Proceedings of the 2003 IEEE International Frequency Control Symposium and PDA Exhibition
Jointly with the 17th European Frequency and Time Forum

Progress Towards a ^{133}Cs – Fountain as Frequency Standard in Brazil.

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Abstract

Recently, ^{133}Cs atoms were trapped in a fountain chamber. About 10^8 cesium atoms are caught in a magneto-optical trap from a vapor cell at room temperature. The "future fountain" has a (1,1,1)-geometry for the laser cooling and launching operation. The difference between this configuration and the usual one concerns the polarization. The three upper beams have the same polarization, in opposition to the three lower ones. The interrogation and preparation cavities were also constructed as well as characterized concerning the temperature tunability in vacuum. The interrogation cavity is made of copper and the quality factor is about 8000. The microwave synthesizer was constructed in collaboration with BNM-SYRTE time and frequency group. The synthesizer was compared to a very stable oscillator at BNM-SYRTE resulting in a short term stability of $9.7 \times 10^{-14}\tau^{-1/2}$.

1 Introduction

The Brazilian time and frequency metrology program began some years ago. The first step was to construct and completely characterize an atomic frequency ^{133}Cs beam standard. The progress obtained was published elsewhere [1, 2, 3]. As the time and frequency metrology domain is in the first beginning in Brazil, it is being necessary to increase the number of researchers working on this subject. This goal is being achieved with the help of the foreign collaborators, mainly the time and frequency BNM-SYRTE group.

In this paper, the recent progress obtained with the second generation of atomic frequency ^{133}Cs standard, the atomic fountain, is described . The construction of the fountain physical structure, as well as the microwave synthesizer and the interrogation and preparation cavities are discussed in details.

2 Description of the atomic frequency standard device

The ^{133}Cs cold atoms frequency standard was constructed having a MOT in a different configuration. The MOT vacuum chamber is made of stainless steel, being 35 cm long and 20 cm diameter and the detection region is placed below, as shown in 1 . The background pressure in the chamber is lower than 10^{-5} Pa -kept by a 60l/s ion pump. The free-flight cylinder is made of AU4G aluminium. A connection of titanium was introduced to join these two parts, to avoid having magnetic material inside the shields, after having tried many times to seal the stainless steel with the titanium to keep the system more compact. A graphite cylinder was introduced in the region between the trapping chamber and the detection region to reduce background gas in this zone. The magneto-optical trap is slightly different from the traditional one. The "future fountain" uses a (1,1,1)-geometry for the launching operation. The anti-Helmholtz coils are not placed in one of the light axis. The trapping light beams are not placed in xy and yz planes, as depicted in 1, while the anti-Helmholtz coils are placed in the y-axis. The major difference between this configuration and the usual one concerns the polarization, all the upper beams have the same polarization and lower one is in opposition.

To trap and cool the atoms some diode lasers (SDL 5410C) are used. A diode laser stabilized in an external cavity configuration and locked on the atomic resonance, pumps a MOPA (Master Oscillation Power Amplifier - SDL model TC30) that delivers 500mW, for 7mW of pumping. The laser linewidth is estimated to be less than 500kHz. Another diode laser in the same configuration is used as a repumping. The amplified beam is used to trap the atoms and also to detect them, as depicted in 2. In a near future there will be an independent laser devoted to

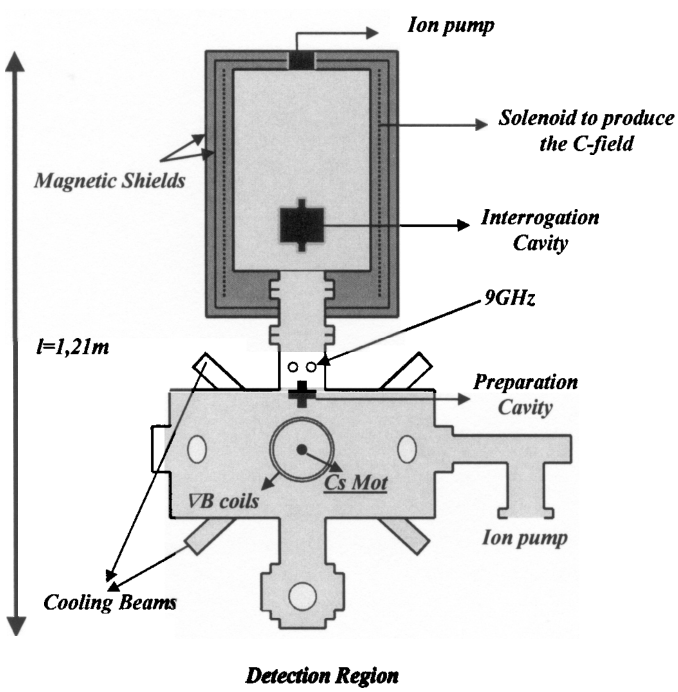

Figure 1: The scheme of the atomic fountain. The C-field region is about 79 cm high. The microwave cavity is 29 cm above the magneto optical trap and the detection zone 17 cm below the trap. The atomic populations, $N_{F=3}$ and $N_{F=4}$, will be measured by induced light fluorescence.

