THE VIBRATION MEASUREMENTS AT THE PHOTON FACTORY STORAGE RING BUILDING

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1. INTRODUCTION

The synchrotron light sources, especially newly constructed low-emittance third-generation light sources, have to be operated in good stability in order to give full scope to their ability. Movements of the synchrotron radiation (SR) axis will reduce the effective brilliance of the SR from the design value.

The Photon Factory is a 2.5 GeV electron storage ring and has been operating since 1982 as a dedicated SR source. The PF ring was upgraded to reduce its emittance from 130 nm-rad to 36 nm-rad in order to be equal to the third-generation light sources [1]. From October 1997, the PF ring has been operating in the new low-emittance optics and the necessity for the beam stability in usual operation has been required.

At the Photon Factory, we have been persuing the various sources of the beam instabilities which deteriorated the SR beam quality in the wide frequency range. Some of the sources were the vibrations of magnets and floor of the ring tunnel, temperature change of the cooling water and the elongation of the storage ring building roof due to sunshine that induced the diurnal motion of the SR beam axis [2].

It was suggested from the data regarding the SR axis vibration that the magnets of the storage ring vibrate together with the light source building. In 1986, the vibration of the ring tunnel floor was measured and the vibration sources were identified [3]. The main causes of the ring tunnel floor vibration were the air-conditioners installed in the light source building as well as the refregirator used for the superconducting wiggler.

In order to reconfirm the vibration sources and to know the mechanical vibration of the storage ring magnets and the experimental hall, we have planed the detailed measurements of the vibrational states of the storage ring building. The effect of the mechanical vibration on the electron beam motion are also measured.

2. VIBRATION MEASUREMENTS

The vibration measurements were performed for three days. On the first and second days PF ring was stopped, and on the third day PF ring was operated as usual in the users time and stored 400 mA electron beam. Measured data of each day are compared in order to know the effects of the storage ring operation. Cooling water of the magnets and the vacuum chambers are flown same in three days.

2.1 Vibration measurement system

The measurement system consists of the vibrational gauges, amplifiers and the digital data recorder. Small vibration was detected by twelve sets of seismometers by Shindou Giken Co. Ltd. and six piezoelectric accelerometers by PCB Co. Ltd. Each signal generated in gauges was amplified and sent to the digital data recorder that performs analog-to-digital transformation and data storage. Data sampling rate was 500 Hz. Measured acceleration data are analysed in FFT and represented as frequency spectrum.

We represent the magnitude of the vibration using the root mean square (RMS) displacements converted from the measured acceleration in the frequency range of 1-100 Hz.

2.2 Ground vibration measurement

First of all we measured the ground vibration at the three points (point A~C) around the light source building. Figure 1 presents the Fourier amplitude spectrum of the displacemnt in the vertical ground motion at the measuring point B. The increase of the ground motion in the frequency range under the 5 Hz are due to the effect of the strong wind blowing on that day. In the frequency range between 10 and 30 Hz, several components arising from the air-conditioners vibration (especially nearby AC6) can be seen. An overall situation of the ground motion at the measured three points is almost same.

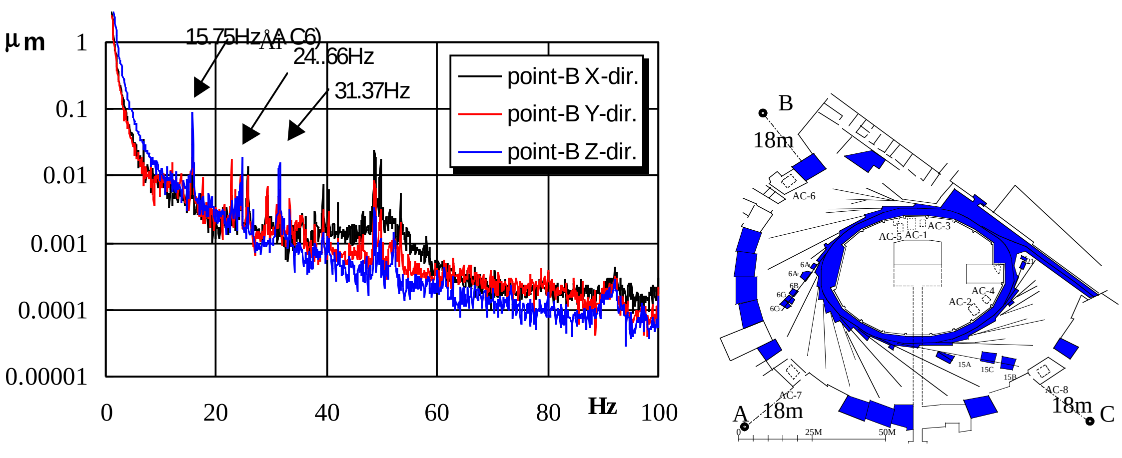

Figure 1 Fourier amplitude spectrum of the vertical displacement of the ground vibration and the position of the measuring points.

