ONR
Quarterly Report for Grant N00014-90-J-1475.
Neutral Atom deBroglie-Wave Interferometry
Year 1, Quarter 2, May - July 1990
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Univ. of California - Berkley

Progress on the project has continued in various areas.

Students:

Katie Schwartz has signed up to perform research on this project for her PhD dissertation. She was an undergraduate at MIT (there working in Dave Pritchard's lab), has completed her second year of Graduate studies at UCB, and has passed her PhD candidacy examinations. She will be fully supported by the Grant. So far, she has performed oven calibrations and is currently at work building and testing diode laser systems.

David Botkin, has completed his first year of Graduate studies at UCB, was an undergraduate at UCB, and has passed his candidacy examinations. He is working part time for this summer of 1990 on the Grant, attempting to design an ion lens system to focus ions from the hot-wire detector onto a Channeltron electron multiplier.

Two other students have become associated with the project, although neither receive support from the Grant. The first is Mathias Rensch, a German student who comes with a US Dept of Education Fellowship. He has completed his first year of Graduate studies at UCB, and has passed his PhD candidacy examinations. The second is Lokesch Duraiappah, who will be a senior at UCB in 90-91.

Vacuum System & Thermal Beam Generation:

The vacuum system now routinely pumps to the low 10^{-7} to high 10^{-8} Torr range with neither bake-out nor LN trapping. With bake-out and LN trapping, a vacuum in the 10^{-9} range should be readily accessible. The new copper oven was tested and produces a potassium beam that was easily detected with a hot-wire/electrometer detector more than 2 meters away. The oven temperature was calibrated vs input power, and a 10°K temperature gradient found between its top and bottom. Splitting the oven heaters onto two separate circuits should reduce this gradient. The oven is supported inside the vacuum chamber through bellows and can be positioned accurately using externally mounted dial gauges. Thus, alignment of the oven to the beam line is now straightforward.

Vibration Isolation System:

Typical building vibrations have been measured to be of order 10 mGal at 10 Hz (the inverse of the desired atomic transit time through the interferometer). A factor of at least 10 and preferably a factor 100 isolation at this frequency is needed for stable matter-wave fringes to be formed.

Typical vibration isolation systems are in essence a simple spring-mass-dash pot linear filter. As a function of the ratio of the exciting frequency to the filter's natural resonance frequency, the amplitude isolation improves with the inverse square of this ratio for a weakly damped system, but only inversely with the ratio for a strongly damped system. Thus the philosophy adopted is to provide a weakly damped suspension with the lowest possible resonance frequency. However, simple pendulums and/or mechanical springs typically have resonances at least 1-10 Hz, which is unacceptably high to isolate vibrations in the 2-20 Hz range. Thus other schemes must be employed.

The original design for the vibration isolation system called for isolation of five of the six degrees of freedom of the apparatus from building vibrations. Horizontal accelerations and rotations about a vertical axis are isolated via an "inverted - pendulum" support tower system with a sway resonance frequency of about 1/2 Hz. A reduction by a factor of 5 in this resonance frequency is readily possible by carving down the support legs, although this operation is preferably delayed as long as possible since the tuning is only one-way. Rotations about horizontal axes are isolated by a 2-axis "universal joint" knife-edge bearing suspension, so that the whole vacuum chamber and interferometer strong back "space - frame" acts similarly to a double pendulum. Current resonance frequencies for both tilt modes are both about 1/4 Hz, readily reducible further by lead brick ballasting.

Originally, it was hoped that the vertical axis could be left un-isolated, since this motion is parallel to the interferometer's insensitive direction. Unfortunately, it has been found that vibration in this direction interferes with the testing of the isolation of the other modes. Thus, it was decided to isolate this sixth mode as well. To do so, a set of four pneumatic pistons was fabricated and installed on the top of the tower, below the universal joint. These are coupled via hoses to a large volume pressure tank. Initial tests of this system indicated a heavily over damped system and a higher than expected resonance frequency. The excessive damping is believed to be due to viscous loss through hoses of insufficient diameter. The higher than expected resonance frequency is evidently due to the piston construction which allows the effective piston area to change with displacement. New pistons with "rolling-seal" diaphragms (similar to those marketed by Newport Research Corporation) have been fabricated and installed, along with larger diameter hoses. These are nearly ready for testing.

