

Variation of the Circumference in a Storage Ring and Expansion of the Building

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Abstract

The Photon Factory storage ring was found to diurnally vary its size along the circumference and the major axis of the ring ellipse. Both circumference and major axis were measured and compared with a model simulation. The measurement told the ring was uniformly expanded, while the simulation told the ring was rather elongated.

1. INTRODUCTION

Performance of a synchrotron radiation facility depends greatly on its beam position stability. At the Photon Factory, beam position stability became disturbingly aggravated for most experimenters when a lower emittance beam was introduced in order to gain a higher brilliance. Beam positions at many beamlines moved diurnally with large amplitudes in both horizontal and vertical directions. Such behavior of beam movement led us to postulate that the storage ring building was thermally distorted due to either solar irradiation or atmospheric heat, causing the building floor to be displaced. To reduce such building distortion, the rooftop was covered with an insulation layer of polyethrene.

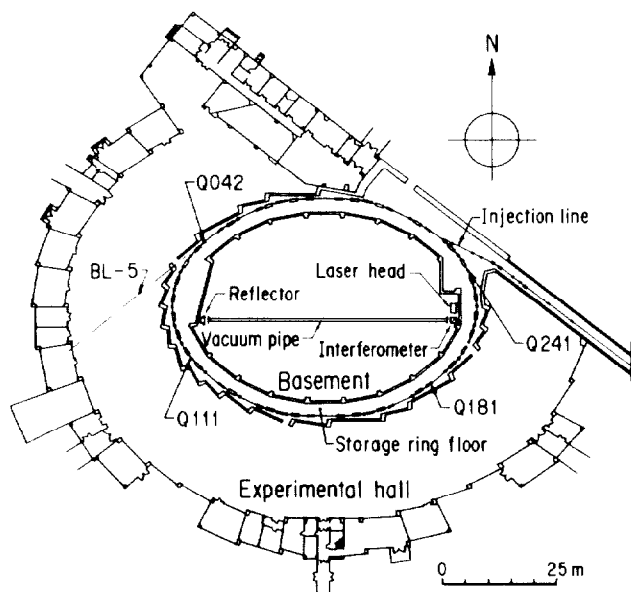


Figure 1. Storage ring building enclosing the ring, and beam lines (not shown) in the experimental hall. A laser interferometer was installed to measure the major axis length across the ring. Some quadrupoles, e.g., Q042 are shown as location reference.

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Before and after the roof insulation, the vertical floor displacement was measured by employing a hydrostatic level measuring system. It was shown that the insulation was effective to reduce the displacement to one third. Also, the building distortion was analyzed by using a computer simulation model. The simulation yielded about the same amount of floor displacement as that measured and proved that the building was distorted under thermal stress [1].

To evaluate the horizontal floor displacement, the following study has been made. First, the ring circumference variation has been measured as the amount of the RF frequency variation to minimize the closed orbit distortion (COD) [2]. The circumference variation thus obtained can, however, provide only the averaged floor distortion. Then, the major axis length of the ring ellipse has been measured with a laser interferometer in order to know unevenly distorted shape of the ring. These measured results of the circumference and the major axis are compared with those computed from a model simulation similar to that introduced previously. Only the case after insulation has been treated below.

2. MEASUREMENT

2.1 Data Taking

Figure 1 shows the plan view of the storage ring building enclosing the ring and the experimental hall where more than 20 beamlines are in operation. The ring is an ellipse with its major axis of about 68 m, minor axis of about 50 m and circumference of 187 m.

The major axis length was measured by using a laser interferometer system since October 91 [3]. The layout of the system is also shown in the figure. A laser beam horizontally emitted from the laser head traveled at the same height as the ring. After going through a vacuum pipe, it reflected back from the reflector placed at the other end of the major axis. The system's resolution was 0.1 μm . The vacuum pressure was kept lower than 10^{-3} Torr. The measurement error was estimated to be less than several microns by taking into account the influence of the air occupying between the optical components and the quartz windows of the vacuum pipe.

The variation in the ring circumference was evaluated from the amount of RF frequency variation obtained from a horizontal orbit feedback system [4], which corrected the dispersion-related orbit distortion. The relation between the RF frequency and the circumference is given by

$$\Delta C = -C \Delta f_{RF} / f_{RF},$$

where C is the ring circumference and f_{RF} is the RF frequency with a design value of 500.1 MHz. The feedback system took COD data every 30 minutes and corrected the RF frequency.

Along with the measurements of the circumference and the major axis, temperature variations were measured every 5 minutes on the rooftop, the ceiling, the ring tunnel floor, the experimental floor and in the atmosphere. After the insulation was applied on the rooftop, the temperature variations were reduced from 21°C to 3°C on the rooftop and from 6°C to 1°C beneath it when the atmospheric temperature variation was about 10°C. These temperature data were provided for the computer simulation.

