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A FAST CAM DRIVEN ABSORPTION CELL BASED ROCKET-BORNE NITRIC OXIDE DETECTOR

P. Muralikrishna
Instituto Nacional de Pesquisas Espaciais - INPE/MCT
C.P. 515, 12201-970, São José dos Campos, SP, Brazil
and
Ednilson Bassani
Escola de Engenharia Industrial
São José dos Campos, SP, Brazil

ABSTRACT

A nitric oxide(NO) detector, making use of a newly developed fast cam-driven absorption cell system is developed for launch on board a Brazilian SONDA III rocket, to measure the height profile of the NO gamma band dayglow emission intensity and thereby to estimate the height profile of the number density of atmospheric NO in the equatorial region. Two absorption cells, one of them containing the gas NO and the other nitrogen are brought in front of the photocathode of a photomultiplier(PM) tube alternately using a cam system. Each cell remains in front of the PM tube for an interval of time fixed by the cam shape. The cam is designed to optimize the time needed for positioning the cells one after the other and also to simplify the operation of the step motor responsible for the movement of the absorption cells. The advantages of this new system over the conventional wheel mounting are also presented.

1. INTRODUCTION

The gamma band dayglow arises from resonance fluorescence of atmospheric NO by solar MUV radiation. The brightest emission band is the (1,0) band near 214.8nm which has an apparent emission rate exceeding 1kR at the base of the mesosphere. Tohmatsu and Iwagami (1975, 1976) developed a rocket-borne nitric oxide self absorption cell for determining the height profile of nitric oxide in the earth's atmosphere, by measuring the intensity of some of the gamma band emission lines from NO. Their NO self-absorption cell makes use of the self absorption effect of NO gas contained in a quartz cell. This cell also acts as a sharp rejection filter for discriminating the gamma band emissions from a continuous background. Two identical quartz cells, one containing NO gas and the other some other gas like nitrogen are alternately brought in front of the photocathode of a properly selected photomultiplier tube and the difference in the flux collected by the PM tube can be used in estimating the gamma band intensity profile from which the height profile of the NO number density can be determined.

An absorption cell system similar to the one used by Tohmatsu and Iwagami (1975, 1976) has been developed by the authors for launch on board a Brazilian SONDA III rocket. A new cam system positions the two quartz cells in front of the photocathode of a Hamamatsu head-on type R431S solar-blind photomultiplier tube. This replaces the conventional mounting of the cells on a rotating wheel whose rotation is generally controlled by a step motor. General features of the NO detector, the basic concepts on which the cam design is based and its advantages over the conventional system are presented here.

2. EXPERIMENT DETAILS

Block diagram of the NO detector is shown schematically in Figure 1. The fore-optics consists of a solar baffle-honeycomb collimator to prevent stray light from falling on the photocathode of the PM tube and to restrict the field of view of the photometer, a narrow band interference filter and a pair of absorption cells with quartz windows, one of which contains NO gas and the other nitrogen both at a pressure of about 100 torr. The collimator, that does not contain any optical component other than a honeycomb view-limiter has an overall length of 120mm and a diameter of 38mm. The honeycomb view-limiter mounted inside the collimator close to the PM tube, is made up of cylindrical tubes of about 3mm diameter and 35mm length providing a circular view cone of about 10o. The interference filter has a pass band of 20nm centered at 214nm with a transmission factor of above 18% in the pass band. The filter pass band includes the atmospheric NO gamma band fluorescent emission lines. The metallic absorption cells, cylindrical in shape, are 35mm long and 30mm in diameter and are provided with quartz optical flats of 25mm diameter and 1.3mm thickness at the entrance and exit windows. One of the cells is filled with NO and the other with nitrogen. While the NO gamma band emission lines produced by transitions between vibrationally excited states and the zero level of NO molecules (see Tohmatsu and Iwagami, 1976) are absorbed by the NO gas in one of the quartz cells, the incident radiation passes practically unaffected through the other cell containing nitrogen gas. The radiation transmitted by either of the cells falls on the photocathode of a PM tube where it is converted into an electrical signal. The PM tube used is Hamamatsu R431S head-on type, has a Cs-Te photocathode that is solar blind and has a spectral response in the range of 160nm-320nm. It has a photocathode of 25mm useful diameter with maximum response at 210nm. The output signal from the PM tube, in the form of pulses with amplitudes proportional to the number of photons incident on the photocathode, is amplified, processed in a data acquisition unit and then transmitted to the ground station by the on board telemetry system. In principle the difference in the intensity of the signals transmitted by the two absorption cells is a measure of the intensity of the NO gamma band emission lines absorbed by the NO cell. The movement of the two absorption cells in front of the PM tube is controlled by a cam system driven by a 180rpm, 7.5o/step step motor . The advantages of such a system over the conventional wheel mounting will be discussed later.

