Horizontal Movement of the Storage Ring Floor at the Photon Factory

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Abstract

At the Photon Factory, the storage ring with an elliptic shape varies its size due to heat generated from many accelerator components and beamline instruments packed in the ring building as well as due to solar irradiation and atmospheric heat. We continuously measured the major axis length of the ring with a laser interferometer, and also measured temperatures at the building roof slab and on two floors of ring tunnel and experimental hall. It was found that the long-term variation in the major axis length is well reproduced by a computer simulation.

1. INTRODUCTION

The storage ring floor of the Photon Factory had been earlier reported to move both horizontally and vertically due to the external thermal stress on the building roof and walls. The vertical floor displacement was measured with a hydrostatic level measuring system [1]. On the other hand, the horizontal and diurnal floor movement was evaluated from the variations in the circumference and also in the major axis of the storage ring [2]. The circumference variation was given in terms of the RF frequency required to sustain the central orbit, while the major axis was measured with a system of laser interferometer.

However, it was found that there may be other sources of thermal stress which cause the ring building to be largely distorted [2]. Further accumulation of data for several months has made it clear that the floor movement is more precisely described by including internal thermal loads on the ring floor and experimental floor: the internal thermal loads may come mostly from the accelerator components such as ring magnets and cooling water pipes, and partly from the beamline components.

To ascertain that both external and internal thermal loads actually give rise to the major axis variation, we first calculated the expansion rate of the major axis to a unit thermal load (1°C temperature rise of structure) imposed on each of the roof slab, experimental hall floor and ring tunnel floor, three different parts of the building structure, where the measurement of temperature had also been made. Using the expansion rates, we next reconstructed the major axis variation from the measured temperatures. Indeed, the reconstructed variation in the major axis has a good agreement with the measured one, the data taken by the laser interferometer system.

2. MEASUREMENT OF MAJOR AXIS

The Photon Factory storage ring has an elliptic shape with a circumference of about 187 m. Its major axis of ellipse is about 68 m and the minor axis 50 m. Figure 1 shows a plan view of the storage ring building composed of the ring tunnel and the experimental hall. Since October 1991, the length variation in the major axis was being measured with the laser interferometer system, as illustrated in Fig. 1 (the overall measurement error of the laser system was estimated to be less than several microns [2]). At the same time, temperature data were taken on the building roof with thermocouples and also on the floors of both ring tunnel and experimental hall with thermistors.

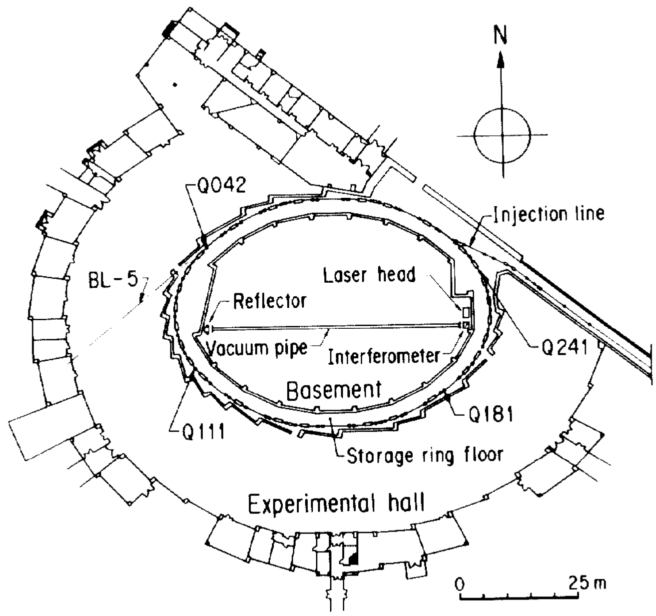

Figure 1. Plan view of the storage ring building of the Photon Factory; the ring tunnel and experimental hall. Also illustrated in the figure is the measurement system of the major axis length, which consists of a laser interferometer, vacuum pipe and reflector.

