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Beam Directivity and Eficiency of Recirculating Oven Using Cylindrical Collimator for Cesum Beam Frequency Standard

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Abstract

We have made a new type of recirculating oven for a cesium beam frequency standard, which consists of a cylindrical graphite tube, a nichrome heater and thermoelectric cooling module. The beam characteristic was investigated by the theoretical calculation using beam orbit simulation. Then sufficient results such as the beam efficiency of 2.5 % and the beam directivity of 2.5 degree were obtained.

Keyword : recirculating oven, collimator, beam directivity, beam efficiency, frequency standard

1. Introduction

A vertical type of cesium beam experimental frequency standard has been under construction at Kinki University[1] to develop new basic technology to obtain the accuracy of 7×10^{-15} which is 1 order better than that of traditional one[2][3]. In Fig. 1 the structure of beam tube is shown. Since 1994, preliminary experiments have been conducted such as vacuum test of the beam tube, measurements of magnetic field characteristic of the solenoid coil inside of 4 magnetic shields, Ramsey cavity, and manufacturing and measurement of 4-pole electrical magnet and recycle oven, as shown in Fig. 1.

In this paper a new design and the beam characteristic of recycle oven is reported.

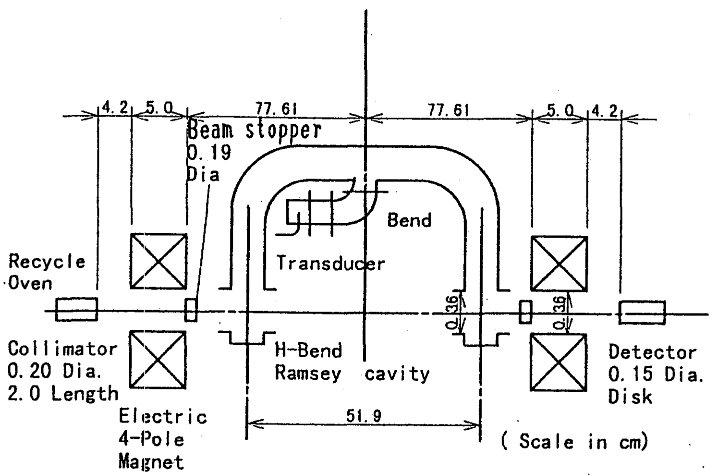

Fig. 1 Structure of beam tube in a vertical cesium beam experimental frequency standard.

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2. Structure of collimator

The recycle oven in cesium beam primary frequency standard NIST- 7 at National Institute of Standard and Technology was recently reported by R. E. Drullinger et al. and they obtained about 2 order improvement in beam directivity efficiency. Their recycle oven consists of porous metal collimator which is cooled to decrease the evaporation of adhesive cesium metal from the inner cylindrical surface. The evaporated cesium metal in oven cell oozes from the collimator wall of oven cell, because the structure of collimator is not cylindrical like usual one from which passes the evaporated cesium metal from oven cell side[4]. In our case, as the structure of collimator a cylindrical tube was adopted, because the usual type collimator output of about 0.5 mm diameter had been stopped up occasionally. For the material for absorption tube, hard graphite is used, which may not become soggy and would not stop up the collimator tube after absorption of cesium metal in vacuum. It is easy to cut and disposable, too. Figur. 2 shows the structure of recirculating oven with the local temperatures of collimator input and output for calculation.

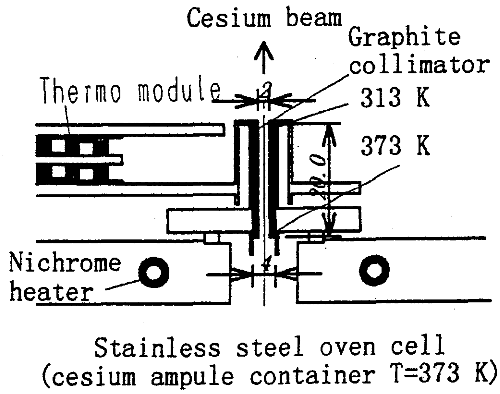

Fig. 2 Structure of recirculating oven.