2.3 Vibration of the air-conditioner

The vibrations of the ground and of the air-conditioner have been recognized as the two main sources of the beam motion. In the light source building, there were eight air-conditioners above the storage ring tunnel and around the experimental hall that surrounds the storage ring tunnel. Before measuring the vibrations of various parts of the light source building, the vibration of eight air-conditioners itself were measured, in order to identify the frequency components of the measured data. Figure 2 shows the vibrational output power of the air-conditioner No.2 (AC2). The rotational frequency of the fan in the AC2 was 890 rpm and the fundamental mode of vibration was 14.8 Hz. The several frequency peaks originated from this fundamental mode were seen in figure 2. Each air-conditioner has its fundamental mode of vibration in the frequency range from 14.8 to 22.5 Hz. Because there are only thin viscoelestic damping pads under these air-conditioners, these vibrations propagated around the light source building.

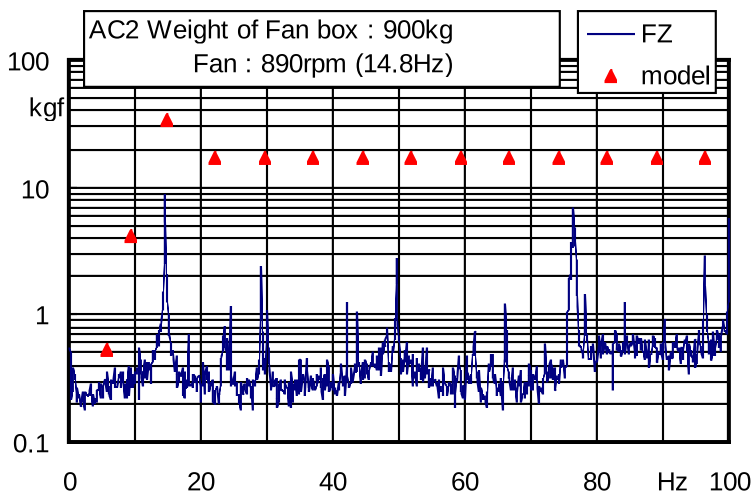

Figure 2 The output power spectrum of the air-conditioner No.2(AC2).

2.4 Vibration of the storage ring tunnel floor

The vibration of the storage ring tunnel floor was measured at twelve points using the twelve sets of probes situated along the storage ring. We measured the three components of the vibration with one set of the probes. The z-direction means vertical direction. Horizontal components has two direction. The direction along the electron beam is called x-direction, and the lateral direction is called y-direction in these measurements.

In the figure 3, the magnitude of the RMS displacements of the ring tunnel floor vibration are shown for each directions. Displacement of the z-direction is larger than the displacement of other two direction, but the magnitude of its displacement is only about 0.04 μm on the average. In this figure, displacements measured with air-conditioners being off are also shown for comparison. At measuring point No.9, vertical (z-direction) displacement measured with all air-conditioners working is about five times larger than the displacement measured with all air-conditioners being stopped.

Effects of the air-conditioners are evident from the Fourier spectrum of this data. Figure 4 presents the Fourier spectrum of the vertical ring tunnel floor displacement at the measuring point No.9. One peak at 14.65 Hz corresponds to the fundamental vibration frequency of the AC2, and another peak at 20.26 Hz also asises from the fundamental vibration frequency of the AC4 (20.3 Hz). The magnitude of the 20.26 Hz peak amounts to 0.1 μm. This displacement is equivalent to 0.07 μm RMS displacement. So the vibration arising from the air-conditioners exhaust almost all of the RMS displacement measured at point No.9.

