

Obtaining turbulent structures at high Reynolds numbers optically with PIV requires long laser plane setups in axial direction. First of all a 2D laser plane will be applied in streamwise direction and axial extensions of turbulent structures can be identified. Hellström et al. (2011) is using Taylor's hypothesis and proper orthogonal decomposition (POD) to obtain instantaneous fluctuations and turbulent structures. To extend the investigation to a 3D domain additionally a cross sectional laser plane will be added and with this combination a 3D space can be constructed by using same algorithms as in Hellström et al. (2011).

Experimental Facility

The main objective of the CoLa-Pipe as a high Reynolds number test facility is to conduct fundamental research, e.g. a contribution to understanding the physical processes and dynamics of turbulence, as well as for supporting industrial projects. In this chapter all the relevant components described, i.e. test section, settling chamber, inlet contraction, tripping devices, power assembly and cooling unit.

Two pipe test sections are available. The lower one is connected to the blower suction side and the other one is mounted at the delivery side of the blower called return line. Both pipe test sections are critical components in the present facility in terms of circularity, degree of surface roughness, straightness, alignment and optical accessibility for special measuring devices such as Laser-Doppler Anemometry (LDA) and Particle Image Velocimetry (PIV). The inner pipe diameter of the lower side test section is D_i = 190± 0.23mm which has a deviation of less than 0.12%. The total length of the suction side, L = 28m, provides a test section length-to-diameter ratio of $L/D_i \approx 148$. The return line has an inner diameter of D_i = 342 ± 0.32mm and a total length of L = 27m as well, providing a length-to-diameter ratio of $L/Di \approx 79$. Both test sections interior surfaces have a measured surface roughness of approximately 3µm being in terms of wall units 0.6 for the maximum Reynolds number of 1.5×10^6. The height of the centerline of the lower pipe test section is 1.55m from the ground, in order to support an easy access to the test section while the operator is standing on the floor of the laboratory and the height of the upper line is 4.55m from the ground, which definitely requires a working platform (Figure 2, Figure 3)

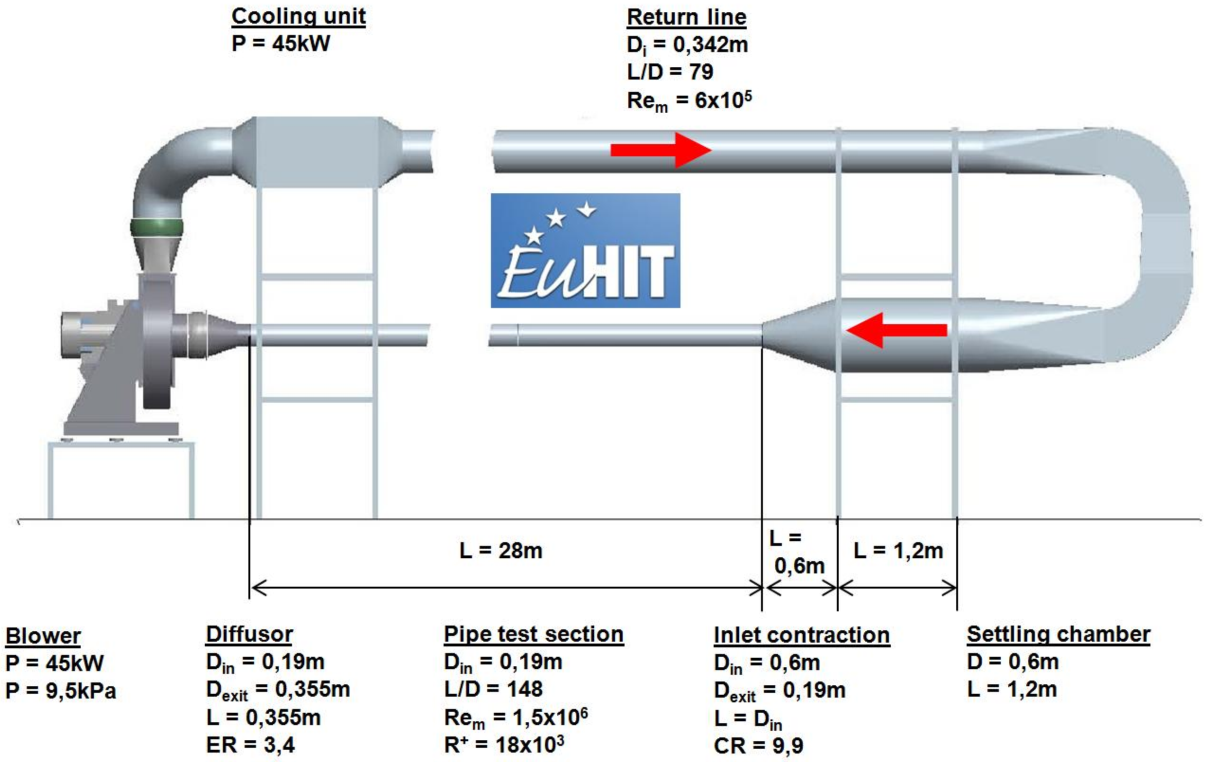
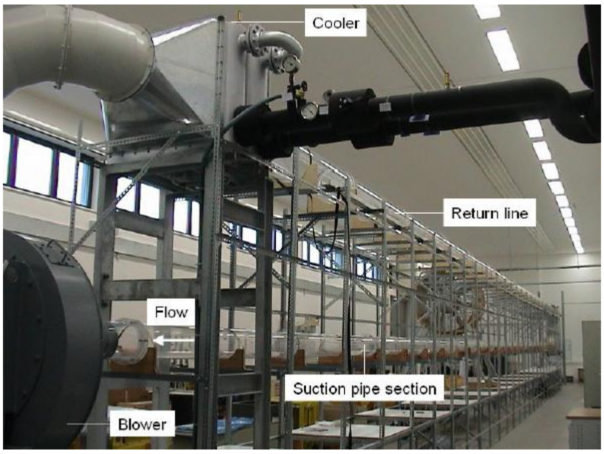


