Beam Characterisation Using Laser Self-Mixing

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Abstract

Non-destructive beam diagnostics are highly desirable for essentially any accelerator or storage ring. This concerns the characterization of the primary beam itself, but also for example of atom and molecular jets that are crossed with the primary beam as experimental targets or for diagnostics purposes. A laser feedback interferometer based on the optical self-mixing effect provides a low-cost, robust, compact and non-invasive sensor for velocity, displacement and density measurements of various targets. This poster presents results from theoretical and experimental studies into the factors influencing the performance and accuracy of this sensor. Parameters that have been assessed include the target velocity, the size of scattering particles, their density, type and scattering properties.

The Task: Gas-Jets

Gas targets are important for a number of accelerator-based applications. Detailed information about the gas jet is important for its optimization and the quality of the beam profile that can be measured with it.

Possible seeders

<table>
<thead>
<tr>
<th>Type</th>
<th>Material</th>
<th>D for liquid flows, µm</th>
<th>D for gas flows, µm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid</td>
<td>Polyethylene</td>
<td>10-50</td>
<td>0.5-10</td>
</tr>
<tr>
<td></td>
<td>Alumina Al₂O₃</td>
<td>2-7</td>
<td>0.2-5</td>
</tr>
<tr>
<td></td>
<td>Titanium TiO₂</td>
<td></td>
<td>0.3-5</td>
</tr>
<tr>
<td></td>
<td>Carbon dioxide CO₂</td>
<td></td>
<td>5-15</td>
</tr>
<tr>
<td></td>
<td>Glass spheres</td>
<td>10-50</td>
<td>0.2-3</td>
</tr>
<tr>
<td></td>
<td>Granules (synthetic coating)</td>
<td>10-50</td>
<td>10-50</td>
</tr>
<tr>
<td>Liquid</td>
<td>Different oils</td>
<td>10-50</td>
<td>0.5-10</td>
</tr>
<tr>
<td></td>
<td>Diethylhexylsebacate</td>
<td>0.5-1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Helium-filled soap bubbles</td>
<td>1000-3000</td>
<td></td>
</tr>
<tr>
<td>Gases</td>
<td>Oxygen bubbles</td>
<td>10-100</td>
<td></td>
</tr>
</tbody>
</table>

The variation of the concentration

The experimental influence of the concentration of TiO₂ seeders in the flow of water on the spectrum of the self-mixing signal with a fixed flow velocity (1.3 m/s). The amplitude of the spectrum peak decreased steadily with decreasing concentration.

Solution: Self-Mixing Laser Diode

Small portion of light is reflected from the study object and returned into the laser cavity. It is then mixed with the original wave inside the laser:

\[ R = \frac{1}{2} |\mathbf{E}_0 + \mathbf{E}_1| \]

\[ I(\omega) = \frac{1}{2} |\mathbf{E}_0 + \mathbf{E}_1|^2 = \frac{1}{2} \left( 1 + \frac{\lambda}{2\pi D} \right) \left( 1 - \cos \left( \frac{2\pi}{\lambda} \frac{D}{w_2} \right) \right) \]

Parameters affecting SM signal:

- Scattered off the rotating disc light:
- The variation of the concentration
- The variation of the velocity

SM fluids measurements with seeders

The experiments were performed with following seeders:
- Milk: 5 µm
- Titanium dioxide TiO₂: 1 µm; 150 nm; 21 nm.
- Aluminium Oxide: 15 nm
- Silica: 200 nm.

The resulting spectrum is the sum of the distribution of all velocities within the illuminated volume, which leads to a different types of spectrums depending on the focusing properties of the laser and the type of the fluids:

Conclusion

This study has been focussed on the optimisation of a SM sensor to measure the velocity of gas jet based beam profile monitors. A theoretical investigation into the spectrum expected for such a sensor has been presented together with a calculation of the expected level of backscattered signal from a gas jet. A range of different seeding materials added to a water flow was investigated, and such parameters as velocity, reflectivity, and concentration of the seeders in the fluid were under study. The laboratory experiments with TiO₂ with different diameters (1 µm, 150 nm, 21 nm) showed the dependence of the peak spectrum amplitude from the concentration of seeders with a minimum concentration of 0.03 wt% still being possible to measure velocities with better than 3% accuracy.

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