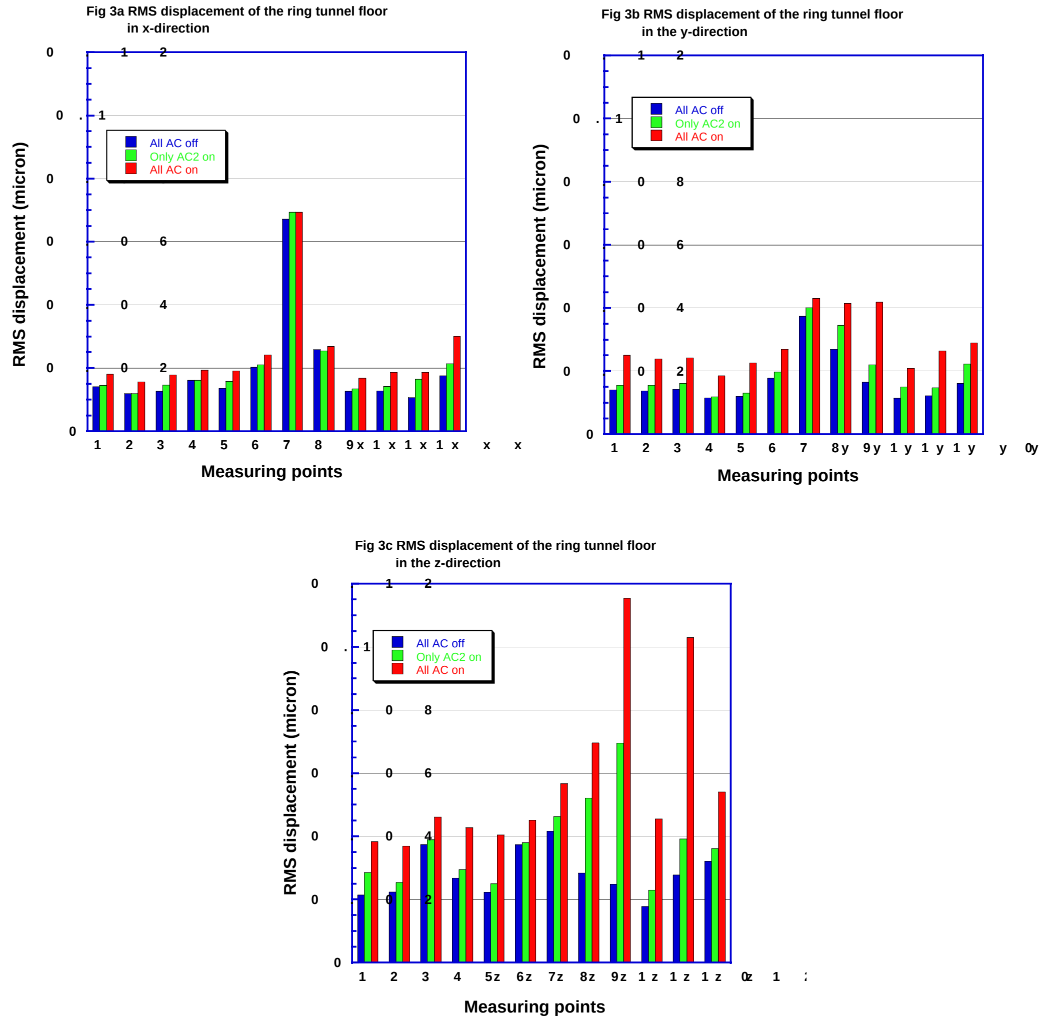

Figure 3 Displacements of the ring tunnel floor vibration.

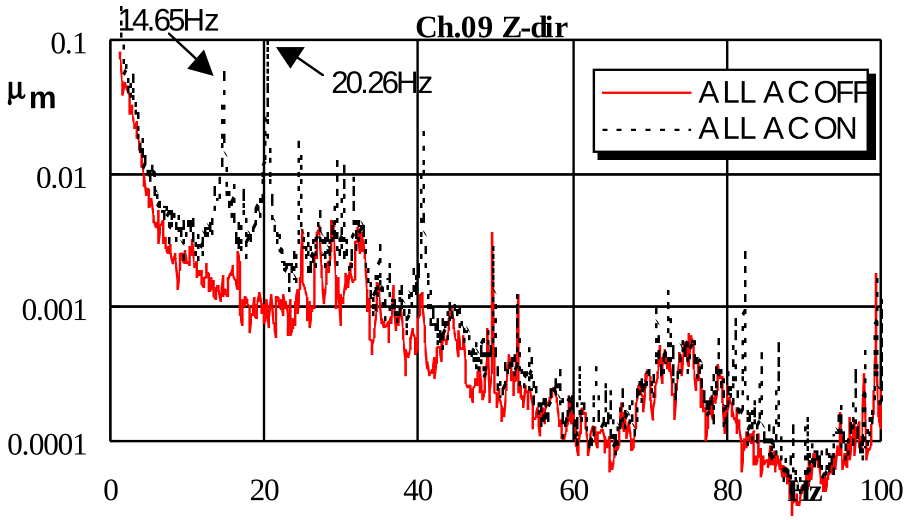

Figure 4 Fourier spectrum of the vertical displacement of the ring tunnel floor at the measuring point No.9. Solid line shows the vibration with all AC are stopped, and dotted line shows the one with all AC are working.

