THERMALLY DRIVEN VERTICAL DISPLACEMENT OF IP QUADRUPOLE MAGNET

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The IP (interaction point) quadrupole magnets of the TRISTAN MR (main ring), QCS and QC1, at every IP sit on the common support made of steel. When all magnets are cycled through injection, acceleration, flattop and deceleration, the environmental temperature in the tunnel changes periodically following the magnet cycle. The magnet support receives the temperature cycles and the quadrupole on it moves vertically due to the thermal expansion and shrinkage of the support. Its movement was measured with the laser interferometer during the physics experiment. This displacement gives an effect on the closed orbit distortions and requires the orbit correction when it becomes serious.

1. INTRODUCTION

The movements of the interaction quadrupole magnets have long been suspected as a source of the frequent change of the vertical closed orbit distortions (COD). Earlier measurements of the tilt and temperature of these magnets showed the possibility of the vertical displacements by the thermal change of the mechanical height of the supporting structures which are made of structural steel [l]. At every interaction point (IP) there is a mini-p quadrupole magnet system, which consist of 2 superconducting quadrupoles (QCS) [2] and 2 normal quadrupoles (QC1), each having 1.2 m and 2.5 m in effective magnetic length, and 58 T/m and 12 T/m in nominal field gradient at 29 GeV, respectively [3]. The QCS and QC1 have the stronger integrated field gradients than other quadrupoles to squeeze the beam vertically to obtain higher luminosity and therefore their displacements have an effect on COD larger than any other quadrupole. If the displaced magnet are hunted using the measured vertical COD data in the beam tracing code, these quadrupoles are obtained.

A pair of QCS and QC1 at every side of IP's are supported by a common support table as shown in Fig.1. There are the 2.7 m concrete pillars on which the support table sits. As concrete has a big heat capacity, its dimensional change due to heat is small and slow compared to the iron structure. The iron height including the bottom half QCl core is 3 m. The ambient temperature measured around these quadrupoles reflects the temperature control of an air-conditioner of the IP experimental hall and has the spatial distribution such that the nearer to the thermo-feedback sensor of the air-conditioner, the closer the spatial temperature to the indicated temperature of this sensor. So quadrupoles at both sides of IP displace independently and this makes the problem complicated. Beam simulation shows that the 20 μm displacements of QCS and QC1 give the 0.2 mm COD [1]. The COD at this level obstructs the beam injection and is subject to the orbit correction.

The vertical COD is corrected on-line by exciting the vertical steering magnets placed close to every defocusing quadrupoles. It is similar for the horizontal COD correction.

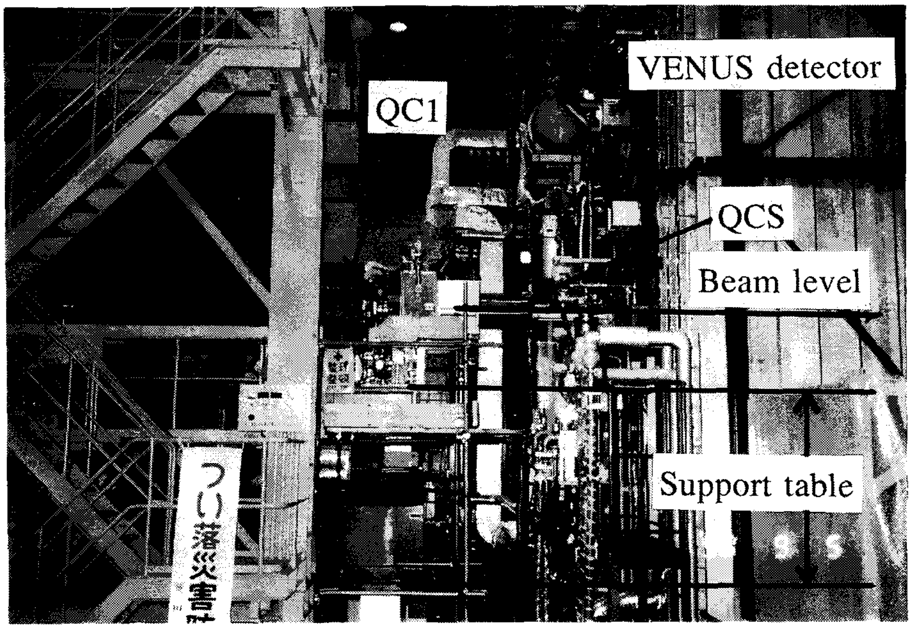

Fig. 1 Supporting table of a pair of QCS and QC1 at every side of interaction points. Picture shows the right side of IP at the Fuji experimental hall.