3. Calculation method

As shown in Fig. 3 a number of emitted cesium atom dN from a small area dS to a small solid angle $d\omega$ is

$$dN = \frac{1}{4} nvdS \quad \cdots (1),$$

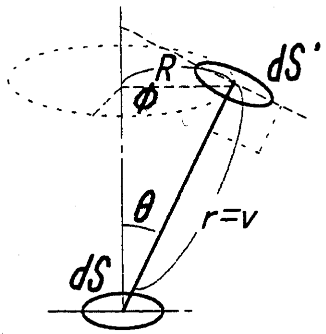

Fig. 3 Beam emission from a small area *dS* to a small area *dS'*.

where *n, v* are the density and the velocity of the atom, respectively, and combined with the velocity distribution function. Then an angle *dS'* of the small area *dS* from the normal of the small area dS can be written as

$$dN = \frac{1}{4\pi} nv \cos\theta \, d\omega dS \qquad \cdots \cdot (2),$$

where $d\omega$ is related with distance r and *dS'* in Fig. 3 as follows

$$d\omega = \frac{dS'}{r^2} = \sin\theta \cdot d\theta \, d\phi \qquad \cdots \cdot (3).$$

Then *dN* is given by substituting equation (3) into equation (2) as follows

$$dn = \frac{1}{4\pi} nv \cos\theta \sin\theta \, d\theta \, d\phi \, dS \qquad \cdots (4).$$

The beam intensity from the collimator input or inner surface to the output for any angle (arbitrary beam orbit) can be numerically calculated by this equation. It is assumed that the density *n* of the inner surface of cylindrical collimator is decided by the saturated vapor pressure of cesium atom absorbed on the surface and that the pressure depends upon the surface temperature.

As shown in Fig. 2, the set temperatures at the collimator input and output are 373 K and 313 K, respectively; therefore the temperature linear gradient promotes the absorbed cesium metal on the wall of collimator to pass through the inside of graphite for recycling to oven cell.

4. Results of calculation

The beam orbit simulation using the above-mentioned equations clarified the beam characteristic about collimator directivity, recycling number of atom, and beam efficiency which depend upon the collimator length and the temperature of the oven cell and the collimator.

Figure 4 shows the beam directivity of the collimator by changing the temperature at collimator output. The intensity in a vertical line means the density of atom number/s/sr. The beam directivity width, which is defined to be half intensity angle, is 2.5 degree at 315 K. It means the improvement of 1/12 in directivity on comparing with that of the traditional collimator. The improvement of number will be described later.

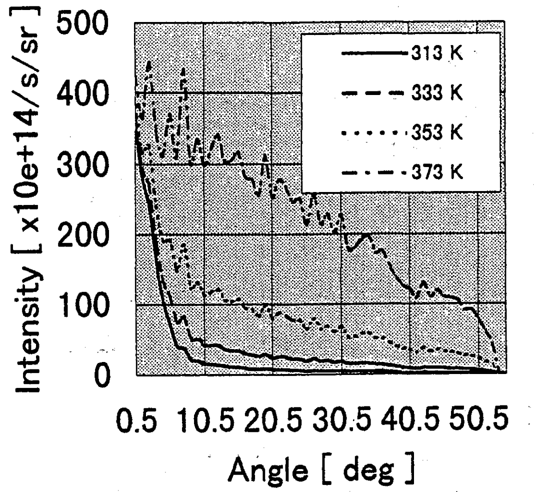

Fig. 4 Beam directivity of 2 cm collimator for different collimator end temperatures.

In Fig. 5 we compared the number of atom passing through collimator tube with that of evaporated atom from the inner surface of collimator. As described later in detail, the number of atom from the inner surface is 1/5 on comparing with that of the direct atom through collimator. It means that the atoms from the surface expands from the collimator output and is almost useless as beam.

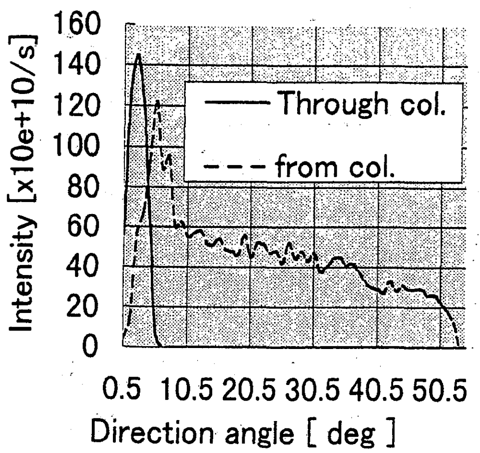

Fig. 5 Directivity of beam through collimator and from inner surface of collimator.

Figure 6 shows the input and output characteristic on temperature dependence in recyculating oven. The input temperature is constant 373 K, though the output temperature is changed. The number of back atom is big, because the inner surface near the input is at high temperature. As the inner suface temperature becomes higher, the number of absorbed atom into garaphite increases and finally becomes minus. This indicates that the number of evaporated atom increases greatly at high temperature and an anti recycling phenomena occurs.