2.5 Vibration of the experimental hall floor

As same as the ring tunnel floor, the vibration of the experimental hall floor was measured using the twelve sets of the probes. The experimental hall surrounds the PF storage ring tunnel and the many beam lines for the SR experiments are installed there.

Because it could not be realistic to measure the vibration of the whole floor, the twelve sets of the probes are settled in the portion of the experimental hall near the beam line No.2. The results of the measurements are shown in the figure 5. The RMS displacement in the vertical (z) direction is larger than the displacements in other directions, as same as in the case of the ring tunnel floor vibration. The number of the measuring points are sequential according that smaller number means nearer position from the air-conditioner. It is evident from the position of the measuring points that the magnitude of the vibration displacement becomes smaller and smaller according as the measuring points becomes further and further from the nearest air-conditioner (AC6).

2.6 Vibration of the storage ring quadrupole magnets

The vibration of the quadrupole magnet (Q-magnet) of the storage ring affects mostly to the behavior of the stored electron beam motion. Then, the vibration of the twelve Q-magnets selected equally from all storage ring Q-magnets were measured. Twelve sets of the probes were situated on top of the Q-magnets. After the lattice change of the PF ring for reducing the beam emittance, two quadrupole magnets and two sextupole magnets in a normal cell have been settled on a common girder.

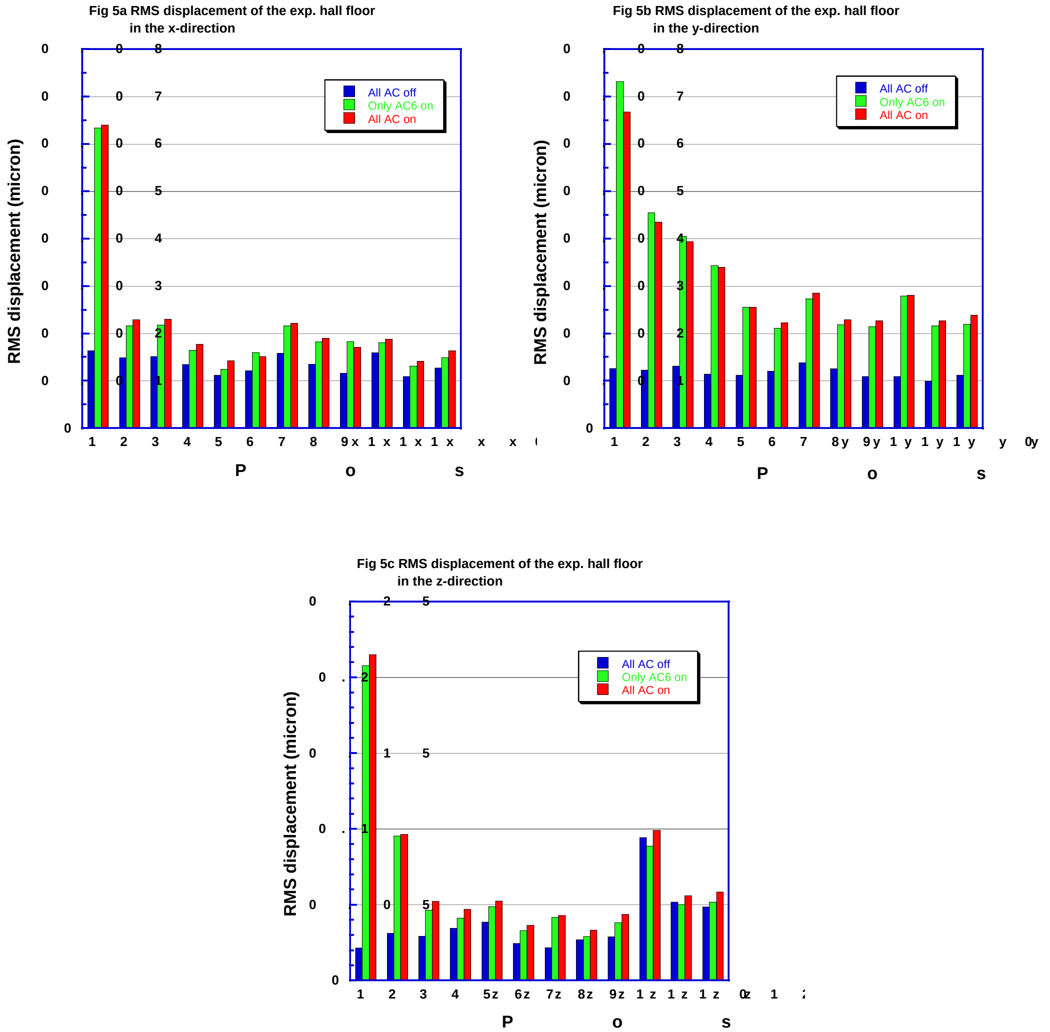

Figure 5 The RMS displacement of the experimental hall floor vibration in three directions.

