NEW POSSIBILITIES FOR VELOCITY MEASUREMENTS AND MODEL EXPERIMENTS IN LIQUID METAL PROCESSING

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Summary Potential difference probes and ultrasound have been employed to investigate liquid metal flows in cylindrical containers. The fluid motion was driven by either a rotating or a pulsating magnetic field. Experimental results containing flow mapping and scaling of mean velocities for very small driving forces will be presented. We report on our new MULTIMAG facility which allows for almost any combination of rotating, traveling, pulsating and d.c. magnetic fields in extended geometries for industrially relevant regimes.

BASIC CONSIDERATIONS

In several branches of materials processing like stirring or casting of metals or crystal growth processes from the melt, large effort is persistently spend on the optimisation of methods and facilities. To achieve an improvement of the final product quality, enhance the process stability, and decrease energy consumption a proper understanding of the underlying fluid flow phenomena is required. Most prominently a better knowledge about the details of the flow structure and the properties of the related heat and mass transport are needed.

During the recent years numerical simulations became an important tool to study these topics. But such calculations alone are often of limited value due to the problems regarding an appropriate modeling, particularly that of turbulence. As a basis for the validation of numerical codes experimental data of the velocity field are indispensable, facing the everlasting problem of the lack of appropriate and available measuring techniques. One of the main problems here is the opaqueness of the liquid metals, almost nothing is available commercially. The potential difference probe (PDP) is mostly applied on laboratory scale. Its functional principle, based on Ohm's law $\mathbf{j} = \sigma(-\nabla\phi + \mathbf{v} \times \mathbf{B})$, where $\phi, \mathbf{B}, \mathbf{v}$ and σ denote the electric potential, magnetic induction of the applied d.c. measuring field, velocity, and the electrical conductivity, reveals already the limitations of this method. Sufficing for measurements of, for example, channel flows of several ten's cm/s in a strong magnetic field the potential difference ϕ becomes formidable small in even medium scale closed flows where the applied magnetic field serves for measurement purposes, only, and must be kept small in order to not disturb the flow.

A new and promising approach is the application of Ultrasonic Doppler Velocimetry (UDV) [1–3]. This non-invasive technique, based on time of flight measurements of short ultrasonic bursts, delivers the complete profile of the velocity component along the direction of sound propagation. However, some serious restrictions always exist to apply the different sensors. Compared to PDP the UDV is slow which may result in less expressive information with respect to turbulence characteristics. Despite the extremely low voltages inherent to PDP a second drawback of UDV is its sensitivity. On the other hand, it delivers spatio-temporal information and is suited to map the whole time-dependent flow field if several sensors are employed, or, as done in the frame of the present work, to map the mean velocity distribution and mean turbulence characteristics if the sensor is traversed.

Industrial scale experiments with hot metallic melts are mostly unaffordable. Often water experiments are used for the validation of numerical simulations. A transformation of these results has to be considered difficult to impossible with regard to meet the relevant characteristic parameters such as Reynolds-, Prandtl-, or Hartmann-number. There exists a multitude of low melting metals which allows for almost any meaningful physical modeling of industrial processes.

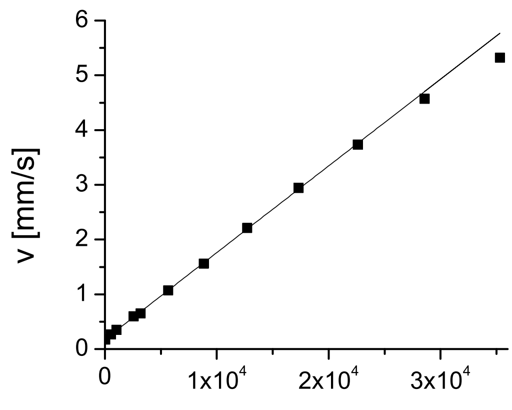

Figure 1. Linear scaling of velocity on the Taylor number below formation of a boundary layer regime