Laser Systems:

The thermal potassium beam will be longitudinally cooled using the now common chirped "spontaneous-decay" cooling mechanism by light from commercial diode lasers. Optical pumping (to prevent leakage into un-desired hyperfine states) is expected to be performed by amplitude modulating the diodes at the potassium hyperfine frequency (about 460 MHz). Transverse cooling of the beam by optical molasses (also produced by diode lasers) will also be attempted with an expected gain in throughput flux of about a factor of 50. Discussions of diode laser technology with Carl Wieman of JILA indicated that the least problematic design for the laser systems is to narrow the laser line-width using a cavity consisting of the laser itself on one end and a diffraction reflection grating on the other. Acquisition (via the personal funds of the PI) has proceeded of a large number of low power laser diodes, along with a thermo-electric cooler, suitable piezoelectric crystals, diffraction gratings, collimating lenses, etc. Construction of custom power supplies for the diodes and the coolers is currently under way. Testing of these components will proceed shortly, followed by their installation on the vacuum system. It is considered prudent to perform the initial tests with inexpensive low power diodes (about 5 mW), and defer acquisition of the more expensive high power diodes (35 mW) until experience has been gained with these easily destroyed items.

Fluorescence Beam-Velocity Monitor:

The first low power laser system will be installed as an atomic beam velocity monitor. Design and construction is underway of optics for monitoring the fluorescence produced by the interaction of the laser with the potassium beam. Thus the first laser experiment will be to measure the thermal velocity distribution from our oven. First, this experiment will provide valuable information (not readily available in literature) concerning the low velocity (non-Maxwellian) components of the beam. Second, it will provide a cross check of the laser bandwidth (for comparison with RF spectrum analyzer measurements). Third, it will provide a final test of the laser design, and thus a working model for duplication to provide sources of cooling and focusing laser radiation in subsequent cooling experiments.

Matter-Wave Gratings:

Although it is not anticipated that matter-wave interference experiments will commence until the second year of the Grant, design and planning for the installation and fabrication of matter-wave gratings has also proceeded. Given difficulties experienced in parallel experiments at MIT, various contingency plans will be available. The current favorite scheme and design calls for fabrication of the gratings on a film if silicon nitrite. The nitrite film is first grown on a wafer of silicon, and then the silicon substrate is etched away in desired areas leaving the remaining silicon as a frame to support the film. Next, the desired slit pattern is exposed in a resist on the film. Finally the slits are etched through the film. The Engineering school at UCB (Cory Hall) has a facility for performing most of these operations on campus. Alternatively, commercial vendors are being interviewed who may be able to provide such custom gratings.

Grating fabrication techniques are is strongly affected by interferometer parameter tradeoffs. A high intensity low-velocity laser-cooled atomic beam (currently being built) greatly relieves many of the fabrication difficulties and allows more options. For example, if the slit dimensions of 1μ can be tolerated, then optical lithography of the slit pattern can be employed, and the gratings can be fabricated at UCB. If, however, slits as narrow as $.25 - .5\mu$ are required, then e-beam lithography will be required, a technique outside the scope of Cory Hall. As a further fall-back, if 12μ slit periodicities can be employed, then the gratings are available off-the-shelf from Aries in the form of wire-grid infrared polarizers (2-3 mo delivery at about $6000). Parameter studies are under way to determine the relevant trade-offs. For example, it may be possible to reconfigure the interferometer to detect Talbot fringes instead of the usual separated beam fringes (this configuration was mentioned briefly at the January ONR sponsored Santa Fe Matter-wave workshop). In such case, the 12μ wire-grids will suffice. Unfortunately, Talbot fringes (sometimes called Fourier and/or Fresnel images) are an obscure part of optics without much practical application, so that the literature about them is sparse, and tedious numerical calculations appear necessary to determine the expected coherence and collimation requirements.

The use of Talbot fringe interferometry is also being considered for another reason. It is planned to have parallel optical gratings on the same substrates as the matter-wave gratings. These will be used in two ways. First, they may be used with a He-Ne laser beam to perform alignment. Second, once optically aligned, they can be used for Talbot fringe matter-wave interferometry immediately. As the velocity of the beam is reduced (via laser cooling), Talbot-fringe resonances will occur at various specific velocities, whereupon the alignment can be further refined at each new resonance. The procedure then can be repeated with decreasing beam velocity resonances down to the lowest velocity, and the separated beam interferometer should then be almost exactly aligned.

Presentations:

In this quarter, one presentation of the project's work was given. This was at an NSF sponsored workshop on the Foundations of Quantum Mechanics. Travel to this workshop was on the personal funds of the PI, and lodging and meals at the workshop were covered by NSF.

Submitted

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