The results of the Q-magnet vibration measurements are shown in the figure 6. These results clearly show that the magnitude of RMS displacement of the Q-magnet vibration in lateral (y) direction exceeds those in other two directions. In case of ring floor vibration, we showed previously that the displacement in the vertical (z) direction was prominent. On the contrary, the vibration of the Q-magnet in the lateral (y) direction was ten times as large as the lateral (y-directional) vibration of the floor. The displacement at the measuring point No.9, especially in y-direction, was affected mostly from the nearby air-conditioners.

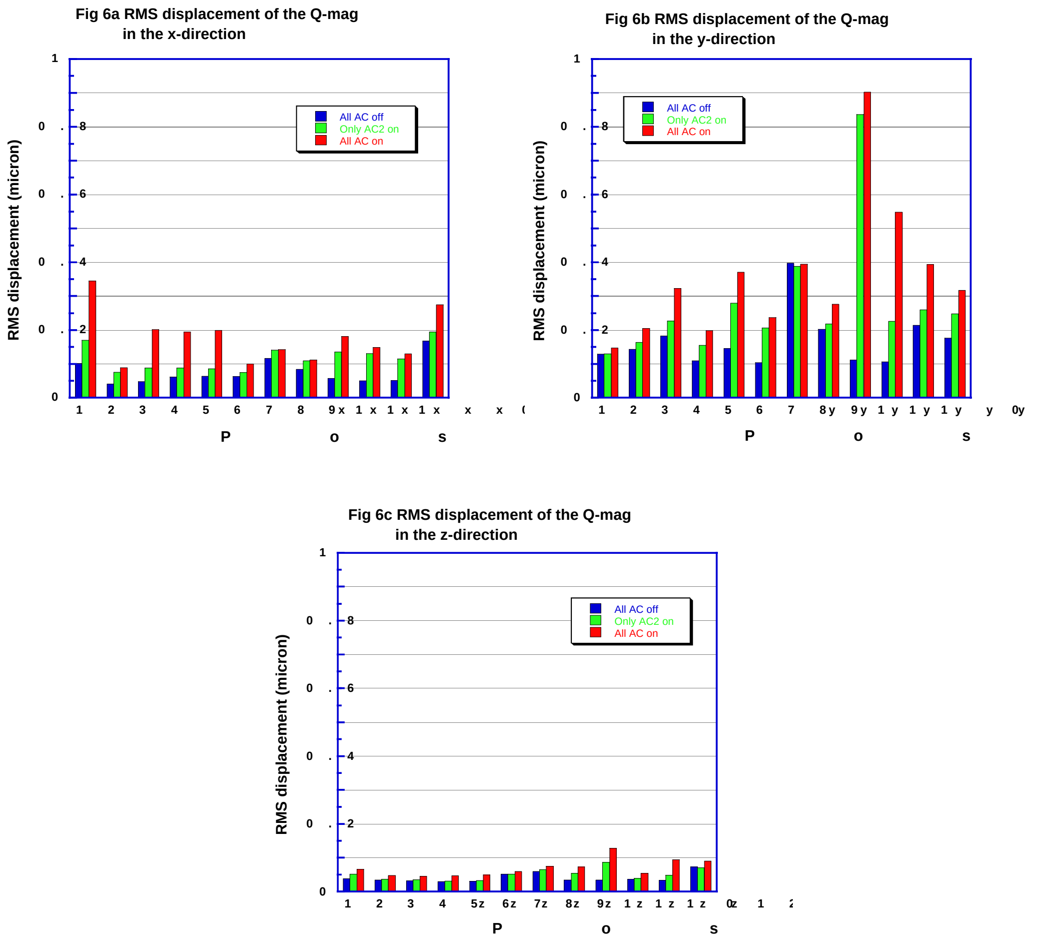

Figure 6 The RMS displacement of the selected twelve Q-magnet vibration.

The Fourier spectrum of the Q-magnet displacement at the point No.9 is shown in the figure 7. Two major peaks at 14.53 and 20.26 Hz already seen in the spectrum of the floor vibration are also seen in this spectrum. Adding to these two peaks arising from the vibration of the air-conditioners, a new peak at 10.74 Hz appears. Because this peak can be seen when all air-conditioners have stopped, it can be estimated that this peak arises from the fundamental resonant vibration of the girder and the Q-magnet.