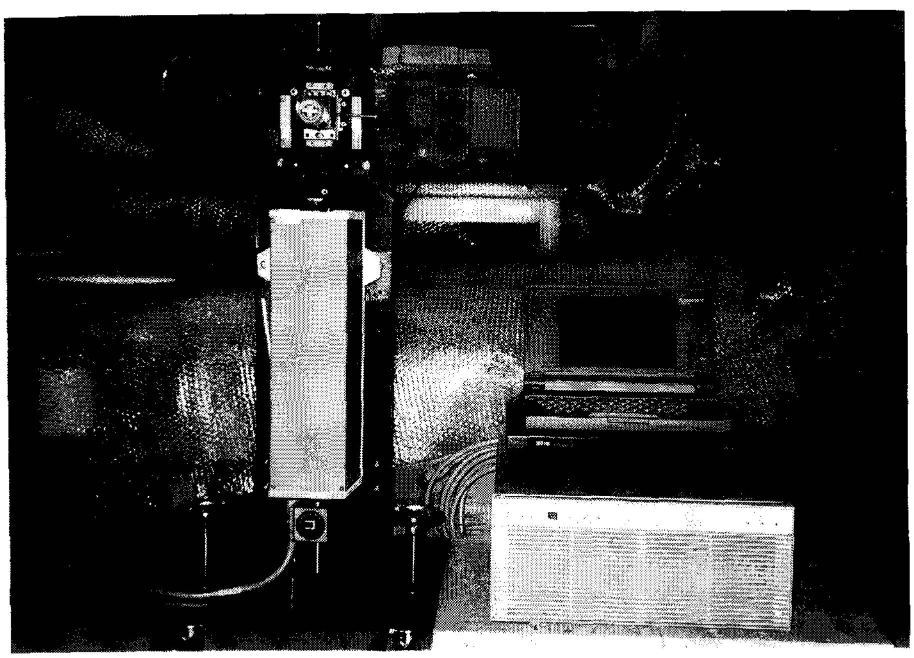

Fig.2 Laser interferometer (HP-5527B). The left is the laser head set on the vertical stand with a remote interferometer atop and the retro-reflector is shown at the bottom. The right is the organizer to install the laser position transducer electronics and a computer with a bus extension box for the GPIB interface on the top.

2. DIRECT OBSERVATION OF VERTICAL DISPLACEMENT

To observe the vertical displacement of QC1 directly, a laser interferometer (HP-5527B given in Fig.2 or HP-5528A) was used. The laser head was set under QC1 vertically and the retro-reflector at the bottom of QC1. The relative vertical displacement was measured for several days at an interval of 30 min. Data were transferred to the personal computer (NEC/PC-9801-NS/T or TOSHIBA/J-3100-GXS) via GPIB interface and stored in the hard disk. No meteorological compensation device was attached to the interferometer, so data were corrected using the atmospheric temperature and pressure which were measured independently near the laser beam and at the KEK site, respectively, at the same time. An error of one ppm is generated by either of the pressure deviation of 2.5 mmHg, temperature deviation of 1 deg. centigrade or humidity change of 100%. However, the humidity compensation was not applied because the measurement was done under air-conditioned. To estimate the height variation of the medium plane of QC1, the thermal expansion (or shrinkage) of the half height of QC1 was taken into consideration. Therefore the movement of the central height of QC1 is given by the sum of compensated laser reading and thermal expansion (or shrinkage). Fig.3 shows the temperature variation which coincides with the magnet excitation (8 GeV at injection and 29 GeV at flattop).