Figure 1: CoLa-Pipe facility at Brandenburg University of Technology (BTU)



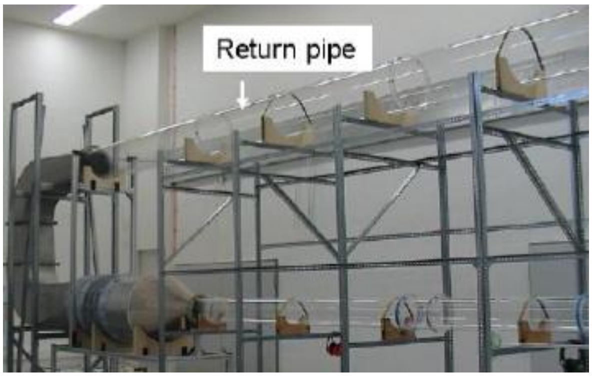


Figure 2: (left) Overview of CoLa-Pipe showing important components
Figure 3: (right) Corners, settling chamber, nozzle and both test sections of CoLa-Pipe

Latest results in literature show that investigations of LSM and very VLSM in pipes are still progressing and it might be concluded that there is still a lack of a complete and common definition for the scales of these structures, in particular, at very high Reynolds numbers. Therefore, a quantitative measure of the energy and the Reynolds stresses associated with such scales are to be clearly defined.

For the highest Reynolds number, there is a turbulent motion which was identified with a dimensionless streamwise length of 47R. Considering the pipe radius of the facility R=9,5cm, this structure has a streamwise extension of nearly 4.5m. It is also clearly observable that the growing character of these structures can be interpreted as “almost linear”. An interesting behavior at Reτ= 5629 was observed that the wavelengths at y/R= 0.1, y/R= 0.3 and y/R= 0.6 are decreasing instead of following the almost linearly growing slope. In principal, this can be interpreted as an exceptional behavior specifically at this Re-number range. To assure this phenomenon a couple of similar studies should additionally be carried out at close Reynolds numbers.