Figure 2 shows two typical examples of these measured data; one is data taken on February 29 to March 6 in 1992 (Data A) and the other on June 26 to July 7 (Data B). The roof temperature T_r is the average of the temperatures measured on the upper and lower surfaces of the roof slab. Filtered data denoted in the figure are "low-pass filtered" data in which short-term fluctuations with a period of less than a few days are filtered out, and the filtered. The filtered data of T_s and T_e in the figure are those of the averaged temperatures. For Data A, the ring first expanded and then contracted with the major axis variation of about 200 μm. The data imply that the major axis variation tends to follow the temperature variations in the roof (coming from external thermal loads) and in the ring floor (mainly coming from internal loads), but that it is insensitive to the temperature at the experimental hall. On the other hand, in the latter half part of Data B the major axis variation seems to correspond to the temperature rise of the experimental hall.

3. SIMULATION

A computer simulation based on a finite element method has been carried out to evaluate the expansion of the major axis to unit thermal loads that are individually imposed on the roof slab and two floors of ring tunnel and experimental hall.

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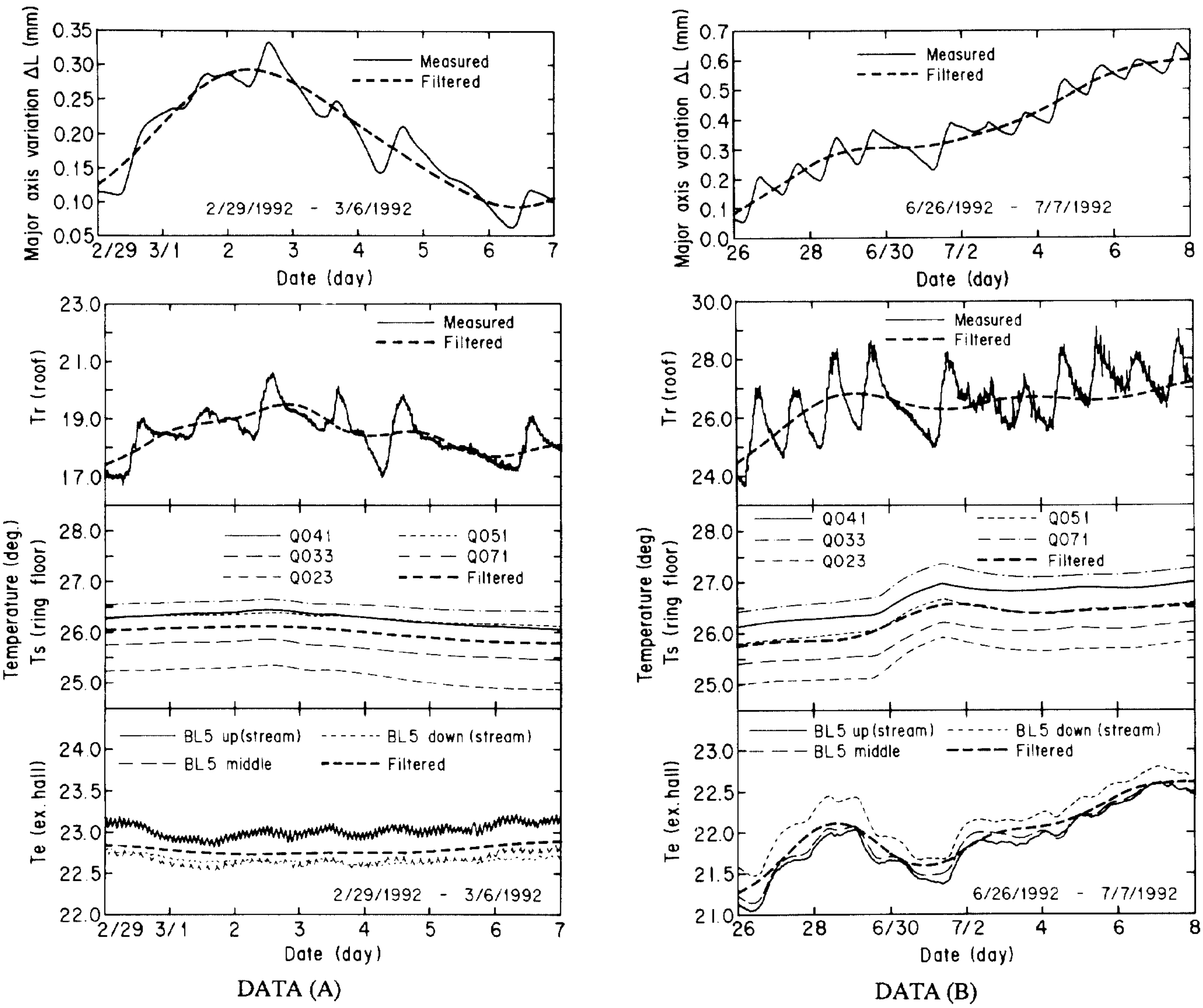

