Intermodulation noise in cold atom interferometers

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Abstract

Cold atom interferometers are highly sensitive instruments that can be used to measure different physical quantities very precisely. Example of such instruments developed nowadays in several laboratories are gyroscopes for the measurement of the Earth rotation. These instruments are based on a cold atom fountain geometry where the microwave cavity is replaced by a Raman laser interrogation. Due to their sequential mode of operation, they suffer from a measurement stability degradation which is similar to the Dick effect appearing in pulsed fountain clocks. In the case of fountain clocks, a continuous mode of operation allows one to decrease the residual intermodulation noise to a negligible level compared to the atomic beam shot-noise[1]. For gyroscopes, a continuous operation could be a means of avoiding this stability limitation.

In the frame of the EuroQUASAR program, we investigate how a continuous mode of operation could improve the measurement sensitivity of cold atom interferometers. The goal is to compare the intermodulation noise level to the shot-noise limit of the interferometer. To bring useful results to the EuroQUASAR community, we started by considering the case of the compact dual atom interferometer gyroscope currently developed at the Institute of Quantum Optics of the Leibniz University of Hannover. In a first step, and to keep the model as simple as possible, we studied only the case of a single gyroscope. The model developed for the estimation of the residual intermodulation noise in our continuous fountain clocks[2] has been adapted to a three-zone Mach-Zehnder type interferometer. It takes into account a continuous monokinetic atomic beam that can have any time-dependence of the atom flux (from continuous to pulsed through multiball) making this model very useful to compare continuous and pulsed operations. In our calculations, we consider only the noise sources coming from the Raman frequency and the retroreflected mirror vibrations. To get realistic results, we use the experimental noise power spectral densities measured on the LUH gyroscope. First results show that a pulsed operation of the gyroscope will bring the resulting intermodulation noise level one order of magnitude above the shot-noise limit, the vibrations noise being the limiting factor. By contrast, calculations for a continuous operation with a phase modulation of the last Raman beam show a clear improvement of the stability, the intermodulation noise reaching a level two orders of magnitude below the present shot-noise limit. These first results seem to show clearly the potential stability improvement of a continuous operation. However, these results have been obtained making ideal hypothesis about the Raman pulses and they need to be confirmed for a more realistic modeling of the atom-light interaction and for the case of a dual interferometer.

Keywords: Intermodulation noise, ultimate sensitivity cold atom gyroscope, cold and slow continuous beam, continuous and pulsed operation

References

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