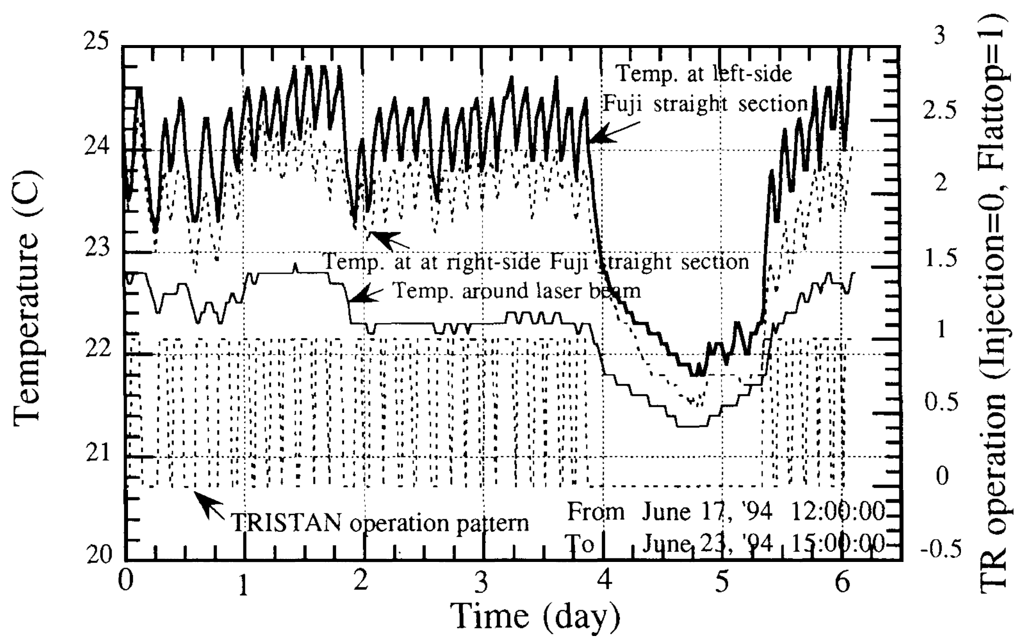

Fig.3 Temperature variation due to the TRISTAN operation. Temperature in the accelerator tunnel follows the magnet excitation.

Comparing the temperature data with the vertical displacement of the QC1 central height, the coincidence of the fine structure is very good as shown in Fig.4. This displacement has no atmospheric pressure compensation because the lack of the pressure data. There was no temperature correlation between outside and inside of the accelerator tunnel under the beam operation. The peak-to-peak height variation due to the magnet excitation is about 0.004 mm which corresponds to the peak-to-peak temperature variation of 0.6 deg. centigrade.

Even if the atmospheric compensation is applied, its effect appears in compensating the large amplitude with longer period than the fine structure as shown in Fig.5. These data for first 9 days were taken while magnets were excited at 8 GeV. In this case the QC1 displaces with a period of one day. Heat flow rate is constant because every magnet excitation is static and the equilibrium state will be maintained if the temperature at the ground surface does not change. The variation with one day period is due to the change of the outdoor temperature.

3. RMS COD AMPLITUDE AND QC1 DISPLACEMENT

Comparing the QC1 displacement with the rms COD amplitude at 8 GeV injection energy where there is no disturbance coming from the magnet excitation. Fig.6 gives the correlation between them. The COD measurements were repeated three times, Run#l, #2 and #3, but were independent each other. The QC1 displacement in Fig.6 was measured continuously through these runs. The case of COD_Run#l shows correlation between the rms COD amplitude and QC1 displacement but the rests have poor correlation. The displacement was observed for only one magnet (QC1-FR, which means the quadrupole QC1 at the right side of the IP at the Fuji experimental hall) but the COD reflects the displacements of all magnets. Poor correlation will be quite natural if considered the superposed individual contributions.

To further the study, two QC1's positioned diametrically opposite place in the TRISTAN-MR ring were monitored simultaneously using two interferometers, one of which was failed after 112 hours. Fig.7 gives the vertical displacements without any meteorological compensation. Both QC1's are supported on the same tables on the 2.7 m concrete pillars.

