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AGEN

Atomic Gyroscope for Enhanced Navigation

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Publishable Summary II

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1 Summary description of project context and objectives

Aircraft navigation and safety in the absence of GPS/Galileo signals can be improved by higher performances Inertial Measurement Units (IMU) and thus by higher performances gyroscopes. The “Atomic Gyroscope for Enhanced Navigation (AGEN)” project aims at showing the feasibility of the development of such an inertial grade gyroscope for aircraft navigation and delivering higher performances than Ring Laser Gyroscopes while having small dimensions and power consumption.

Atom (atomic) gyroscopes hold the promise of reaching even better performances, but their state of development is presently in the “research” stage and user’s requirements in terms of size, power consumption, cost and performances will be analyzed and targeted. Such a development may open up new application fields such as unmanned commercial flight, enhanced navigation for Unmanned Aerial Vehicles (UAVs), enhanced marine, sub-marine and Unmanned Surface Vehicle navigation. A conceptual design will be performed, allowing the trade-off between various concepts. Laboratory tests will be restrained to validating the gas cell, the heart of an atomic gyroscope, showing the feasibility of such a concept. This development will bring redundancy and will enhance the robustness of guiding systems relying on Galileo.

2 Description of work performed and main results

In the first year, the project was focused on identification of end user requirements and establishing a conceptual design supported by extensive modelling.

The system specifications was derived based on a market study, application analysis and user requirements. From the investigation of application reference scenarios, the most demanding applications are in Unmanned Aerial Vehicle (UAV) systems and applications in aircraft with no regulatory need requiring the use of a gyroscope such as Very Light Aircraft (VLA), or small rotocraft. These form the basis for the definition of the reference requirements of the system, defining the AGEN gyroscope’s technical characteristics and operation modes at system level.

A state of the art on atomic gyroscopes has been analysed, identifying two main approaches: Nuclear Magnetic Resonance (NMR) gyroscope and Atomic Spin Gyroscope (ASG) based on co-magnetometer. Their key performances, limitations and advantages were compared to the end-user requirements. These activities were concluded by a trade-off that triggered the conceptual design.

Based on specifications and on the review of the state of the art, project has designed the architecture and key components of the atomic gyroscope. Supported by rigorous theoretical modelling, the scope of the conceptual design has covered study of various architectures, according to the number of gas cells and detection methods. The design of micro-fabricated gas cells are proposed so as to minimize magnetic field gradients and keep very small physics package. A signal and error model of the gyro has been established for conceptual design of control loops, paying special attention to the Fourier frequency bandwidth of the angular rotation rate spectrum. It has allowed us to predict main parameters of the physics package, identify main test points and specific test bench to address in the experimental testing part of the project.

Conceptual electronics design has identified main interfaces, units and partition of the control loops between H/W and S/W implementation.

The complexity of involved physics phenomena and building of an adequate signal & error gyro model appear much higher than expected initially in the project plans. These resulted in significant delays. In particular, the optimization of the gas composition of micro-fabricated cell scheduled initially to the end of the first project year was shifted to the second year.

In the second year, the project was focused on fabrication of representative gas cells, building the test bench and measuring cell parameters. All these activities has allowed us to validate the design parameters and thus to validate the concept. While building the test setup has been accomplished as planned, fabrication of cells with specific gas components reveals that procurement of pure Xe isotopes is not so straightforward. Very long delivery time of these essential components shall be accounted for in future steps of development.