Figure 2. Variation in the major axis and temperatures in three different parts of the building structure. The T_S, T_r and T_e denote the temperatures at the storage ring floor, the roof and the experimental hall floor, respectively.

The structure modeling for simulation is already described in Reference [1] and [2]. Thereafter, the expansion rate of the major axis to a unit load is called thermal weighting factor. The result of simulation is shown in Fig. 3, where the ring expansion due to thermal loads is exaggeratedly depicted. As seen in the figure, the major axis of the ring is more susceptible to the temperature variation in the ring tunnel than in the other two.

Table I Thermal weighting factors of the major axis expansion

locations	weighting factors [μm/ ° C]
Ring floor (C1)	220
Roof (C2)	86.7
Exp. floor (C3)	37.3

The thermal weighting factors defined above, which we can calculate from the simulation, are listed in Table 1. Hence the variation in the major axis may be written as,

$$\Delta L = C_0 + C_1 T_s + C_2 T_r + C_3 T_e \ , \qquad (1)$$

where the C_0 is a constant to adjust the data offset and the other C's are given in Table 1.

4. COMPARISON

To compare the measured variations in the major axis with the ones calculated using the temperatures at three different parts of the building structure, the following procedures were taken:

(1) We take the average of temperatures measured at three points along a beamline in the experimental hall (see Fig. 2), and assume that the temperatures in the whole experimental hall be represented by the average. Similarly, we also take the average of temperatures measured at several points of the ring tunnel.

(2) Then, all data, the measured variation in the major axis and the temperatures of the roof, experimental hall and ring tunnel, are low-pass filtered as described in Sec. 2, because we are mainly interested in a long-term behavior of the building distortion in this paper.

(3) Finally, we substitute three filtered data of temperature into Eq. (1) to obtain an estimate of the major axis variation.

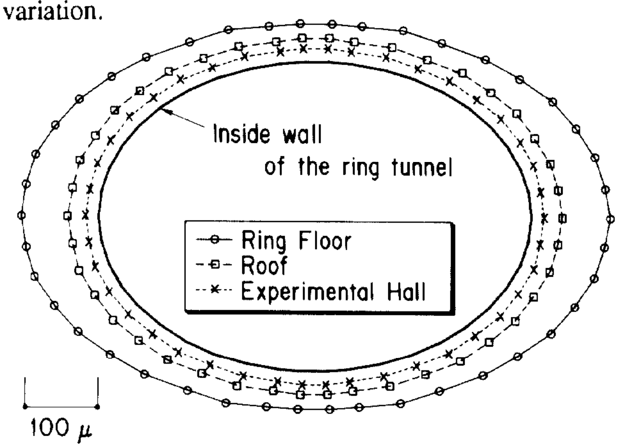

Figure 3. Simulated horizontal displacements of the storage ring for unit thermal loads, which are separately applied to three different parts of the building structure; roof, experimental hall floor and the ring tunnel floor.