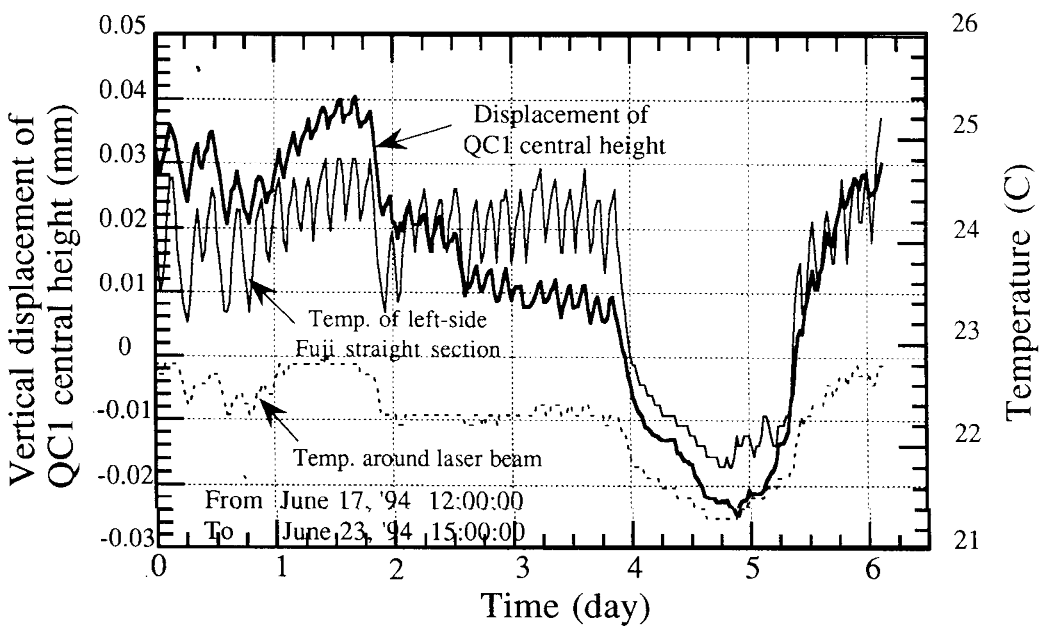

Fig.4 Vertical displacement of the QC1 central height whose fine structure coincides well with that of temperature.

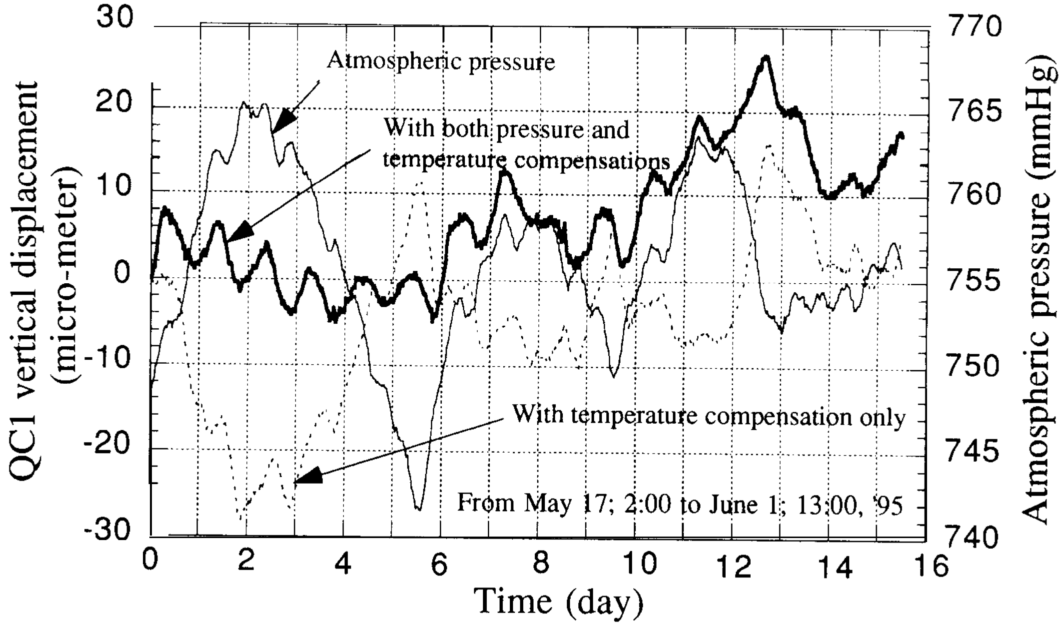

Fig.5 Effect of the atmospheric pressure. It appears in the variation with the longer period. For first 9 days all magnets were excited at 8 GeV, for next 4 days all magnets were not excited because of accelerator maintenance, and for last 3 days magnets were excited again.

