Laser Frequency Stabilization

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1 Introduction

In Dr. Korsch's lab, we are constructing a laser frequency stabilization system to lock our near-infrared laser to the D_2 transition of Rubidium (780nm). Many optical and atomic physics experiments require these systems to reduce the fluctuations in frequency from a diode laser that occur over longer time scales [2]. Existing literature suggests multiple methods for locking to a given wavelength. The first method we will investigate uses a scanning Fabry-Perot interferometer, and a reference wavelength using the Doppler-free atomic spectra of Rb $5S_{1/2} \rightarrow 5P_{3/2}$ found with a saturated absorption technique [7][2][3]. Once we have achieved a saturated absorption signal with limited noise, we will use the PID function of the DLC Pro Digital Laser Controller to enable Top of Fringe locking. Time allowing we may also set up a Dichroic Atomic Vapor Laser Lock system as an alternative laser locking method to find the most efficient stabilization [4]. If successful, graduate student research will use our stabilization system for measuring the Faraday rotation arising from spin-polarized ^{3}He samples. These experiments rely on spin-exchange optical pumping to polarize ^{3}He. This method polarizes Rb as an intermediate, held in a chamber above the experiment containing polarized ^{3}He. The required structure of the system can lead to Rb contaminating in the polarized ^{3}He. The 780nm laser is necessary to probe the extent of Rb contamination in the experiment.

2 Theory

The Fabry-Perot interferometer contains two confocal mirrors with reflectivity of close to 99%. Once light enters the cavity, it is repeatedly reflected back and forth, constructively interfering and increasing the intensity of the light between the mirrors. Only around 1% of this light will exit the cavity, causing the theoretical outgoing intensity of the cavity to equal its incoming intensity. The Fabry-Perot selectively allows frequencies resonant with the length of the cavity, allowing us to measure adjustments to the laser frequency with high precision[3]. The other necessary element to our stabilization system will be the saturated absorption spectroscopy of Rb. Saturated absorption is a technique used to measure an atom's transition frequency at a higher resolution by minimizing

Doppler broadening due to the atoms' thermal motion. This technique uses two counter-propagating beams which overlap in a small region within a Rb sample. Both beams are derived from one laser to ensure identical frequencies, and one, the pump beam, is significantly stronger than the other, the probe beam. If we set the laser frequency to the transition frequency, both beams will interact with the same group of atoms with a velocity of zero in the direction of the beams [6]. We will read a decrease in absorption at the resonant frequency since the pump beam will have already excited some of the atoms the probe beam would interact with. The peak corresponding to this decrease in absorption is ideal for locking to Top of Fringe or Side of Fringe locking. Both methods use the derivative of the absorption peak as an input for the laser controller PID. Side of Fringe locking used the slope on the side of the Doppler-Free peak as a locking reference. This summer, we may test if Side of Fringe will provide a good lock. However, it can interpret amplitude changes in the peak as changes in frequency. Misinterpretation could create an inefficient lock, especially if there are fluctuations in room temperature and current supplied to the laser. Top of Fringe locking, the first method we are analyzing, avoids this issue. Top of Fringe uses frequency modulation and demodulation to obtain the derivative at the saturated absorption peak maximum.[5][1]

3 Procedure

Laser Coupling As a first step to creating our stabilization system, we tested the alignment of optical equipment we will be using with a visible HeNe (633 nm) laser before moving on to the final infrared (780nm) laser. A visible laser allows us to become more familiar with redirecting, focusing, and coupling a laser before working with an invisible and higher power beam. In the first week, we practiced coupling and decoupling the HeNe beam to a single-mode fiber optic cable and took wavelength measurements of the decoupled beam with a WA 1000 Burleigh wavemeter. We could only take measurements via the fiber optic port when using a multimode fiber at higher currents. More internal alignment may make the fiber optic port more feasible in the future, but free beam measurements have been acceptable for our initial setup. During our first alignment with the 633nm, we were unable to achieve the expected periodic oscilloscope signal from the Fabry-Perot. Lack of signal may be due to the internal mirrors of the cavity being optimal for near-infrared wavelengths, not including 633 nm, as we could read the expected signal after switching to the 780 beam.

After our initial week of testing alignment techniques using the visible 633 nm laser, we transitioned to using the 780 nm laser we will be stabilizing. The 780 nm laser has a built-in fiber dock that couples the laser directly into a fiber optic coupler. Unfortunately, when using the Polarizing maintaining single-mode fiber we would prefer to use, only around 20% of the beam is successfully coupled into the fiber. The percentage of light coupled into a fiber is optimized when the focal point is centered and smaller than the fiber opening. Small adjustment screws on the fiber-dock or free standing coupler move the position of an internal lense which can align this focal point with the fiber. Single-mode fibers have a much smaller opening than multimode fibers, making alignment much more challenging. We hope to increase the coupling into the fiber further eventually, but for the first iteration of our stabilization system, we used a multimode fiber to avoid intensity loss.