2.2 Data Analysis

The present analysis used a set of data taken on December 7, 1991. Figure 2 shows there was a strong correlation between the atmospheric temperature and the major axis. The major axis varied about 68 μm , reaching its minimum around 8:00 and maximum around 16:00, while the atmospheric temperature varied about 10°C with its minimum at 7:00 and maximum at 15:00. Both maximum and minimum points for the major axis came one hour later with respect to those for the atmospheric temperature.

In the figure, the f_{RF} is shown to be similarly correlated to the atmospheric temperature. As the temperature rose, the RF frequency decreased, indicating the ring circumference was expanded.

3. SIMULATION

A computer simulation was carried out to evaluate building distortion due to thermal stress. The model was based on the finite element method, by which a static solution of the building distortion was obtained at every hour of the day for a given set of temperature distribution.

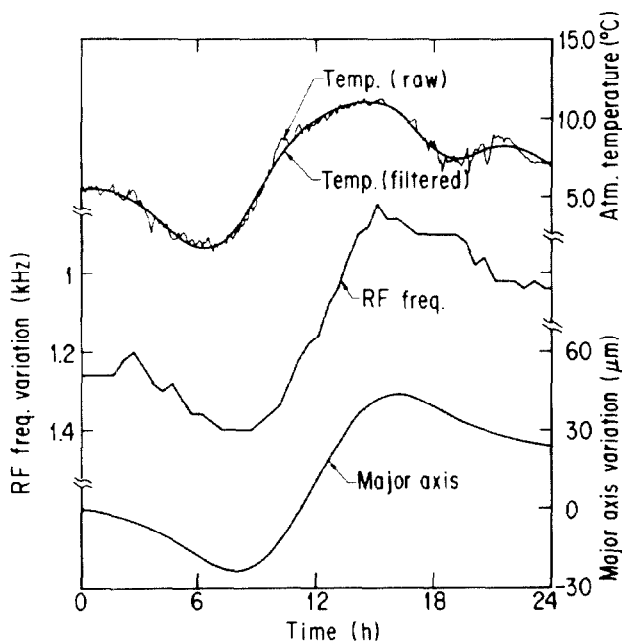


Figure 2. Variations of the RF frequency, the major axis length and the atmospheric temperature. A smoother curve of the temperature is attached in order to show its slowly varying components of data.

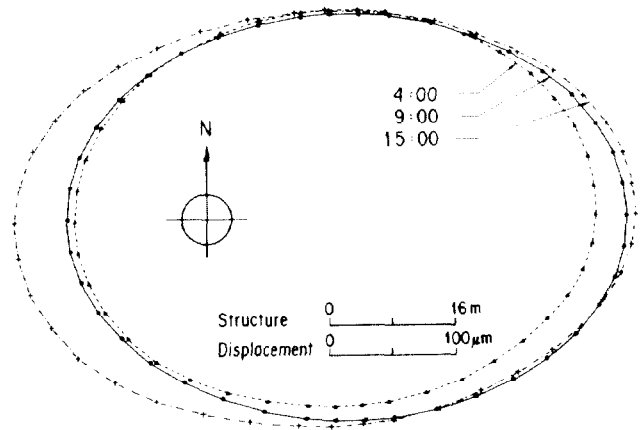


Figure 3. The storage ring ellipse simulated for external thermal load. Horizontal displacement is shown in a magnified scale. Ellipses shown here are those at 4:00, 9:00, and 15:00.

The present modeling includes the following new assumptions other than those already mentioned in our earlier papers [1]:

The piles anchoring the building foundation to the ground are represented by springs with 3-dimensional components. The horizontal strength of spring is reduced by a so-called group-pile coefficient, which is set to a commonly used value of 0.15. This assumption makes the floor more susceptible to the expanding force coming from the roof and walls.

The thermal load from solar irradiation and atmospheric heat is of only concern to this simulation model. The followings are the new procedures used to evaluate such thermal loads:

- The thermal load to the floor was evaluated from the temperatures measured on the ring tunnel floor at several points near Q042 and along BL5 on the experimental floor. The input data of temperature were taken to be uniform along the floor depth.
- The thermal load to the outer walls was evaluated by using the heat distribution analysis with the room temperature fixed at 24°C and the actual atmospheric temperature. The absolute value of temperature rise was readjusted by referring to the temperature measurement made at a point on the outer wall.

Figure 3 shows the simulated horizontal distortion of the storage ring ellipse. The ellipse first expanded eastward and then westward following the sun's movement.