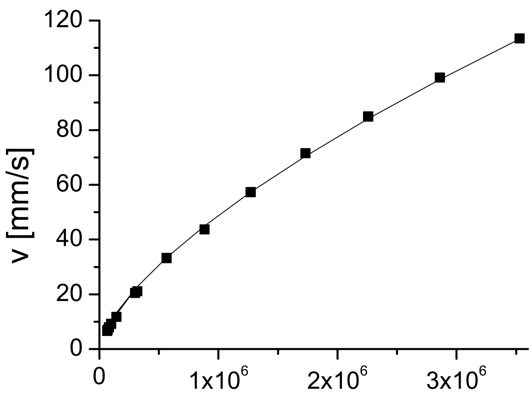

Figure 2. $Ta^{2/3}$ scaling law in the turbulent regime

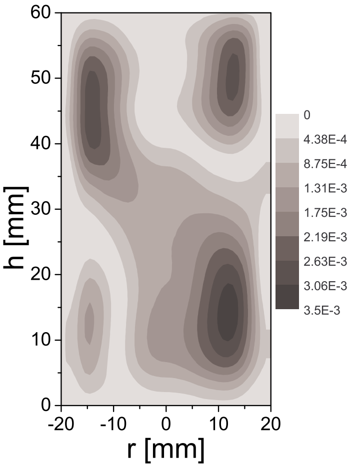

Figure 3. Streamfunction of a pulsating magnetic field driven flow

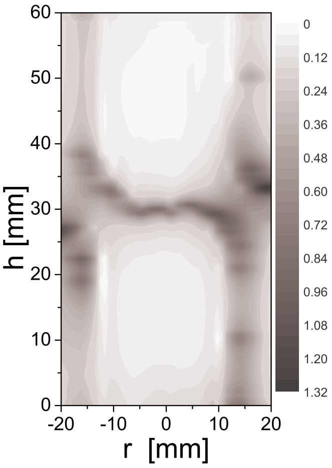

Figure 4. Turbulence degree belonging to the flow in Fig. 3

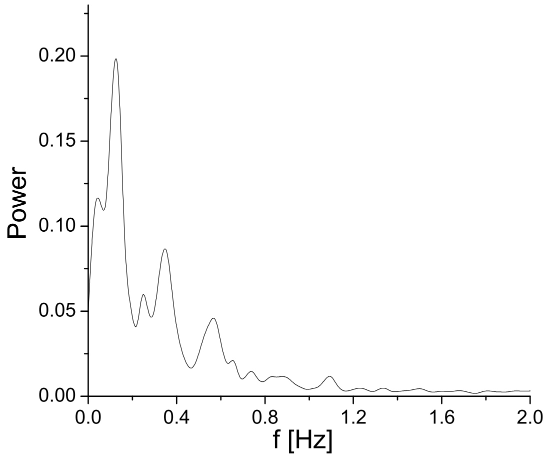

Figure 5. Power spectrum of velocity fluctuations in the center of the vessel

EXPERIMENTS

Modern electronic equipment for data acquisition is able to bridge the gap between the trustworthy direct numerical simulations, capable to cope with a strength of the driving parameters slightly above the instability threshold, and experiment. We employed extremely low-noise amplifiers in combination with steep analog filters to extend the measurable range down to a Taylor number $Ta = \sigma\omega B^2 L^4/(2\rho\nu^2)$ of 32, only, in the case of a rotating magnetic field (RMF) driven flow. Here ω, L, ρ and ν are the frequency, typical dimension, density and viscosity. The PDP measurements in Fig.'s 1 and 2 are in very good agreement with the theoretically predicted scaling laws for different flow regimes. The critical Ta was found to be approx. 1×10^5 which agrees well with theory. For this first time experimental validation of the linear scaling of the viscous controlled regime voltages as low as a few nano-volt have been reliably measured.
A pulsating magnetic field (PMF) was employed to generate fluid motion in a container of 6 cm height and 2 cm radius. From the UDV measurements of the vertical velocity component attained by a 1 mm sensor movement across the whole diameter of the vessel the absolute values of the streamfunction shown in Fig. 3 were calculated. The double vortex structure typical for induction-furnace like configurations can be clearly seen. Fig. 4 depicts the related distribution of the turbulence degree. In [4] PDP measurements and numerical simulations have been done. There the data were acquired at mid-height close to the rim, which turns out from Fig. 4 to be a good position for that purpose. One very low frequency oscillation of $\approx$ 1Hz is reported. The spectrum from UDV measurements in the centre of the container reveals additional frequencies as can be seen in Fig. 5.

MULTIMAG

As shown above, various types of a.c. magnetic fields lead to different flow structures. There are proposals to make use of two field types, for instance, a combination of an RMF and a traveling magnetic field (TMF) to increase the mixing of the metal baths. Nowadays demands may be even one step ahead. Instead of investigating the results of the application of a magnetic system its tailoring with regard to a desired flow structure seems far more promising. With the MULTIple MAGnetic field type facility we set up such a flexible system which permits the independent amplitude variation of RMF, TMF, PMF and the d.c. homogeneous and cusp components, with independent frequency variation for the alternating components. Industrial demands are met with a large experimental volume of 1/2 m in height, diameter of 36 cm and high field strength made possible by a compact design using water-cooled hollow copper profiles in combination with current-controlled 3-phase high power amplifiers. These special developed current sources [5] allow for arbitrary waveforms of $3 \times 160 A_{eff}$ for each of the field types including any phase relation and overlaying of d.c. offsets respectively superpositions of several frequencies.

References

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