Two types of cells were manufactured or procured : the small-size MEMS cells having a tablet shape and large glass blown cylindrical cells. Implementation of envisioned tests required us to overcome much more challenges than it was initially expected in the plan. Thus fabrication of MEMS cells with target gas composition has required unexpectedly extensive testing. More than fifty MEMS cells were optically tested as opposed to the initial plans for only a few MEMS cells. Our initial plans were to detect NMR signal using narrow linewidth laser for spin-polarized optical pumping and detection. Such optical source offers low power consumption, high efficiency and stability. These features are very attractive for practical implementation of NMR gyroscope as discussed in Ph.D. Thesis by E. J. Eklund, as well as in the public communications by Northrop Grumman. However, in the experiment, we have not been able to detect NMR signal in high pressure cells and using optical beams with large diameters. Negative outcome was also reported for the prototype in above mentioned thesis, possibly for similar reason. We noticed however that selected single-frequency pumping scheme differs from the one in successful laboratory demonstrations utilizing broadband spin polarized optical pumping. Puzzled by consequences of such a difference in the interaction regime with the alkali atoms, we established novel theoretical model and verified it in various experiments. This approach brings us a credible tool for estimation of spin relaxation time in function of the cell size and optical beam diameter, spotting the importance of the ground state relaxation time in alkali atoms. Most importantly, it allows us to understand the necessity of RF modulation of narrow linewidth laser and to evaluate performance improvement from using such dual frequency pumping technique. Previously, spin-polarized dual frequency pumping of alkali atoms was used in the crossed-beam scattering experiments with electrons and alkali atoms but have never been reported in the literature on NMR magnetometers or NMR gyroscopes. Using our modeling tool we optimize the optical beam diameter in function of the cell size and its composition and predict the ultimate performance for NMR gyro operating either in single-frequency or dual frequency mode of the spin-polarized optical pumping. In particular we find that efficient single-frequency spin polarized pumping in large cells require tight focusing of the laser beams. Under this conditions and using large glass cells, navigation grade performance can be reached even in uncoated cells. For small-size MEMS fabricated cells, the navigation grade performance can be reached only if the dual frequency pumping is used with large diameter optical beams.

Based on these outcomes we established exploitation plan and future roadmap to envisioned product of a miniature atomic gyroscope.

3 Expected final results and potential impacts

Atomic spin gyroscopes prototypes (ASG's) using nuclear spin angular momentum (NSAM) for rotation measurements were first developed in the 1980's by the firms Singer and Litton, replacing mechanical rotors by atomic spins. Although both designs have reached navigation grade performances, their weak point was the requirement of a stable and homogeneous magnetic field. This put stringent constraints to the design of shielding and magnetic field coils, leading to large and expensive devices.

The recent development of micro fabrication technology for chip scale atomic sensors, such as atomic clocks and atomic magnetometers means that the chip-scale atomic spin gyroscope (ASG) based on NMR will reach navigation grade precision in the near future. The most advanced demonstrated prototype approaching the final product is built by Northrop Grumman Corporation from US. Researchers and engineers from Princeton University and China have demonstrated an alternative approach utilizing Spin-Exchange Relaxation Free regime. Nevertheless, this architecture (known as "the co-magnetometers") is not as mature and miniaturized as NMR gyros.

The rotation measurement sensitivity and stability reached by these ASG's is either similar to or better than that of Fibre Optic Gyroscopes (FOGs), but in a much smaller package, so in terms of Size, Weight and Power (SWaP), there is a step change with respect to the present generation of FOG aircraft navigation gyroscopes. This will enable ASG's to be introduced on smaller size aircraft, as well as using multiple ASG's on large aircraft to provide significant redundancy, ensuring safety when easily disturbed GPS signals become problematic or simply unavailable.

An analysis of exiting demonstrators and prototypes all over the globe has revealed an issue related to the Fourier frequency bandwidth of the angular rotation rate spectrum. AGEN concept is free of this drawback. The experimental testing has revealed that dual frequency spin-polarized pumping approach allows to get high performance even in using small size cells without specific provisions for wall anti-relaxation coatings. With this new key points for the future development of this technology, Europe may recapture a supremacy in the field of ASGs.

4 Project public website

The project website is available for the public access at the following address:

http://agen.tekever.com/

Sections concerning project members' publications, project highlights and related events are regularly updated.