As mentioned earlier, the expected output from the PM tube is a sequence of short period pulses with an inter-pulse period equal to the dwell period of each absorption cell in front of the PM tube. Amplitude of each pulse is a measure of the integrated number of photons falling on the photocathode of the PM tube through the filter-absorption cell combination. For the purpose of analysis two consecutive pulses in the pulse sequence are to be considered at a time. The amplitude of one of them is proportional to the integrated photon flux received through the NO cell and that of the other is proportional to the integrated flux received through the nitrogen cell. Knowing the spectral response and other optical characteristics of the detector from laboratory calibrations one can estimate the integrated intensity of the NO gamma band emission lines absorbed by the NO cell. The NO number density profile can then be deduced from the height profile of these NO gamma band emission lines. The basic principle of operation of a detector of this type along with relevant theoretical aspects are given in Tohmatsu and Iwagami(1976).

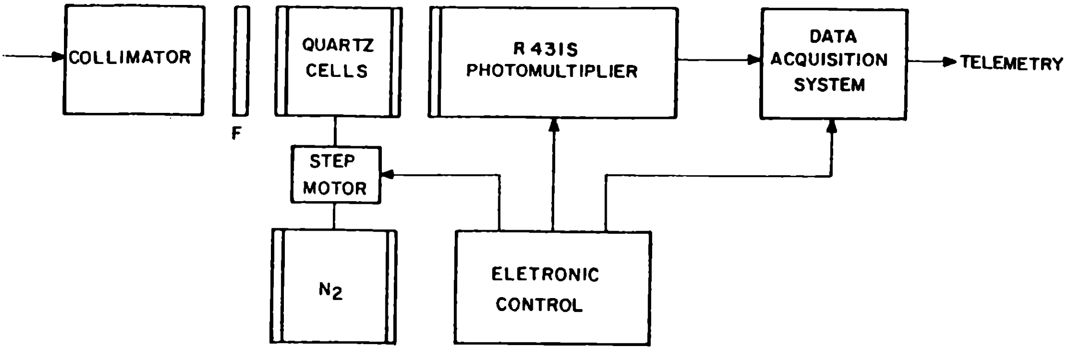

Figure 1. *Block diagram of the rocket-borne nitric oxide detector showing the important subsystems.*

Mechanical details of the NO detector are shown in Figure 2. The most important innovation in the present system is in the mounting of the two quartz cells in front of the PM tube. Unlike the case of the conventional wheel mounting, in the present system the two cells are mounted on a disc close to each other and the movement of the disc is controlled by a cam system (Figure 3). This disc undergoes an oscillatory motion bringing the two cells alternately in front of the photocathode of the PM tube for a predetermined time interval. This oscillatory motion of the disc is produced by the cam coupled to the disc by a shaft. The cam rotates around its own axis. The profile of the cam is chosen in such a way as to keep either of the cells in front of the PM tube for a fixed and equal duration of time, the transfer times from one cell to the other also being equal.

The most important aspects taken into consideration in designing the cam profile are the following.

(1) The period for which each cell remains in front of the tube must be about 30 ms.

(2) The transfer time from one cell to the other must be as short as as possible.

(3) The motor responsible for the movement of the cells should not be subjected to excessive torques. This can be achieved only by increasing the transfer time of the cells and by selecting a smooth curve for the transfer part of the cam profile.

From the above considerations, a constant speed of 180 rotations per second is chosen for the cam. The cam profile is chosen to bring each of the cells in front of the PM tube three times during every rotation. This gives rise to the following sequence of events, the time of the first event being chosen arbitrarily.

(1) NO cell is in front of the photocathode of the PM tube for about 28ms.

(2) The NO cell is replaced by the nitrogen cell in about 28ms.