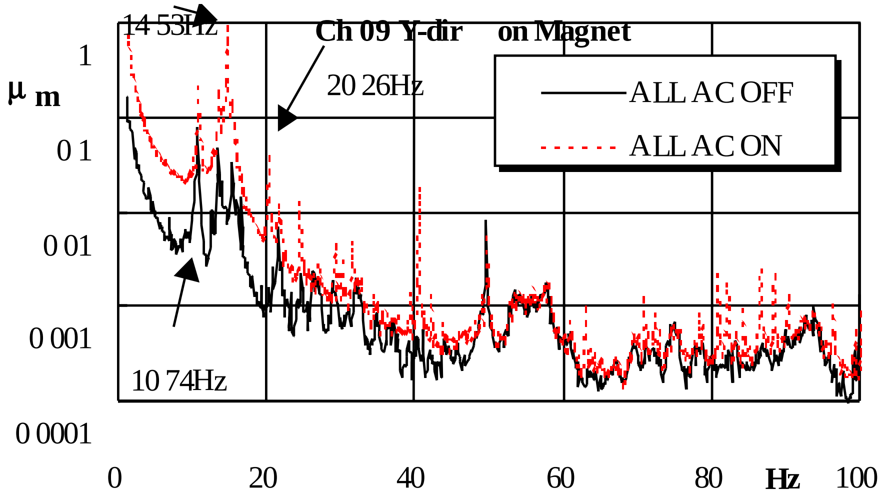

Figure 7 Fourier spectrum of the Q-magnet vibration.

2.7 Vibration of the girder and the Q-magnets

To investigate the vibrational properties of the girder and the quadrupole magnet, we have performed the hammering test and measured the fundamental resonant frequencies. In the figure 8, the Fourier spectrum of the Q-magnet vibration is presented with the sprctrum of the floor for comparison. The vibration of the Q-magnet was amplified at frequencies between 10 and 20 Hz. There were many peaks in this frequency range. The paek at 10.38 Hz, already seen in figure 7, arises when the Q-magnet swayed on the girder in the lateral direction. Another remarkable peak at 13.18 Hz arises from twisting the girder's leg. The picture of the vibrational state of the Q-magnet and the girder is presented in the figure 9. This picture shows that the top of the Q-magnet vibrates heavily comparing to other part of the magnet and girder.

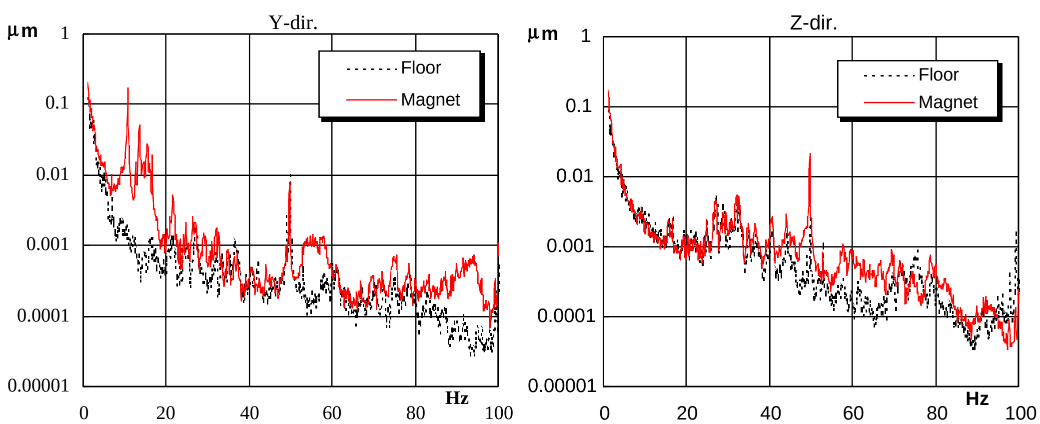

Figure 8 Fourier spectrum of the Q-magnet vibration in the lateral (y-) direction and the vertical (z-) direction.

