# Investigation of Conical Magneto-optical Trap as a Source of Slow Atoms

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***Summary* — One of the key elements of atomic sensors is a cold-atom source. It should be relatively simple, controllable, robust and compact. Conical magneto-optical trap (MOT) can become a useful tool for such devices as an atomic fountain, a gravimeter. We have developed and investigated the conical magneto-optical trap as a source of slow atoms on the rubidium fountain.**

***Keywords— metrology, time and frequency standard, atomic fountain, cold atoms, conical trap.***

## I. Introduction

One of the key elements of atomic fountains is a cold-atom source. For convenience the source should be simple, reliable and robust with a high flux of loaded atoms. While maintaining the same measurement accuracy on the rubidium fountain, a higher atom flux makes allows to reduce the time of the measurement cycle of the fountain and improve the signal-to-noise ratio. One of the methods to achieve this is to use the conical magneto-optical trap as a source of slow atoms.

We have developed the conical magneto-optical trap [1] as a source of slow atoms on the rubidium fountain.

## II. The conical magneto-optical trap as a source of slow atoms

Magneto-optical trap in a conventional configuration consists of a spatially nonuniform magnetic field and three orthogonal pairs of counter laser beams having opposite circular polarization (Fig.1 (a)). The magnetic field is created by a pair of coils in an anti-Helmholtz configuration. The direction of polarization in a conventional six-beam MOT is determined by the gradient of the magnetic field of the coils. One of the ways for obtaining such polarization as shown in the figure 1 (a) is using of quarter-wave plate and retroreflecting mirrors.

To simplify and further compact the construction, it is possible to replace two pairs of beams and reflecting mirrors with a conical reflector [2]. In such compact traps, one wide laser beam gets on the conical surface of the mirror. As a result, three pairs of laser beams with the opposite circular polarization are automatically produced inside the conical reflector as shown in the figure 1 (b), and atoms can be trapped.

In order to realize the conical MOT as a source of slow rubidium atoms, a small hole with a diameter about 1 mm is made at the apex of the reflector (Fig. 3 (c)). In this case, atoms are first captured in the trap and then pushed through the hole at the apex of the reflector due to the resulting imbalance in the intensity of laser radiation. A beam of laser-cooled atoms will be directed into the capture area of the fountain's main trap.

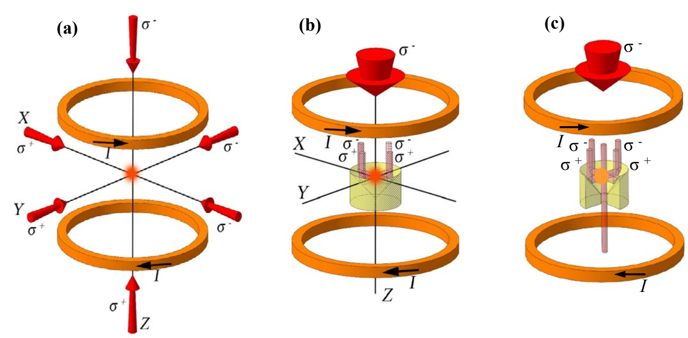


Fig. 1. Magneto-optical trap in a conventional configuration (a), in a conical configuration (b) and as a source of slow atoms (c).

MOTs in a conical configuration are more compact, less sensitive to mechanical influences and less demanding to vacuum optics than the previously used LVIS and 2D-MOT, while the fluxes of atoms in them are the same [3].

## III. Experimental setup

The figures 2 shows a 3D-model of the experimental setup. Our experimental setup consists of a rubidium atoms source, a conical mirror reflector in a vacuum chamber, a single laser beam, magnetic field produced by pair coils in anti-Helmholtz configuration, a video camera for visual inspection of an atomic cloud, a photodetector used to measure the main characteristics of an atomic beam.

The source of rubidium atoms is a glass ampoule with natural mixture of rubidium isotopes 87 and 85, placed in a thin-walled titanium cylinder. After reaching the operating pressure in the vacuum chamber, it is possible to crush the ampoule and flows of rubidium vapor get into the vacuum chamber of the MOT. In order for the flow of rubidium atoms to be directed towards the center of the trap, the source output into the chamber is designed as a multi-channel collimator. The rubidium source is equipped with a vacuum valve, and if necessary, the rubidium source is cut off from the trap.