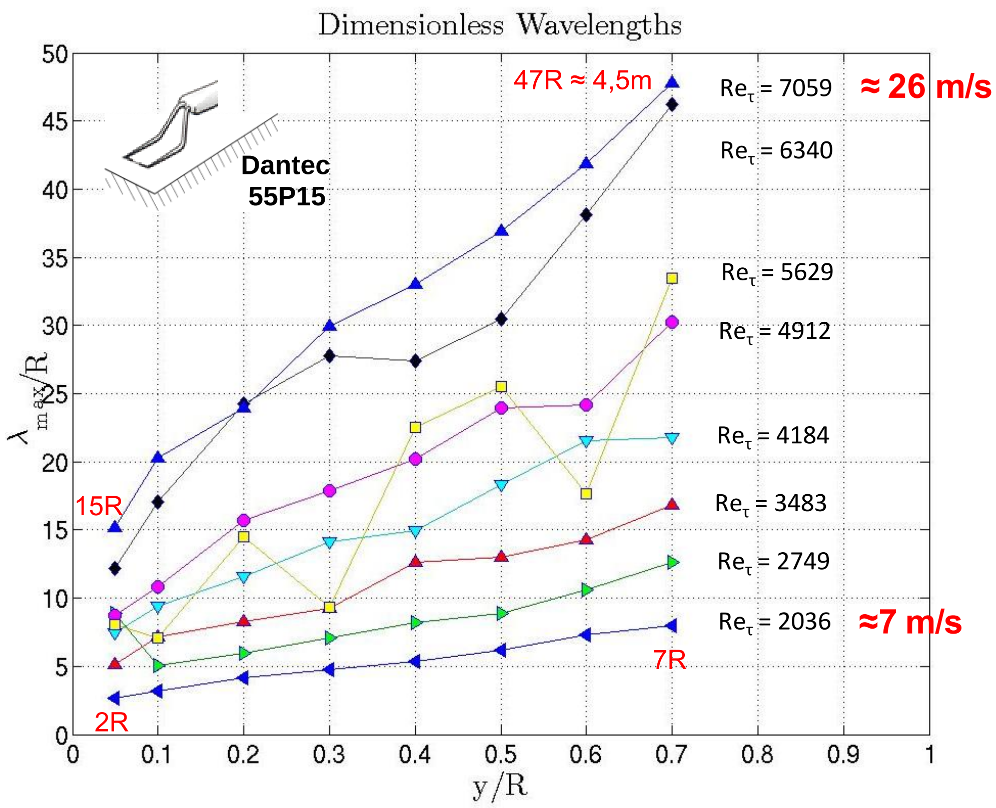


Figure 4: Dimensionless wave lengths of captured turbulent structures on different wall-normal positions and at different shear Reynolds numbers

Hot-wire probes generate time dependent velocity data which are converted to power spectra and wave lengths to detect the above discussed structures. However this intrusive measurement technique contains the limitation of considering only signal processing without any optical information. At this point application of a non-intrusive measurement technique is essential to obtain visual knowledge about turbulent pipe flow structures. In preparation of this proposal “Particle Image Velocimetry” (PIV) is applied for the first time on CoLa-Pipe to get more quantitative and spatial information on the velocity fields, in collaboration with LaVision GmbH (Göttingen, Germany).

Some preliminary measurements were performed in CoLa-Pipe at various Reynolds numbers with two different configurations; streamwise (axial) and cross-sectional. Considering the wave lengths of turbulent structures according to Figure 4, at least a section of 2 meters length needs to be observed by PIV. Figure 5 shows the streamwise PIV setup with 4 high resolution cameras focusing on laser sheet (thickness: 2mm) from above. In terms of limitation of aperture angle and long distance, use of 4 cameras for this experiment was necessary. Next configuration is a cross-sectional PIV setup as shown in Figure 9b. Both configurations have been carried out at x/R=180 to 200 which corresponds to fully developed turbulent flow.

