3-D Vector Flow Estimation With Row–Column-Addressed Arrays

Simulation and experimental results from 3-D vector flow estimations for a 62 × 62 2-D row–column (RC) array with integrated apodization are presented. A method for implementing a 3-D transverse oscillation (TO) velocity estimator on a 3-MHz RC array is developed and validated. First, a parametric simulation study is conducted, where flow direction, ensemble length, number of pulse cycles, steering angles, transmit/receive apodization, and TO apodization profiles and spacing are varied, to find the optimal parameter configuration. The performance of the estimator is evaluated with respect to relative mean bias $\bar{B}$ and mean standard deviation $\sigma^\prime$. Second, the optimal parameter configuration is implemented on the prototype RC probe connected to the experimental ultrasound scanner SARUS. Results from measurements conducted in a flow-rig system containing a constant laminar flow and a straight-vessel phantom with a pulsating flow are presented. Both an M-mode and a steered transmit sequence are applied. The 3-D vector flow is estimated in the flow rig for four representative flow directions. In the setup with 90° beam-to-flow angle, the relative mean bias across the entire velocity profile is ($-4.7, -0.9, 0.4$)% with a relative standard deviation of ($8.7, 5.1, 0.8$)% for ($v_x$, $v_y$, $v_z$). The estimated peak velocity is $48.5 \pm 3$ cm/s giving a $-3$% bias. The out-of-plane velocity component perpendicular to the cross section is used to estimate volumetric flow rates in the flow rig at a 90° beam-to-flow angle. The estimated mean flow rate in this setup is $91.2 \pm 3.1$ L/h corresponding to a bias of $-11.1$%. In a pulsating flow setup, flow rate measured during five cycles is $2.3 \pm 0.1$ mL/stroke giving a negative $9.7$% bias. It is concluded that accurate 3-D vector flow estimation can be obtained using a 2-D RC-addressed array.