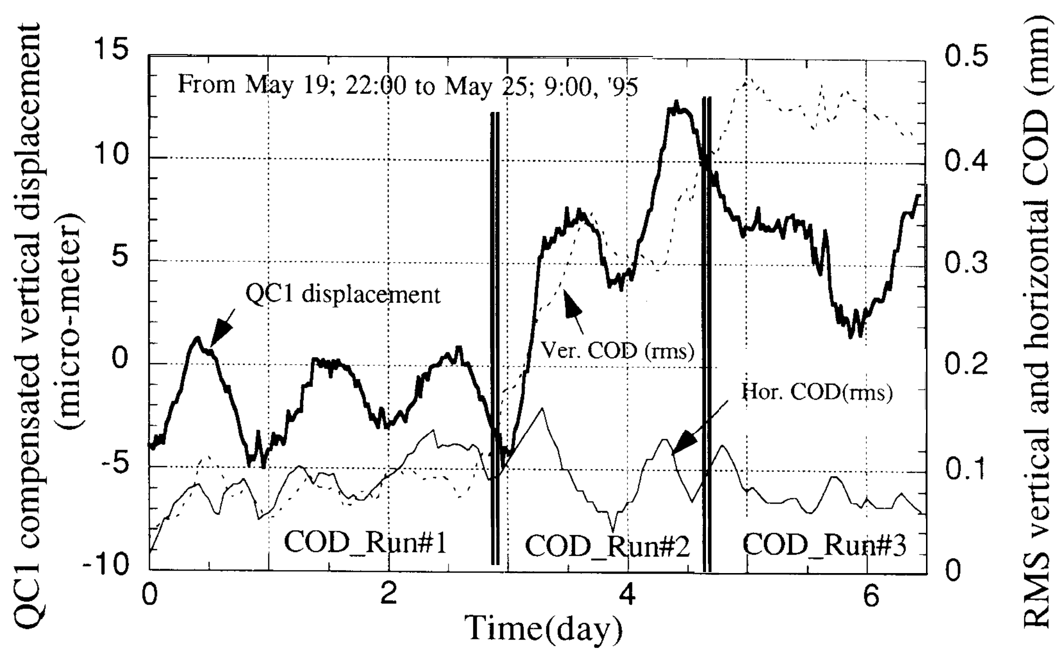

Fig.6 Correlation between the rms COD amplitude and the QC1 vertical displacement. All magnets were excited at 8 GeV.

Two displacements have similar behaviors but are different in details. The reason of the difference is that temperatures at both sites change independently. The TRISTAN-MR ring has four fold symmetry and has four experimental halls, each separated by the 90 degrees curved sections. At the rest two experimental halls (Nikko and Oho), QCS and QC1 are supported in the same way but different from Fig.1. Height of the support table is shorter. An example of the temperature variations in these three halls is given in Fig.8.

Every experimental hall is air-conditioned separately, so the temperature differs and there is no temperature correlation between halls as shown in Fig. 8. At the Fuji experimental hall there is a big temperature deviation from other halls. The structure of the TRISTAN tunnel differs at the Fuji experimental hall where the injection channels of electron and positron from the accumulation ring (TRISTAN-AR ring, 377 m in the circumference) are connected at the middle of the both sides of the experimental long insertion as shown in Fig.9. The AR ring is located at 4 m underground, whereas the MR ring at 11 m underground. The AR ring, closer to the ground surface than the MR ring and having two experimental halls at the ground level, is easily affected by the outdoor temperature variation. Ventilation through the injection channels gives the temperature variation at the Fuji experimental hall as shown in Fig.8 and also at the Fuji experimental long insertion.