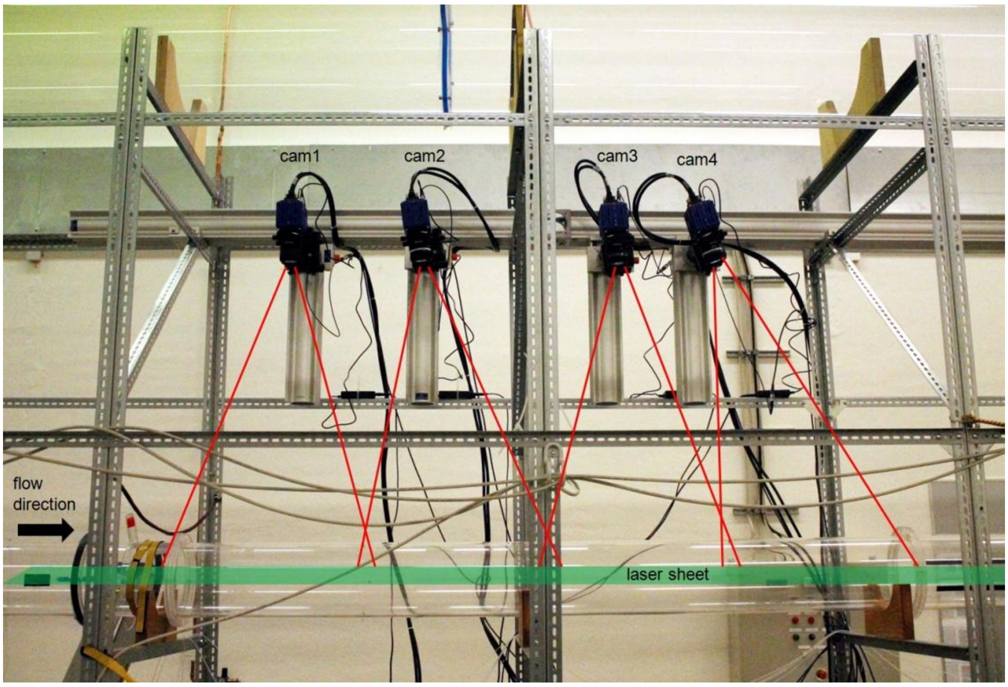


Figure 5: Streamwise PIV configuration at CoLa-Pipe

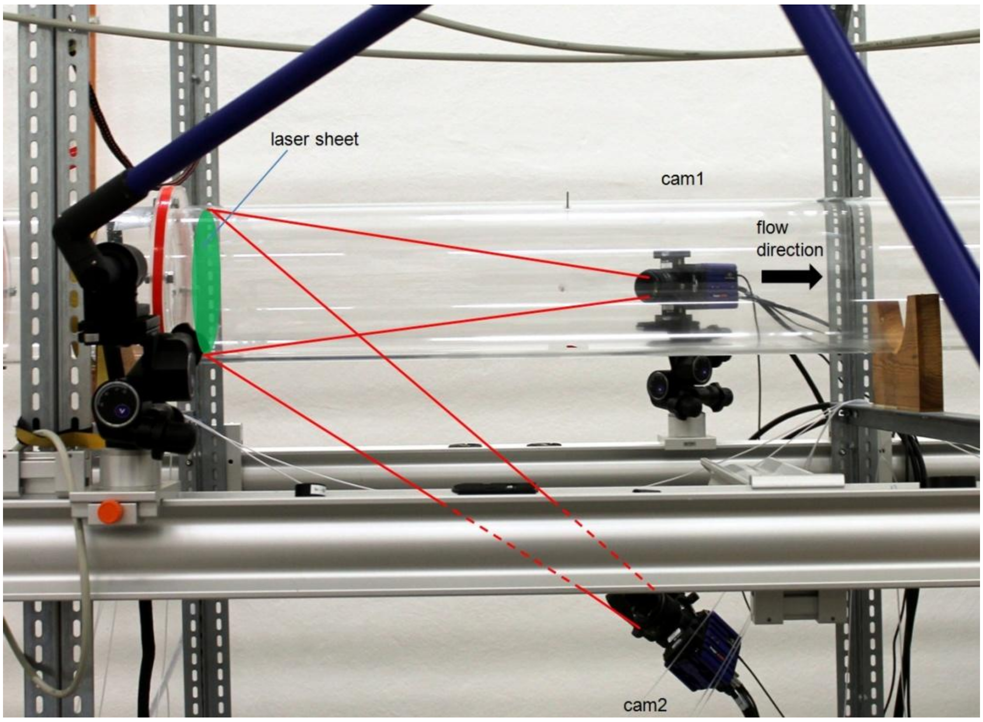


Figure 6: Cross-sectional PIV configuration at CoLa-Pipe

Preliminary results of these measurements at $Re_b \approx 140000$ are illustrated in Figure 7 for the streamwise configuration and in Figure 8 for the cross-sectional setup.