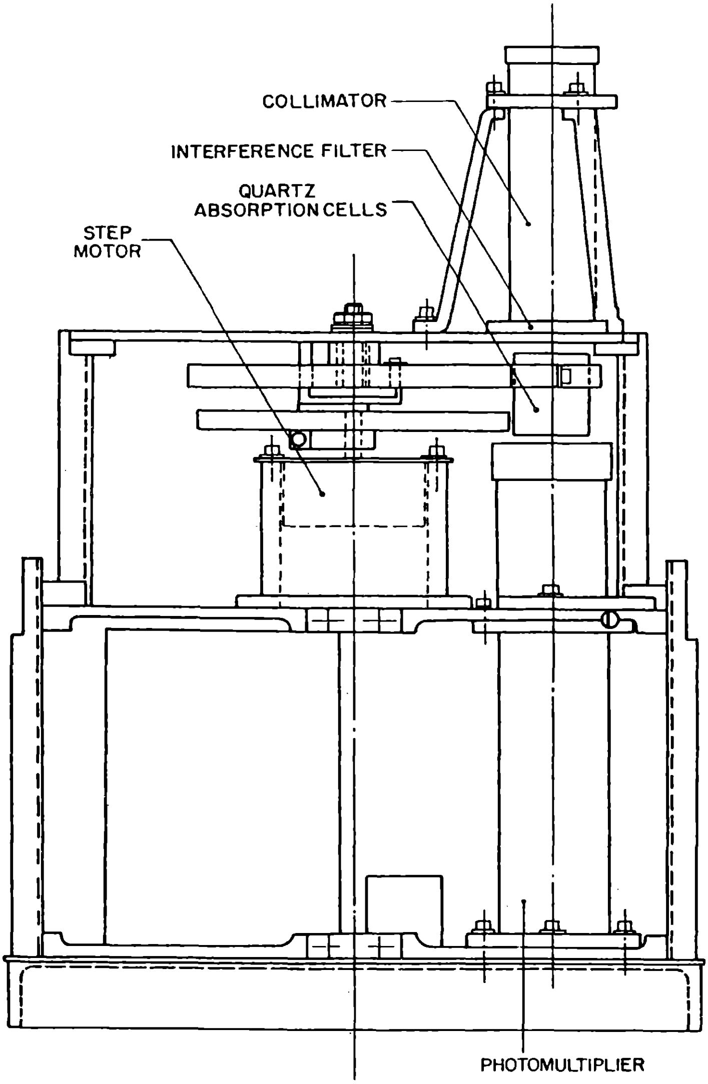

Figure 2. *Mechanical design drawing showing the mounting of the mechanical components including the cam system on the payload segment of a SONDA III rocket.*

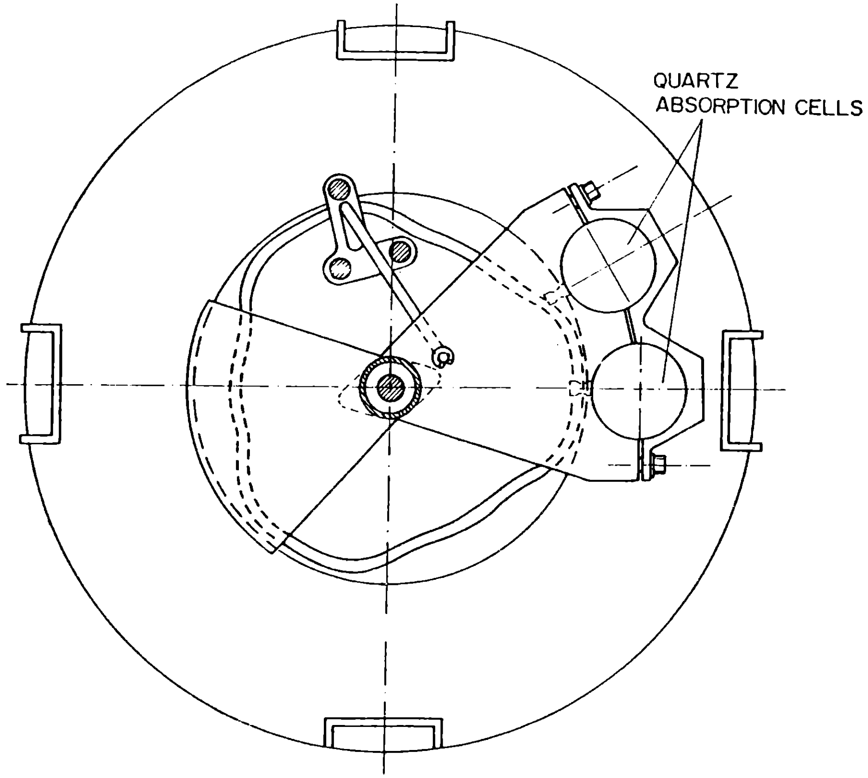

Figure 3. *Schematic representation of the cam system showing the cam profile and the shaft that moves the disc on which the two quartz cells are mounted.*

(3) The nitrogen cell is in front of the photocathode of the PM tube for about 28ms.
(4) The nitrogen cell is replaced by the NO cell in about 28ms.
(5) The sequence starts over again with Event (1).

3. CAM PROFILE

Shown in Figure 4. is a linear plot of the cam profile for one full rotation of the rotor. The profile segment that controls the movement of the shaft and the disc is chosen as shown below.