Figure 4 shows the measured and calculated variations ΔLs in the major axis of the ring for the same periods of time as in Fig. 2. The calculated ΔL well agrees with the measured one, though there is still a little amount of fluctuation in the calculated ΔL. We have also made a similar comparison for raw data of temperature, which is not presented here. In this case, not-filtered fluctuations of temperature, that is, diurnal and more rapid ones, directly reflect on the calculated ΔL, whereas raw data of the major axis have an amplitude of diurnal or rapid fluctuation by a factor of two or more smaller than the calculated one. This is probably because the true average of the roof temperatures is not accurately represented by the averaged data T_r, which include largely changeable temperature on the upper surface of roof. However, it is clear that the above procedures are valid enough to investigate long-term variations.

In conclusion, the long-term variation in the major axis length of the Photon Factory storage ring was well reproduced by a computer simulation using the measured temperatures, and it was found that both external and internal thermal loads give rise to the building distortion. As early reported, the long-term as well as short-term distortions of the ring closed orbit, whatever their cause is, have already been suppressed by an orbit feedback system. Since the Photon Factory ring is a second-generation synchrotron light source, however, both thermal loads may seriously affect the performance of a third-generation light source.

5. SUMMARY

The following is a summary of the results obtained from the above-mentioned measurement and analysis:

(1) Thermal weighting factors of three different structure parts of the ring building were evaluated using a computer simulation model. The simulation showed that the weighting factor of the ring tunnel floor has a larger value than the other two, though the temperature itself is more stable at the tunnel floor.

(2) Since the measurement of temperature is limited to some localized places in the whole building, there might be some unknown sources that greatly affect the variation in the major axis. The measured variations in the major axis length, however, showed a good agreement with the calculated ones that were calculated only using three temperature data and the weighting factors evaluated from a computer simulation. Thus we may conclude that the temperature variations in three kinds of structure parts of the building, that is, roof, experimental hall and ring floor, are major sources for horizontal movement of the Photon Factory storage ring building.

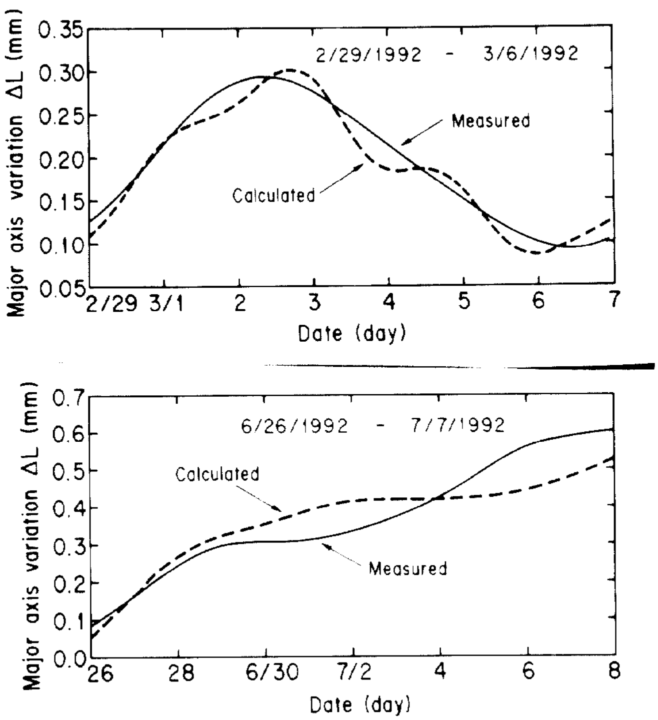

Figure 4. Measured and calculated variations of the major axis. Note that filtered data are treated here.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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