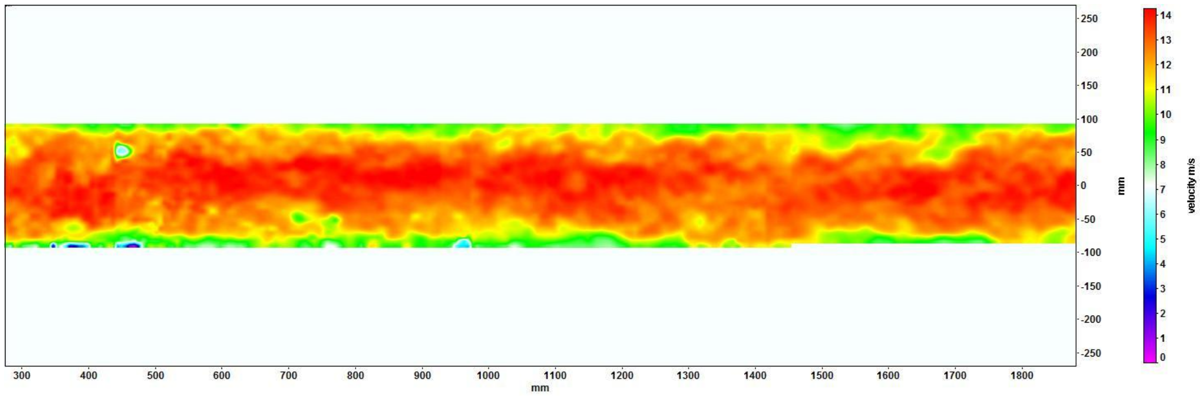


Figure 7: Preliminary PIV results at $Re_b \approx 140000$ for streamwise configuration in CoLa-Pipe: snapshot of mean streamwise velocity

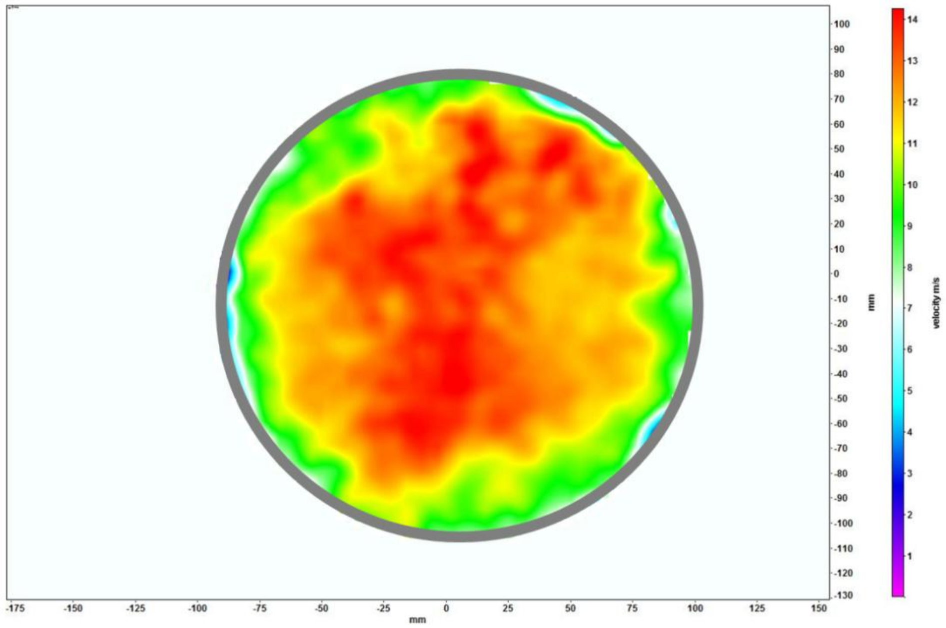


Figure 8: Preliminary PIV results at $Re_b \approx 140000$ for streamwise configuration in CoLa-Pipe: snapshot of mean streamwise velocity

First results show a good agreement with previous hot-wire measurements. Following steps will focus on detecting turbulent motions in PIV by determining their wave numbers & wave lengths.

Acknowledgments

The author is supported by the DFG-German Research Foundation as a part of the FOR1182 project. CoLa-Pipe facility is used as a part of the Eu-HIT (European High-Performance Infrastructures in Turbulence) program.

References

König, F., Zanoun, E.-S., Öngüner, E., Egbers, Ch., 2014: CoLaPipe - The New Cottbus Large Pipe Test Facility at BTU Cottbus, Review of Scientific Instruments, 85, Issue: 7, 075115

Kim, K.C., Adrian, R.J., 1999: Very large-scale motion in the outer layer, Phy. of Fluids, 11, No.2

Guala, M., Hommena, S.E., Adrian, R.J., 2006: Large-scale and very-large-scale motions in turbulent pipe flow, J. Fluid Mech, 554, 521–542

Vallikivi, M., 2014: Wall-bounded turbulence at high Reynolds numbers, PhD thesis, Princeton University

Öngüner, E., Zanoun, E.-S., Egbers, Ch., 2014: Structure Investigation in Pipe Flow at High Reynolds Numbers, (poster presentation) iTi 2014-Interdisciplinary Turbulence Initiative, 22-24 September 2014, Bertinoro, Italy

Hellström, L., Sinha, A., Smits, A., 2011: Visualizing the very-large-scale motions in turbulent pipe flow, Phy. of Fluids, 23, 011703