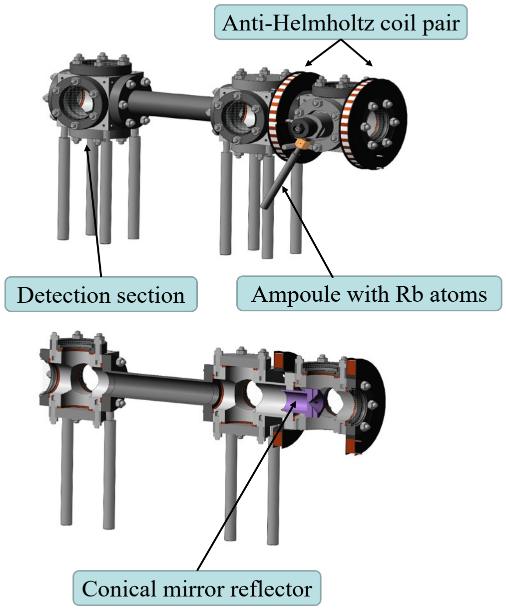


Fig. 2. 3D-model of the experimental setup.

Optical vacuum windows are designed for the introduction of laser radiation into the trap and visual observation of a cloud of atoms. The optical glass is made of fused quartz with an anti-reflective coating, applied on both sides at a wavelength of 780 nm. An ion pump with pumping rate of 75 l/s (N2) provides an ultra-high vacuum inside the experimental setup.

The quadrupole magnetic field for MOT with a gradient of approximately 7 G/cm is created by a pair of coils in the anti-Helmholtz configuration, whose axis coincides to the atomic beam. Two pairs of additional coils allow to control the cloud of trapped rubidium atoms.

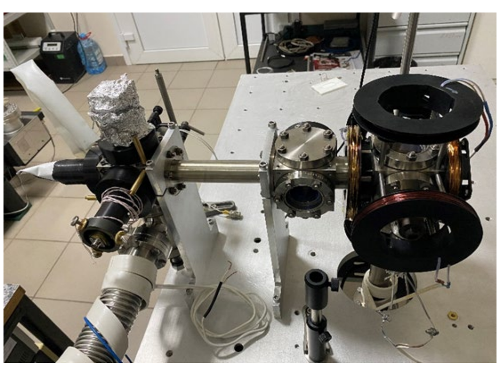

Fig. 3. The source of slow atoms.

The laser system includes two diode lasers: Toptica TA Pro, generating radiation for cooling and detection, and Toptica DL100 for repumping radiation. The frequency of laser radiation is stabilized through feedback by saturated absorption spectroscopy. Cooling and repumping laser beams were combined in an one polarization-maintaining optical fiber.

The diameter of the cone is 2 cm. The diameter of the incident laser beam in the MOT was 2 cm, so the whole surface of the conical mirror reflector is illuminated. Because of the four holes in the reflector (Fig. 4), the cloud of trapped atoms is observable and controllable.

During the experiment, a photodetector was mounted on the upper window of the detection section of the MOT. The detection beam, detuning at frequency from the resonance transition $5^2S_{1/2}$ F=2 → $5^2P_{3/2}$ F=3 $Rb^{87}$ at 140 kHz, passed through the transverse window of the detection section. Thereby detection laser beam was directed transversely through the atomic beam and detected on a photodiode.

A cloud of trapped rubidium atoms was obtained in the MOT and a fluorescence signal was registered in the detection section. A photo of a trapped rubidium atoms is presented in the figure 5.

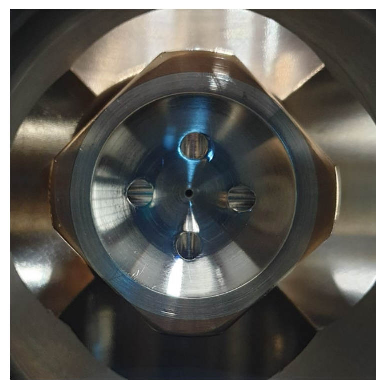

Fig. 4. The conical mirror reflector in a vacuum chamber. Because of the four holes in the reflector, the cloud of trapped atoms is observable and controllable.

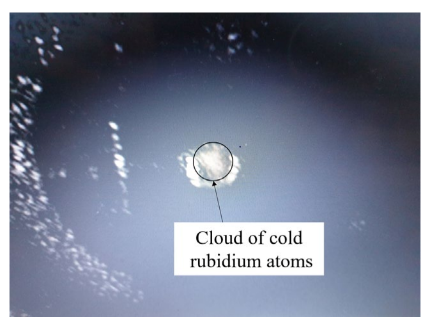


Fig. 5. The cloud of trapped rubidium atoms in the conical MOT.