- Segments A, E and I are circular with 50mm radius and represent angular segments of the rotor corresponding to say θ = 0-30°, 120°-150° and 240°-270° respectively. The circular segment causes the corresponding cell to remain fixed in front of the PM tube.
- Segments C, G and K are also circular with 60mm radius and represent angular segments of the rotor corresponding to θ = 60°-90°, 180°-210° and 300°-330° respectively.

- Segments B, D, F, H, J and L are cycloidal in shape governed by the basic equation,

$$y = \frac{10}{\pi}\left[\frac{\pi\varphi}{30} - \frac{1}{2}\sin\frac{\pi\varphi}{15}\right]$$

where y is the displacement in millimeters to be added to 50mm in the case of segments B, F and J and to be subtracted from 60mm in the case of segments D, H and L. φ is the angular variation from 0 to 30°.

It should be mentioned here that the cycloidal part of the cam profile was selected after analysing the mechanical performance characteristics of various other types of curves. The major advantage of the cycloid is the smooth variation of the gradient along it from one point to another. The gradient is what decides the variation in the motor torque needed for the movement of the shaft along the cam profile. Thus a smooth variation in the gradient guarantees smooth variation in the motor torque.

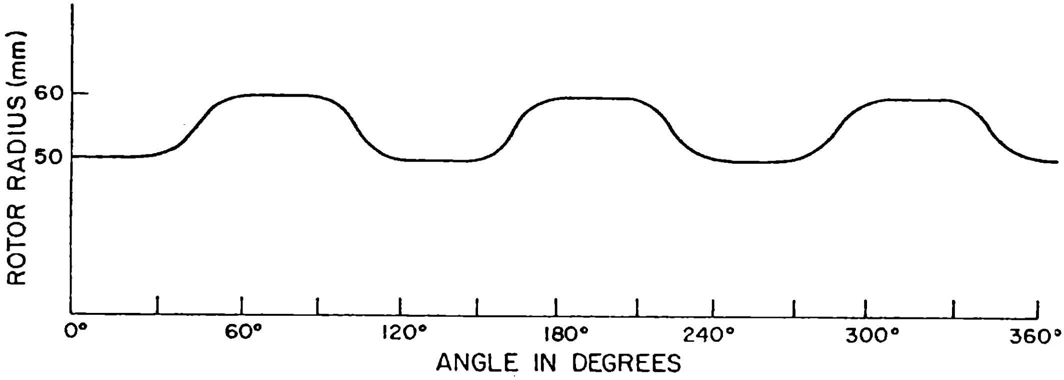

Figure 4. *Linear plot of the cam profile.*

4. ADVANTAGES OF THE CAM SYSTEM

Several problems associated with the conventional wheel mounting of the cells can be resolved by the introduction of the cam drive. Some of the advantages of this new system are the following.

(1) The cam system avoids jerky mechanical movements of the motor as well as the mount wheel of the cells. In the new system the motor rotates continuously.

(2) The cycloidal transfer profile chosen for the replacement of one cell by the other guarantees a smooth transfer and thus maintains practically a constant torque for the motor during the whole operation period. In the conventional wheel mount the motor experiences sudden changes in the load and hence has to operate with a highly nonuniform torque.

(3) The cam system guarantees alignment of the cells in front of the optical system while the conventional wheel mounting necessitates additional monitoring of the alignment.
(4) With the new system one can reduce the measurement period with each cell without increasing the motor rotation rate. For example, in the present case, for each rotation of the cam the absorption cells are changed three times. In the conventional wheel mount the cells are changed only once during every rotation of the wheel.
(5) Either a step motor or a continuous motor can be employed to drive the cam system.
(6) Cell or calibration source movements can be programmed in advance by proper choice of the cam rotor profile. The order in which each one of them should align with the optical system can also be easily programmed.
(7) Compared with the conventional wheel mounting the new cam system is more compact and thus occupies less physical space.

Advantage (4) above of the new cam-driven system implies possibilities to obtain better height resolution for the measurements. In the experiments reported by Tohmatsu and Iwagami(1975, 1976) a pair of data points, one with the NO cell and the other with the nitrogen cell was obtained in more than 1.6s, 0.8s being the time period for which each cell was in front of the PM tube. Such a system, when used on board a rocket moving with a velocity of 2km/s in the height region of interest will represent a height resolution of 3.2km. The new cam-driven system gives a pair of data points in 112ms thereby reducing the height resolution to less than 250m. However one must remember here that the sensitivity of the PM tube puts a lower limit on the height resolution that can be achieved. Since the cam-driven system changes the cells in front of the PM tube at least three times faster (for each cam rotation the cells are changed three times while in the conventional wheel mount the cells are changed only once for each rotation of the wheel) than the conventional system and therefore gives a height resolution at least 3 times better than the conventional system.

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