Atom Interferometry for inertial sensors: fundamental and practical sensitivity limits

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Atom interferometry is in continuous progress since early 90's, as well in term of domain of applications as in term of performances. When used as inertial sensors to measure acceleration or its gradient or rotation rate, this method is intrinsically highly sensitive, which makes it as a technological break-up for applications in geophysics and inertial navigation. Compared to standard technologies, the two main advantages are the accuracy and the long-term stability of the measurements when integrating the signal during a long period of time. Nevertheless, in order to achieve these performances one has to achieve good sensitivity in short time scale, and the question of the "fundamental" or "practical" limit is still and open question.

Inertial sensors based on atom interferometry benefit from the development of cold atom methods as the area of the interferometers scales as the square of the interrogation time. By opposition, the use of cold atom sources leads to a reduce flux of atoms and may limit the sensitivity to the quantum projection noise, which scales as the square root of the number of atoms). This limit is often presented to argue about the need of sub-shot noise protocols and especially the use of squeezed atomic sources to overcome the problem. Nevertheless, up to know or to some very specific exceptions [1], as atom interferometer with ultra-cold atomic sources in space [2], a practical limit coming from spurious vibrations makes these methods useless and has to be addressed first. This comes from intrinsic principle of the cold atom experiments in which the preparation, the interrogation and detection are realized sequencely. These are two consequences: first dead times between consecutive measurements and second the result is accessible only at the end of the sequence. Such measurement is then limited by the aliasing effect do to the sampling, the lost of information between to consecutive interrogations. Moreover, because we don't have the information before the detection we have to limit the interrogation time (the sensitivity) to guaranty that the total phase shift is smaller than π such away the is no ambiguity on the fringe number.

In my presentation, I will discuss the different methods we have tested and developed to address this problem in the case of cold atom accelerometer (accelerometer or gravimeters) and cold atom gyroscopes. One method consists in the correlation between the atomic interferometer signal and a classical sensor signal (from a mechanical accelerometer as an example). This method enables to overcome the limit due to the ambiguity on the fringe number [3-4], to filter the noise [5] and eventually to realize a hybrid sensor [6] with no dead time in which the atomic sensor calibrates the signal issued from the classical sensor. This method is limited in performance to the intrinsic sensitivity of the classical sensor during the dead time period. To go furthermore, we are developing measurement methods with no dead times that we have tested up to know in clock configurations and that we expect to use soon on atom interferometry. The first way consist in the synchronization of the interrogation moments with the preparation of the successive atomic samples such a way there is always at least one atomic sample inside the interferometer at any time [7]. Because there is no more dead times, we can average the spurious vibrations faster in order to be limited only by the detection noise, and eventually the quantum projection noise. When the limit comes from ambiguity in the fringe number, because we can't use the correlations or when there are no good enough, a more complex method based on week measurement during the interrogation period can be used to keep a long interrogation time [8]. This last method is more suitable for ultra-cold atoms and is expected in the next generation guided atom interferometers.

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