Saturated Absorption After successfully decoupling our laser back into a free beam using a ThorLabs FiberPort PAF-X-15-B, we constructed our first saturated absorption experiment based on the teaching lab by . This method relies on a 70/30 beam splitter placed after two initial guiding mirrors. The beam splitter allows the probe beam to continue through the Rb cell and towards a photodetector. The beam splitter reflects the pump beam toward two additional mirrors, directing it back through the Rb cell opposite the probe beam. The signal of the photodetector can be read by an oscilloscope or directly input to the laser controller, where we can use the signal for our lock. We noticed the laser was diverging, leaving the fiber port, so we introduced a 500mm lens before the Saturated Absorption guiding mirrors. This lens narrows the beamwidth over the distance the laser interacts with the rubidium cell. We added a 250 mm lens for a similar purpose in the Fabry-Perot alignment to reduce the intensity loss we experienced from the beam width exceeding the Fabry Perot cavity width. Initially, we set up the beam splitter in the incorrect orientation, resulting in the probe beam having a higher intensity than the pump beam. Despite this mistake in our setup, We did achieve a successful saturated absorption spectrum. We next introduced two additional beam splitters in our experiment. The first diverts a portion of the beam to be measured by the Burleigh wavemeter. The second split part of the laser to the Fabry-Perot aligned adjacent to the saturated absorption.

Alignment Techniques Our initial plan was to use a visible HeNe 633 nm laser as a reference beam to align the infrared laser. While we may use this technique in later steps, we successfully aligned both the Fabry-Perot and saturated absorption spectrum without a reference beam by using an infrared-sensitive camera. For aligning the Fabry-Perot using the camera, we removed the back photodetector of the cavity so that the camera could lie flush with the back aperture. We made initial course adjustments so that the laser was able to pass through both cavity openings. Once some amount of the beam exits the cavity, it is detected by the camera. We can adjust the Fabry-Perot adjustment screws and guiding mirrors using the camera image as feedback. We make small adjustments to concentrate the light to a single centralized beam which corresponds with the cavity's fundamental mode. Additionally, we used the camera software to display a readout of the image intensity and maximize this number.

The infrared camera was also a valuable tool in first testing that the Rb was excited by the laser. In this application, we mounted the infrared camera to face the side of the Rb cell. We covered the cell and camera to reduce ambient light. After turning on the laser, the camera image showed a lighter region of flashing photons. This signal results from Rb atoms emitting 780 nm photons as they fall back to the ground state.

Alignment of the Saturated Absorption setup required manipulation of more mirrors but was more forgiving than the Fabry-Perot alignment. To efficiently align the system, we first removed the Rb oven from the table. We aligned the probe and pump beam so that they overlapped at the point where the center of the cell would be. We then replaced the cell on the optical table and were able to select a saturated absorption signal.

4 Discussion

Lock Measurement In the first weeks of research, we have completed the initial construction of the foundation of our laser lock system. From here, we must demonstrate a successful lock on to our desired frequency. We hope to explore a second method for implementing saturated absorption and perform more tests on changing the temperature of the Rb cell. Our next step is to collect data on how far the laser drifts unlocked as a baseline to compare our locking techniques' success. W.Bodron has created a program to record the x position of a Fabry-Perot peak on the oscilloscope. With this x position measurement and the known FSR between extremes on the oscilloscope of 1.5 GHZ, we can measure the frequency change of our laser over time. Initially, measurements indicate a linear drift of the unlocked laser; however, longer measurement times and data on the changing room temperature will give us a clearer picture of the laser's long-term behavior. Last week, we also took data for the laser drift when we set the lock but did not adjust the PID parameters. The laser appeared to drift less than the unlocked trial, only changing in frequency by 30 TTT of the unlocked laser change. While this is hopeful, both data sets were over a short period. Our data analysis predicts that the distance between two Fabry-Perot Peaks corresponds to a change of 3 *10-12 m. We plan to fix the cavity length and scan through one FSR with the laser frequency as a brief test. We will measure the wavelength of the laser with the Burleigh Wavemeter. We expect to observe the 3 pm change. However, the wavemeter response time may limit this experiment.

Alternate Configurations We are using our current saturated absorption configuration while we familiarize ourselves with the laser controller locking features. However, we will eventually change the system's layout since the probe and pump beam are not currently at an optimum intensity ratio. When we reconfigure our optical elements, we will next try a saturated absorption method that uses polarization changes to create two counter-propagating beams rather than change the geometry of our current setup. In this method, a polarized pump beam passes through the Rb cell and is then rotated by a quarter-wave plate and reflected through the cell to serve as the probe beam. Using polarization changes may be a better solution as the beam splitter approach is optimal with a 90/10 beam splitter rather than the 70/30 we are currently using. Additionally, with the beam splitter approach, the probe beam creates the need for a laser shield close to the optical elements to prevent an uncontrolled beam. With the polarization method, we could ideally limit the angle of the probe beam and terminate the pump beam without the need for an inconvenient shield.

Another question we will next investigate is if changing the Rb temperature will affect the quality of the laser lock. Our Rb cell currently lies within an oven, which allows us to vary the temperature of our Rb atoms. We did a preliminary test of this function, and observed absorption in our cell increased over increasing temperatures as expected. One remaining question is if the spectrum produced at higher temperatures is more favorable for Top of Fringe locking.

If Top of Fringe proves to provide a reliable lock, we can repeat the experiment using a potassium cell. The DL laser is adjustable over a wide range of frequencies, and locking on to a Potassium cell will be necessary if the laser needs stabilization at 765 nm. Potassium is also used in SEOP to expedite spin-exchange due to its smaller atomic radius than Rb. A 765 nm laser will allow researchers to test for K in the ^{3}He cell. By the end of the summer, we aim to demonstrate improved long-term stability of the DL pro laser at our desired wavelength.

References

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