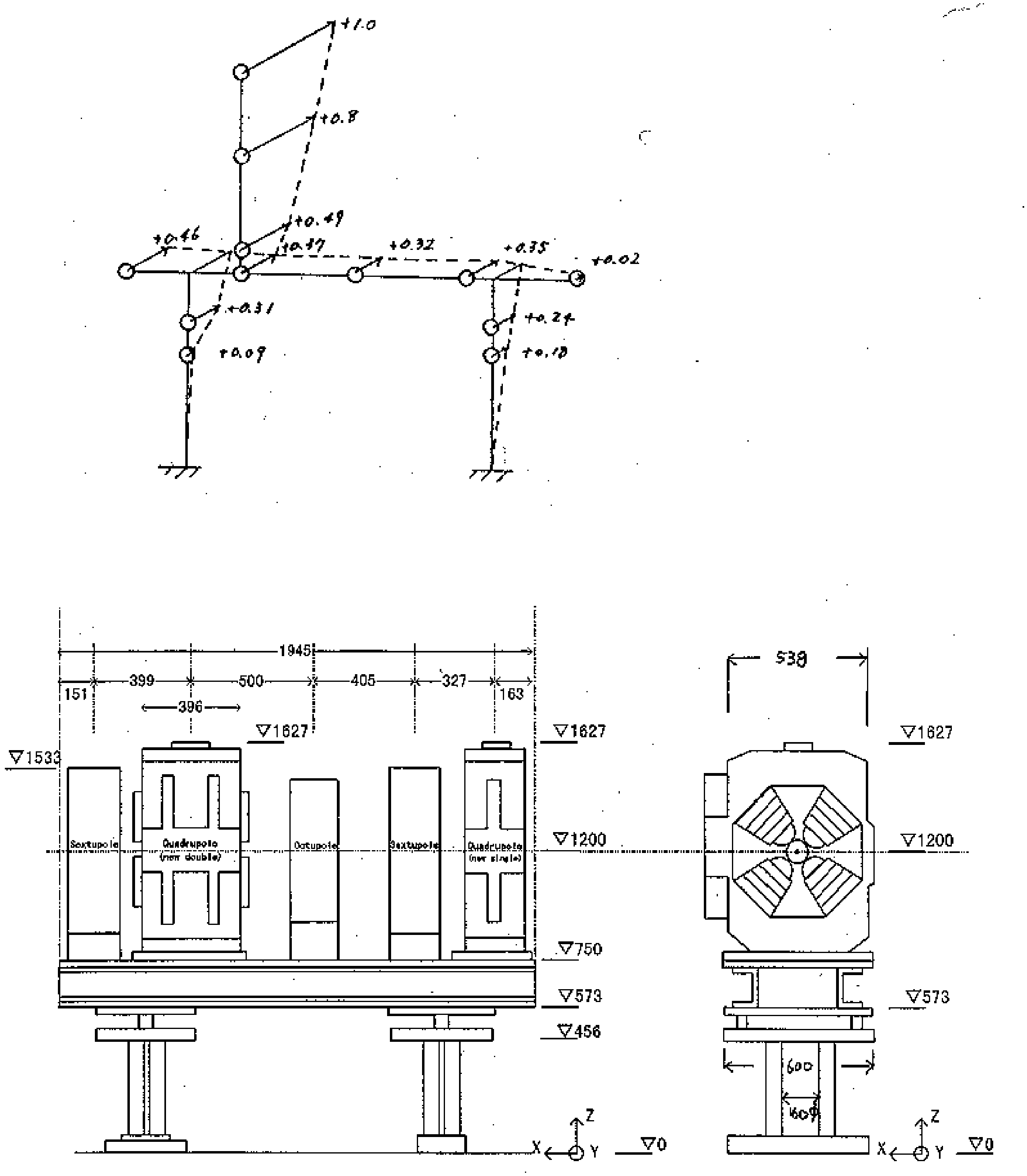

Figure 9 Vibrational state of the Q-magnet and girder.

2.8 Vibration of the stored electron beam orbit

The sixty-three beam position monitors (BPMs) are installed in the PF storage ring in order to measure the electron beam orbit. But if the detection units of the BPMs themselves vibrate or displace, the resolution of the beam position measurement gets worse and incorrect beam position data are detected. The vibration of the detection unit of the BPM was measured and the vibration of the position of the stored electron beam was also measured. The piezoelectric accelerometer was settled on a vacuum tube of the detection unit of the BPM, and beam position data was collected using the data taking system of the BPM. Sampling rate of the BPM data was restricted within 83 Hz and maximum number of the beam position data was 101, owing to the program of data taking system.

The vibration of the BPM detection unit was thought to be same as the Q-magnet vibration, because the BPM detection unit was fixed directly to the end of the Q-magnet yoke. But we found that the Fourier spectrum of the BPM detection unit was amplified in the frequency range below 30 Hz. It was supposed that the vibration due to the cooling water flow was added to the vibration coming from the air-conditioners.