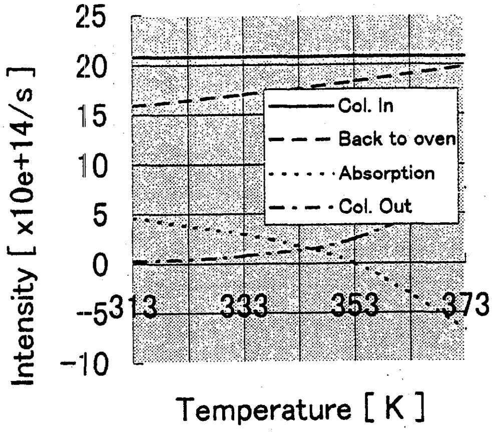

Fig. 6 Recycle oven characteristic : input to collimator, back to oven cell, absorption of collimator inner surface and output from collimator depend upon collimator end temperature.

Figure 7 shows the characteristic on beam intensity in case of the output constant temperature for different collimator lengths. The shorter length of collimator effect is good in conductance.

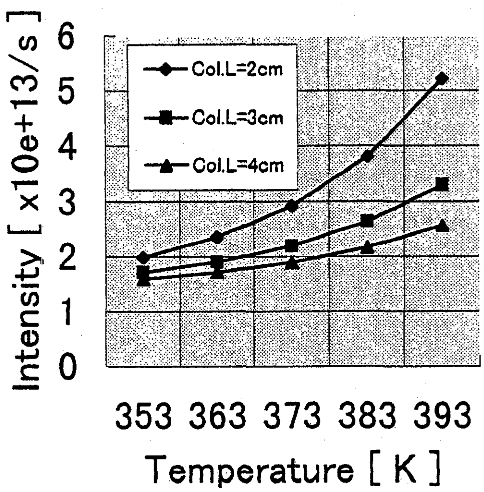

Fig. 7 Collimator out beam depend upon oven cell temperature at collimator end temperature 313 K.

In Fig. 8 we investigated the number of atom into the magnet, which contributes as beam for the frequency standard. It showed no dependence on length, as expected. We calculate atoms passing through the ring area of 0.95-1.8 mm at constant distance 6.2 cm from the collimator input to the ring area which locates at the middle position of the magnet. In case of temperature 393 K and collimator length 4 cm, 80 % of the atoms go through the collimator tube without collision, since the mean free pass is 8.8 cm in the case.

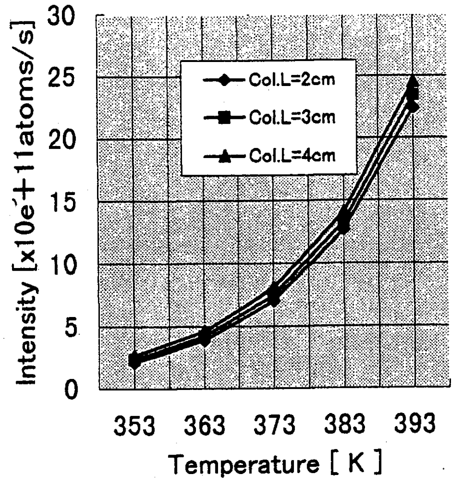

Fig. 8 Beam to magnet depend upon oven cell temperature at collimator out end temperature 313 K.

In Fig. 9 we investigate the beam efficiency which means the ratio of the number of the above-mentioned beam to magnet and that of collimator output. In case of the collimator of 4 cm length the beam efficiency becomes 4 % which means 16 times improvement by recycling on comparing with that of traditional one.

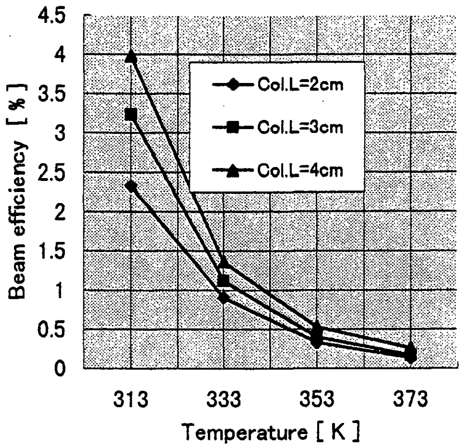

Fig. 9 Beam efficiency (beam to magnet/collimator output beam) depend upon the temperature of collimator output end at oven cell temperature 313 K.