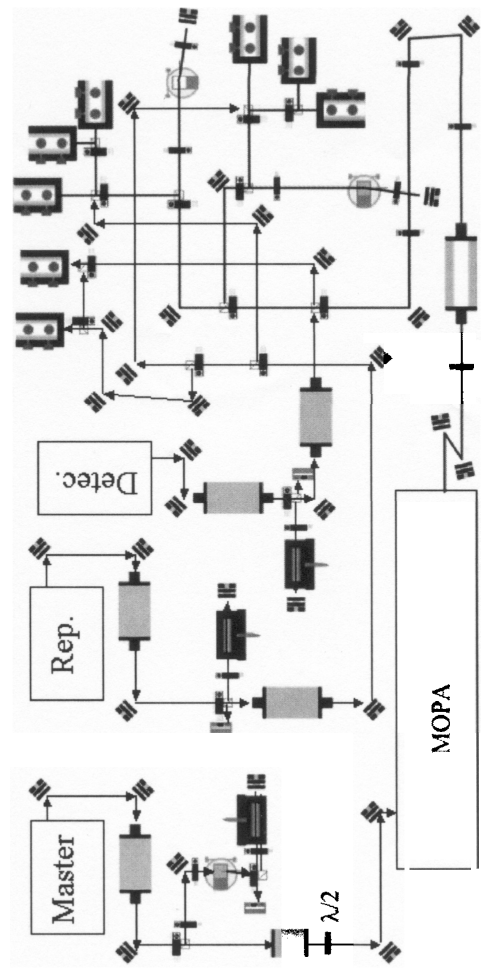

Figure 2: Scheme of the optical table with all the elements necessary to trap the atoms.

the detection process. Optical fibers preserving polarization are used to bring the laser light from the optical board to the main chamber, where the beams are expanded. The optical power of each beam is about 12mW, the beam waist is 26,8mm at $1/e^2$ and the intensity is about 1,97 mW/cm^2, which is enough to trap and cool the atoms since it is much higher than the saturation intensity. The trapping beams are resonant with the transition $6^2S_{1/2}$ (F = 4) $\rightarrow$ $6^2P_{3/2}$(F'= 5), and the repumping tone is locked on the $6^2S_{1/2}$(F=3)$\rightarrow$$6^2P_{3/2}$ (F'=4) transition.

The magnetic field necessary to create a quantization axis is produced by a solenoid 79cm long. The interrogation cavity is made of copper and the preparation one is of titanium. The interrogation cavity quality factor is about 8000, and it can still be increased. It is estimated to be possible to reach 10000 for the quality factor. To investigate the atoms we will use the fundamental mode of the cavity (TE_{011}). The preparation cavity has a low quality factor, and temperature dependence is very soft, since titanium is a bad thermal conductor. The interrogation and preparation cavities are fed with the signal produced by the microwave synthesizer constructed for this purpose, as will be described in the next section.

3 The microwave synthesizer

3.1 The production of the interrogation signal

In an atomic frequency standard, based on the transition between two hyperfine levels, the resonance frequency is in the microwave domain, and it is necessary to have a very stable hyperfrequency signal source to interrogate the atoms. To produce this signal, a microwave synthesizer was constructed with the worth collaboration of the BNM-SYRTE time and frequency team, having a similar topology of some chains already operating with their atomic frequency standards [4]. The main parts of the synthesizer are the three high performance oscillators: 4.596 GHz (DRO 4R596-10SF – Omega Technologies), 10 MHz (BVA – OCXO 8600 – Oscilloquartz) and 100 MHz (500-07542A – Wenzel Associates Inc). The 100 MHz crystal oscillator is phase-locked to the BVA at low frequencies (below 30 Hz), providing it with the better phase noise characteristics from each of them. The 100 MHz signal is then doubled and inserted in a sampling mixer, which performs the subtraction of the 23th harmonic of this input with the main harmonic signal coming from the DRO (4.596 GHz). The output signal from the sampling mixer is compared with an external 3.6 MHz, supplied by a DDS (DS345 – Stanford) that uses the BVA as an external reference. This comparison provides the phase-locking of the DRO, allowing modulation through the DDS programming. The other DRO output is connected to a waveguide filter whose band is centered on its first harmonic (9.192 GHz _ -15 dBm).

This synthesizer was compared to other chains, including the one corresponding to the PHARAO clock, and the square root of the Allan variance is shown in figure 3. The obtained stability due to these comparisons of the 9,192GHz signal from both chains has shown to be $9.7x10^{-14}\tau^{1/2}$.