## IV. Experimental results

The following experimental results were obtained: the dependences of the photodiode signal (which is proportional to the total flux of atoms) on the cooling detuning, on the cooling laser power and on the trap-loading time (Fig.6).

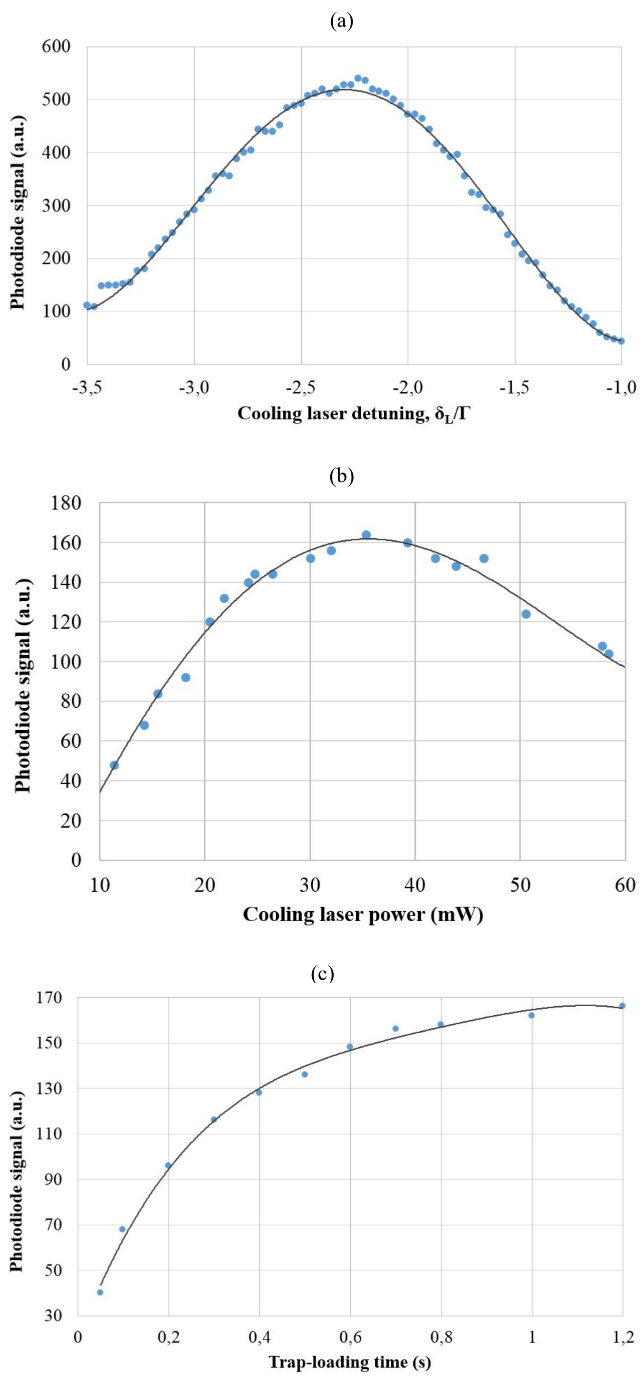


Fig. 6. The photodiode signal is proportional to the total flux of atoms. The dependences of the photodiode signal on the cooler laser (a), on the cooling laser power (b) and on the trap-loading time (c).

The highest flux of atoms was observed when the cooling light detuning was from -2,5 Γ to -2,0 Γ, that is consistent with the previously obtained experimental data [4]. The optimal cooling laser power turned out to be from 30 to 40 mW. The best value of the accumulation time was 0,5 -1 s. The mean velocity of atomic flux is $v_{mean}$ = 10,9 m/s.

## V. Conclusions

Due to its relative simplicity, controllability and compactness, a magneto-optical trap, using a single laser beam, realized in a conical configuration can become a useful tool for atomic fountains and other atomic sensors (for example, a gravimeter [5]). The main characteristics of the atomic beam were measured. The obtained results prove that the conical MOT can be successfully used on the atomic rubidium fountains. In the future, we want to continue researching the conical MOT and try to use it for the atomic rubidium fountain.

## References

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