5. Conclusion

We manufactured the recyculating oven with a graphite collimator whose output temperature showed 331 K due to the thermal conductance from the collimator input of temperature 373 K. In future we may improve the temperature resistance between the input and output of collimator.

In calculation we showed beam directivity 2.5 % and beam efficiency 2.5 % for the collimator in Fig. 2. If we would set the temperature of oven cell from 373 K to 393 K and collimator length from 2 cm to 4 cm, the beam intensity could increase 4 times and the collimator output beam may decrease until 50 %. In this case the beam efficiency can be 4 %, which means 16 times improvement by recycling.

Acknowledgement

I would like to express the researchers who gave us useful discussion and comments on this work, especially to Mr. T. Morikawa, and Dr. R. E. Drullinger who sent to the author the valuable data on his recyculating oven and many comments.

References

(1) Koji Nakagiri, Jun Umezu, Yasusada Ohta, Masatoshi Kajita, Noboru Kotake, Takao Morikawa (1995) Design and Preliminary Results of a Vertical Cesium Beam Frequency Standard Proc. 5 th Symp. Freq. Stand. Metro., (World Scientific 1996) Woods Hall USA, Oct. 15-19, 1995, 417-418

(2) Koji. Nakagiri, Masaaki. Shibuki, Masatoshi. Kajita, Noboru. Kotake and Kouichi. Sebata (1991) CESIUM FREQUENCY BEAM FREQUENCY STANDARD, Journal of Communication Research Laboratory, Vol.39, No. 1, 23-41.

(3) Koji. Nakagiri, Masaaki Shibuki, Haruo Okazawa, J. Umezu, Y. asusada Ohta, and Haruo Saitho (1987) STUDIES ON THE ACCURATE EVALUATION OF THE RRL PRIMARY CESIUM BEAM FREQUENCY STANDARD, IEEE Trans. Instrum. Meas., Vol. S, IM-36, 617-619.

(4) R.E.Drullinger, D. J. Glaze and D. B. Sullivan (1985) A RESERCULATING OVEN FOR ATOMIC BEAM FREQUENCY STANDARDS *Proc. 39th Symp. Freq. Cont., Philadelphia,* 1985 (IEEE, Piscataway) 13-17.

和文抄録

セシウムビーム周波数標準器用円筒コリメータ使用リサイクル原子源のビーム指向性と効率

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近畿大学で従来型のセシウムビーム一次周波数標準器の確度を一桁近く改善する基礎技術確立を目指して、「垂直型セシウムビーム周波数標準実験器」を開発している。1994年以来、真空予備排気、静磁場の特性測定、4極電気磁石の製作及び特性測定、リサイクル原子源の製作、ライゼムイ共振器の製作実験等を実施している。

リサイクル原子源の周波数標準器での採用は、米国標準技術研究所のNIST-7の例があり好結果を得ている。我々のリサイクル原子源はこれを参考に設計したが、普通のコリメータで径が0.5mm位で小さい場合、ビームが出口の穴を塞ぎ出てこなくなることを経験しているのでNIST-7のようにしみだした原子をコリメータ内で通過させるのでなく、穴の開いたコリメータを通してその内壁に付着した原子をリサイクルさせることにした。

このコリメータ材としては、取り扱いが容易なグラファイトをまず試験する。どの程度の穴の径で、どれ位の硬さのグラファイト材料が、この方式で有効か実験で明らかにする必要がある。グラファイトは吸着特性が優れ加工、使用後の交換が容易であり、経費節約ができるなどの利点がある。しかし、セシウム金属を吸着した後空気にさらして水分を吸収するとふやけて穴を塞ぐ危険性がある。このため、硬いグラファイトを用いてできるだけ空気にさらさないようにする。

上記のリサイクル原子源を製作し、コリメータ入り口側の温度373Kのとき、出口側の温度331Kを熱電素子1段で得た。また、シミュレーション計算により、製作したリサイクル原子源と今後の改善、運用により期待される特性を明らかにした。

製作した直径2mm、長さ20mmのコリメータで入り口の温度373K、出口の温度313Kの場合、ビーム指向性を1/12に改善する。コリメータ温度を373Kから20K上昇させることによりビーム強度を4倍にすることができる。そして、コリメータの長さを2倍の4cmにすることにより外に出る原子を1/2に減少でき、周波数標準器の周波数安定度を約2倍弱改善できる。この場合ビーム効率は4％となり、リサイクルによるビーム改善度は16倍となる。