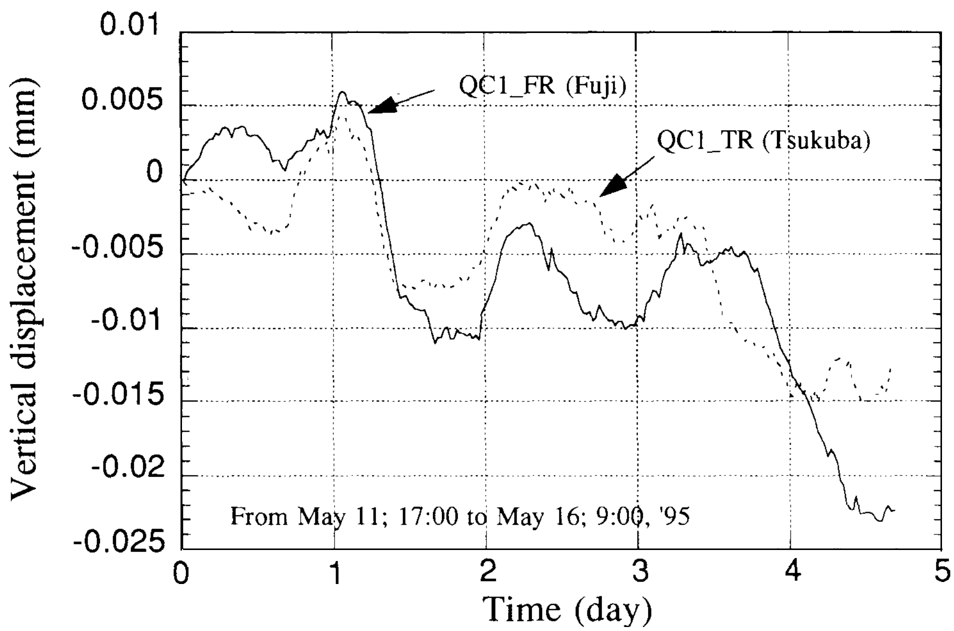

Fig.7 Vertical displacements of two QC1's positioned at diametrically opposite place of the TRISTAN-MR ring. One is in the Fuji (QC1-FR) and the other is in the Tsukuba experimental hall (QC1-TR). Roth magnets sit on the support tables with same structures. Data have no meteorological compensation.

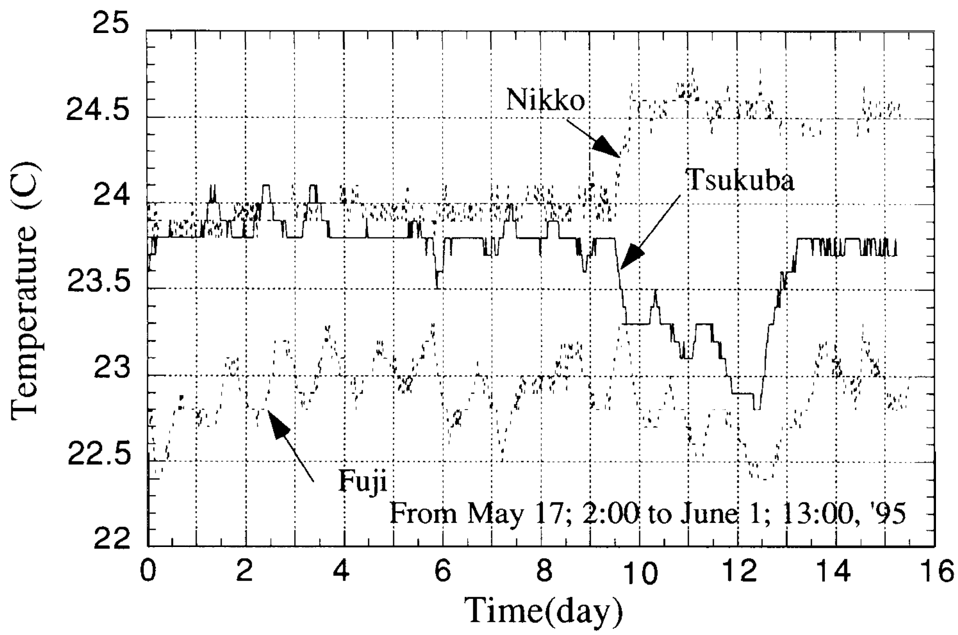

Fig.8 Temperature variation near at QC1 in three experimental halls (Fuji, Tsukuba and Nikko). For first 9 days all magnet excited at 8 GeV, for next 4 days all magnets were not excited because of accelerator maintenance, and for last 3 days magnets were excited again.

4. CONCLUSIONS

Main sources of the vertical COD fluctuation of the TRISTAN-MR ring will be the vertical displacement of the strong focusing elements close to IP'S. Direct observation of this displacements were performed using the laser interferometer in the experimental halls under the beam operation. Concluding the results,

(1) Temperature in the MR tunnel changes according to the pattern of the beam energy and consequently the quadrupoles of the mini-p system displace vertically. Temperature variation differs in each experimental hall.

