First Direct Observation of the Dust-Trapping Phenomenon

Dust trapping has long been an unwelcome and mysterious phenomenon in electron storage rings; it leads to a sudden decrease in beam lifetime. At the Photon Factory Advanced Ring (PF-AR), dust trapping has been a perpetual nuisance to synchrotron radiation experiments since their beginning in the 1980s. However, during recent research on dust trapping at the PF-AR, video cameras serendipitously captured the culprit behind this phenomenon; the cameras recorded a luminous micro-particle trapped in the beam, just as if a shooting star were traveling in the beam tube (Fig. 1). The research was conducted by a team of three scientists at the Accelerator Laboratory, and the paper reporting their remarkable discovery [1] was selected for the October 26 issue of Physical Review Focus [2].

The reported finding is the first time that dust-trapping phenomenon has been directly observed since the dust-trapping hypothesis was proposed nearly 30 years ago [3]. Thus far, the existence of trapped dust had been only indirectly documented by the detection of bremsstrahlung gamma-rays emitted as a result of the interaction between dust and electron beams [4]. The trapped dust was observed while the abovementioned team was conducting an experimental study using a unique device (Figs. 2 and 3) that was designed to trigger dust trapping by means of intentional electric discharges. The team persisted with the electric discharges as dust sources because their careful investigation during user operations at PF-AR had strongly suggested that electric discharges often caused dust trapping. The primary purpose of the experimental study was to demonstrate that the electric discharges triggered the dust trapping, and the video cameras were originally intended to obtain visual evidence of electric discharges. In the early stages of the study, the purpose was accomplished; it was experimentally confirmed that two kinds of electric discharges, namely, the discharges generated by an applied high DC voltage and that generated by strong beam-induced fields triggered dust trapping.

In addition, and highly importantly, the movies recorded by the video cameras during the memorable experiment presented some useful information about dust trapping. The dust was observed to move longitudinally along the beam orbit at an estimated speed of 10 m/s or more. Moreover, theoretical considerations regarding the cause of the light emission from the dust concluded that thermal radiation emitted from the trapped dust could be strong enough to be detected by standard video cameras if its temperature was 1200 K or higher. In fact, it had been theoretically predicted that trapped dust could acquire a high temperature (e.g., nearly 1800 K for titanium) as a result of the ionization energy deposited on the dust through its interaction with the electron beams [5]. The trapped dust, therefore, must have a high thermal strength.

The PF-AR stores a 6.5-GeV and 60-mA electron beam in a single bunch mode. Typically, the transverse bunch size is 1.5 mm in the horizontal and 0.15 mm in the vertical, and the longitudinal bunch length is 20 mm. The estimated size of trapped dust ranged from submicrons to several microns.

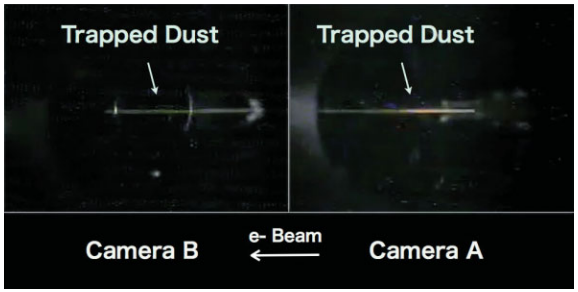

Figure 1
Snap shot from movies captured by two video cameras during the experiment in which trapped dust was first observed. The original movie is available on the web [2].

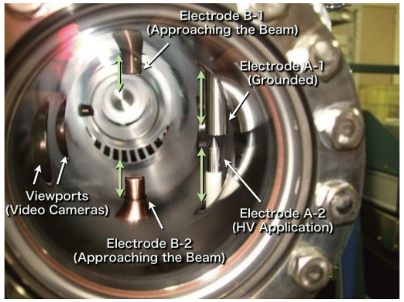

Figure 2
Interior view of discharge device. Two pairs of the electrodes are remotely controlled to provoke intentional electric discharges.

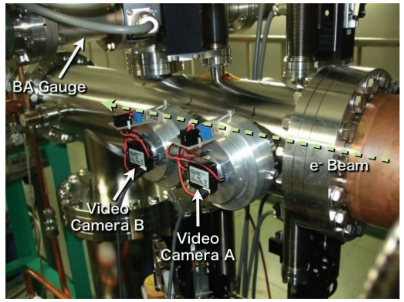

Figure 3
Exterior view of discharge device. Video cameras A and B detect electric discharges at electrodes A and B, respectively.

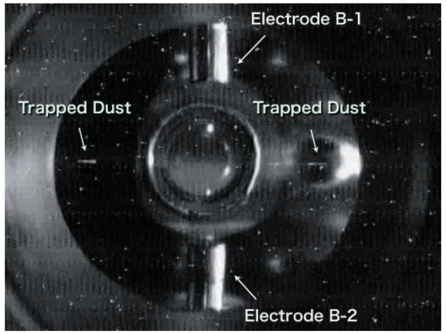

Figure 4
Snap shot from movie captured by supersensitive camera, illustrating that at least two dust particles were simultaneously trapped by the beam. The interspersed white dots are noises due to radiation.

Since the direct observation of dust trapping was found to be an effective and promising method for elucidating dust trapping, the team improved the sensitivity of the cameras so as to observe trapped dust particles of smaller size or at lower temperatures. The new cameras were approximately three orders of magnitude more sensitive than the previous standard cameras.

As was expected, the supersensitive cameras caught images of trapped dust particles more frequently and revealed that the dust particles could stay in a same position for a long time. Further, it was found that multiple particles could be trapped simultaneously (Fig. 4). For a complete understanding of the dust-trapping phenomenon, it will be necessary to perform more detailed experiments and calculations. However, by carrying out direct observations of dust trapping, the team has paved the way for more comprehensive research on the causes behind the sudden decrease in beam lifetimes.

REFERENCES

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