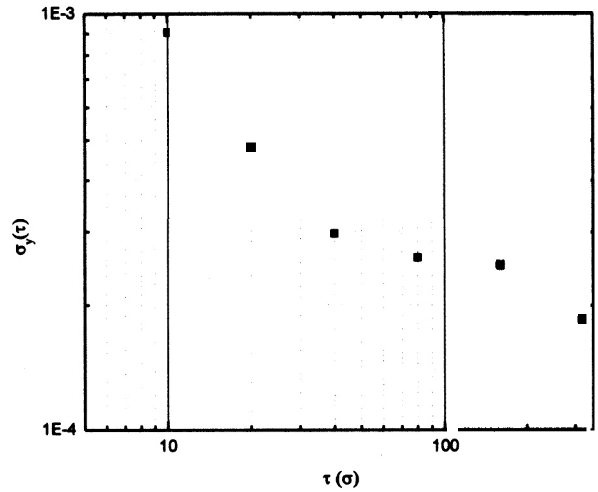

Figure 3: Allan Standard deviation of the two chains. The fitted short-term stability is $\sigma_y = 9.7 \times 10^{-14}\tau^{-1/2}$, where τ is the averaging time.

3.2 The production of the preparation signal

To supply the microwave preparation signal, part of the signal generated in the first synthesizer is used as an input for this second one. In this case, a DRO at 9.192 GHz (10.84 dBm) is inserted in a sampling mixer and subtracted from the 46th harmonic of a 200 MHz signal derived from the interrogation chain. The sampling mixer output is compared with a 7.3 MHz provided by a DDS (SR345 – Stanford) and phase-locks the DRO. In order to avoid some perturbing fields during the interrogation phase, after the atoms pass by the preparation cavity, the signal is switched off by the temporal sequence controller. This is done by using a switch with 80dB of isolation (F192A – General Microwave)

4 Recent results

As mentioned before it was observed that this system is as efficient as the traditional one, to trap and cool the atoms. About 10^8 atoms were trapped in a MOT configuration, as depicted in figure 4. Efforts are being concentrated to better adjust the trapping coils in order to minimize the atomic loss when the magnetic field is turned off to perform the sub-Doppler cooling.

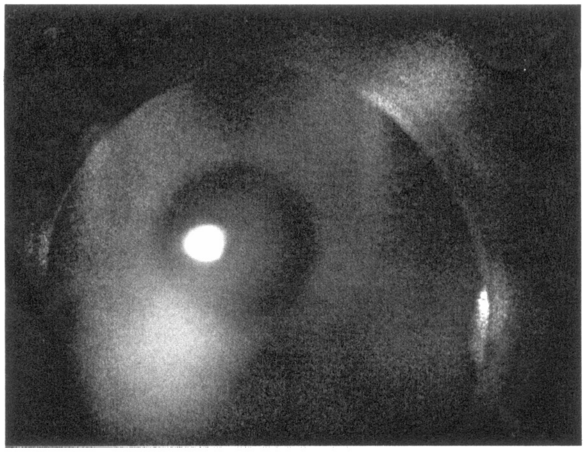

Figure 4: Image of the magneto optical trap obtained by a CCD camera, in the atomic fountain. About 10^8 atoms are trapped into the cloud, the density is about 10^{11}atoms/cm^3.

5 Conclusions

As part of the ongoing research on time and frequency metrology in Brazil, the progresses obtained with the system that will be the first cold atoms frequency standard in Latin America were presented. All the mechanical parts were constructed in Brazil. It was hard to converge to a system that could be kept at low pressure during a long time. As there are three different types of materials the traditional procedure to beak all the structure to reach low pressure failure many times. Although, finally after implementing a differential baking procedure the 10^{-5} Pa limit was reached. The microwave synthesizers were built in collaborations with the BNM-SYRTE team. About 10^8 atoms were cooled in an optical molasses. The next step is to improve the MOT conditions and leave the atoms to fall, evaluate their temperature by the time-of-flight technique in the detection region. Afterwards, the atoms will be launched upwards, following the usual course to obtain the Ramsey fringes.

References

[1] F. Teles, D. V. Magalhães, M. S. Santos, G. D. Rovera, and V. S. Bagnato, "Evaluation of the first brazilian atomic clock," *IEEE*, vol. 47, pp. 1111–1114, 2000.

[2] F. Teles, M. S. Santos, D. V. Magalhães, A. Bebeachibuli, and V. S. Bagnato, "Analysis of the signal obtained with the cs-brazilian atomic clock.," *Proceedings of 14th European Frequency and Time Forum*, April 2000.

[3] F. Teles, M. S. Santos, D. V. Magalhães, A. Bebeachibuli, and V. S. Bagnato, "Characterization of the brazilian cs clock: Accuracy and major shifts.," *Metrologia*, vol. 39, pp. 135, 2002.

[4] G. D. Rovera, G. Santarelli, and A. Clairon, "Frequency synthesis chain for the atomic fountain primary frequncy standard.," *IEEE. Trans. Ultra. Ferro. and Freq. Cont*, vol. 43, no. 3, pp. 179, 1996.