4. COMPARISON

4.1 Major Axis L and Circumference C

Figure 4 shows both measured and simulated results for the variation of the major axis of the ring. The diurnal variation of the major axis length L was measured to be 68 μm and simulated to be 72 μm . The peak point appeared at 16:00 for the measurement and at 15:00 for the simulation. However,

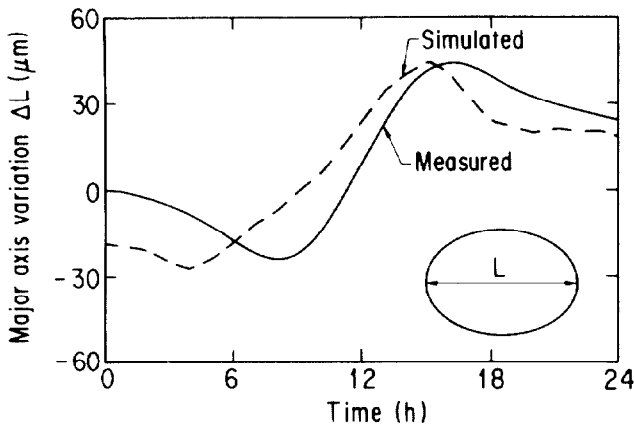


Figure 4. Variation of the major axis length both measured with a laser interferometer and simulated from a computer model.

the minimum point in the simulated result appeared 4 hours prior to that measured. The reason for this discrepancy is unknown at this stage. Detailed investigation must be made for input data to the heat analysis and time-dependent effect must also be included.

Figure 5 shows the ring circumference variations both measured from the RF frequency variation and simulated from the model. The peak-to-peak value was 190 μm in the measurement and 150 μm in the simulation.

4.2 Ratio $\Delta L/\Delta C$

Table 1 summarizes the values obtained for the day of concern. The simulation reproduced relatively well the measured values. The ratio $\Delta L/\Delta C$ from the simulation was larger than that of the measurement, indicating the storage ring ellipse was rather flattened along the minor axis for the simulation. From the fact that the measured value of $\Delta L/\Delta C$ was almost the same as L/C , the ring circumference seemed to have been uniformly expanded. However this may not be what has really occurred to the building because the injection line was not included in the simulation. Some extra thermal stress might have been imposed on the injection region, promoting the region to be distorted irregularly.

Table 1
Measured and simulated variations of the major axis length L and the ring circumference C .

	Measured	Simulated
$\Delta L(\mu\text{m})$	68	72
$\Delta C(\mu\text{m})$	190	150
$\Delta L/\Delta C$	0.36	0.48

where $L/C=0.364$.

5. SUMMARY

The followings are the results obtained in this analysis that has dealt with one day behavior of the building distortion:

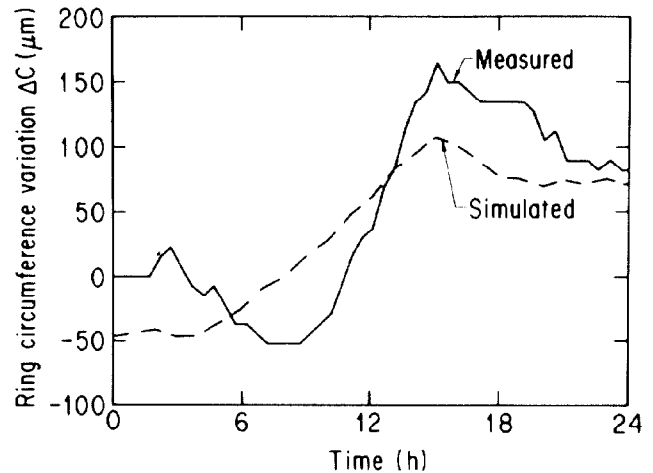


Figure 5. Variation of the ring circumference both measured as the RF frequency variation and simulated from a computer model.

- (1) Both major axis and ring circumference variations were strongly correlated to the atmospheric temperature.
- (2) The major axis of the ring was measured to diurnally vary 68 μm . The circumference similarly behaved as the axis and varied about 190 μm .
- (3) Simulated results of the major axis and circumference variations came into good agreement with those measured. The ring ellipse seemed to be more flattened in simulation than in measurement. To verify irregular expansion, the minor axis need at least to be measured.

There are other sources of thermal stress which cause the ring to be distorted. The most unwelcome is the thermal stress coming from start-up periods of the ring operation. During every start-up period, the ring building takes at least 10 days or so to come to a steady thermal equilibrium. About 2°C rise of floor temperature seems to cause the major axis to vary a few hundred microns [5]. Of course, when the ring is operated steadily, the diurnal variation discussed in this paper mainly appears.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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