Figure 10 shows the Fourier spectrum of the vertical beam position vibration at the BPM No.52. Two major peaks at about 18 and 32 Hz were aliasing peaks arising from the wide sampling interval. The efects of the air-conditioners appear as the broad peak around 15 Hz, and its magnitude is about 3 μm. It is necessary to measure the electron beam motion with finer sampling to resolve the each contribution of vibration sources.

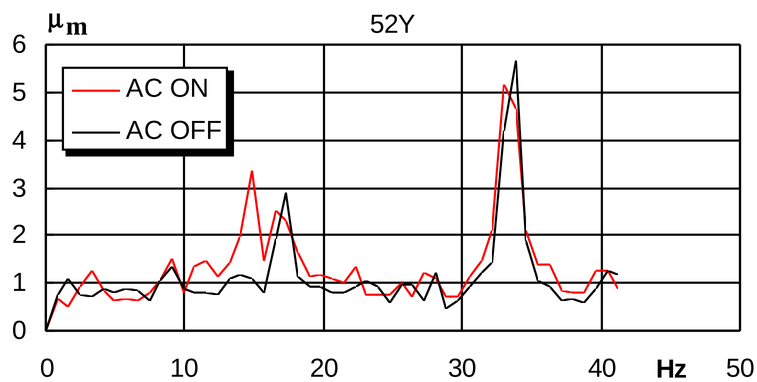

Figure 10 Fourier spectrum of the vertical beam position vibration at BPM No.52.

3. SUMMARY

Results of the vibration measurements at the Photon Factory storage ring building are compared in figure 11. We summarize the results below.

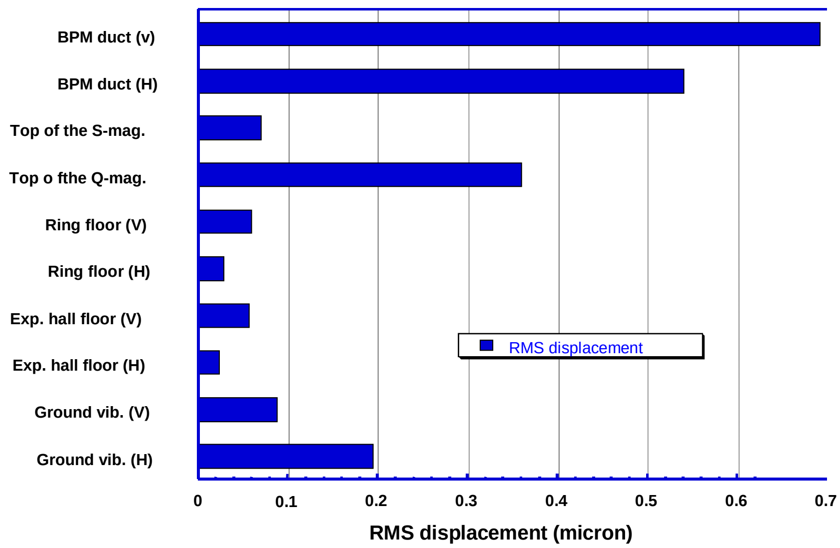

Figure 11 Summary of the vibration measurements at the Photon Factory storage ring building.

(1) The vibrations of the ring tunnel floor and the experimental hall floor, comparing with the vibration of the ground surrounding the storage ring bulding, are same order in the 1 ~ 5 Hz range, and 1/3 ~ 1/5 in the 5 ~ 100 Hz range, in the vertical and the horizontal direction.
(2) The effects of the vibration arising from the operating eight air-conditioners can be seen in the Fourier spectrum of the vibration of the ring tunnel floor, experimental floor, Q-magnets and BPM vacuum duct.
(3) The vibrations of the Q-magnet and girder at frequencies near their fundamental resonant frequencies have been amplified 100 times in the lateral direction comparing to the floor vibration.
(4) Correlation between the vibration of the BPM vacuum duct and the vibration of the electron beam motion is unknown for the lack of the precise data.

The obvious cure for the propagation of the air-conditioner vibration is the installation of the thick viscoelastic damping pad beneath the air-conditioner. From the simulation of this pad, the reduction of the propagated vibration amounts to -20 dB. On the other hand, though the ground vibration itself does not harm the beam quality now, with the advance of the beam stability it is necessary to compress the effect of the ground motion in the future. We will start the test experiment of the «Tuned Mass Damper (TMD)» system attached to the magnets for the small ground motion damper. It can reduce the vibration of the magnets at the fundamental resonant frequencies.

4. REFERENCES

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[3] K.Huke, *Jpn. J. Appl. Phys.*, **26**, 285 (1987).