(2) The fine structure of the vertical displacement of the mini-p quadrupole coincides with the temperature variation due to the magnet excitation in the MR tunnel.

(3) Gradual slow change of temperature in the experimental hall does not coincide with the beam operation pattern, but it is superposed to the fine structure and contributes to the vertical displacement with longer period. Its peak-to-peak variation is 1.7 degrees and coincides with the variation measured at the level of the magnet support table of the experimental hall. Floor temperature has the same tendency but the amplitude was smaller. This slow change is due to the control of the air-conditioner.

(4) It takes about two days to attain the equilibrium state of the vertical quadrupole position after the startup of the normal beam operation up to 29 GeV. Temperature in the MR tunnel at the equilibrium state is higher by 2 degrees compared to the equilibrium temperature when waiting at injection energy at 8 GeV for long time.

(5) Temperature correlation between inside and outside of the MR tunnel was observed as the periodical vertical movement of IP quadrupoles only when all magnets were excited stationary.

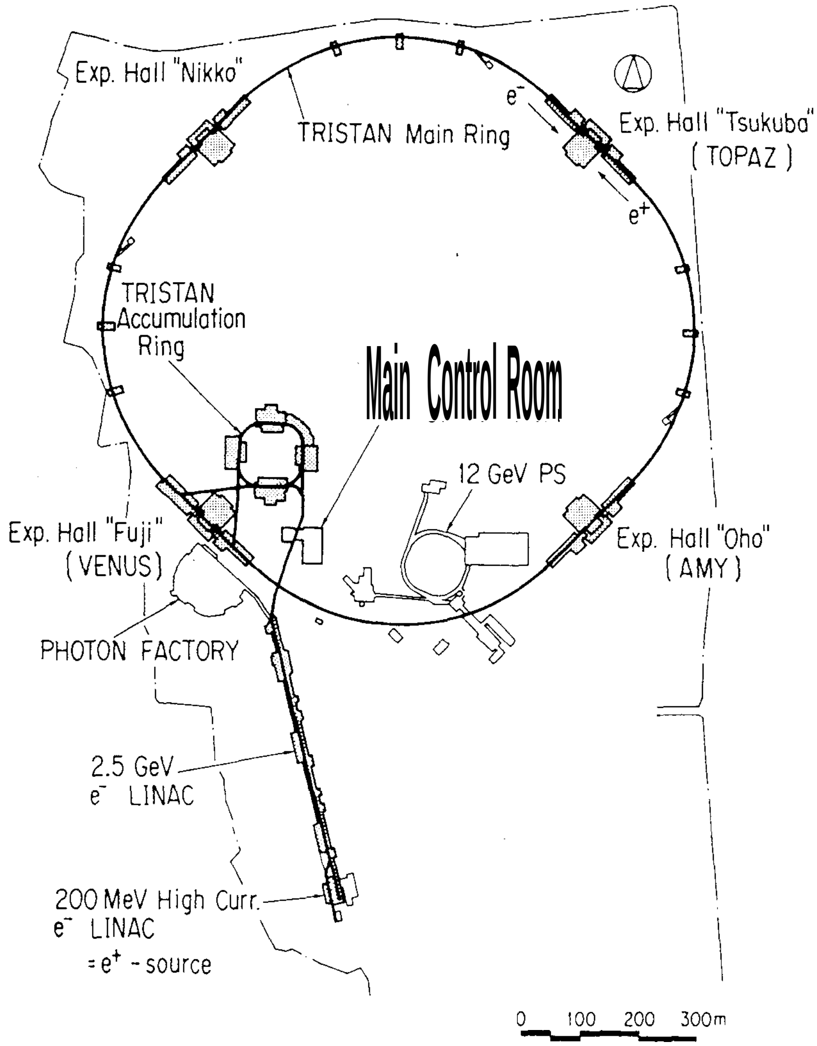

Fig.9 Interconnection of the TRISTAN-MR and -AR rings. AR ring is 4 m underground and MR ring 11 m underground. They are connected by the electron and positron injection channels at both sides of the Fuji experimental hall.

Magnitude of the vertical displacement of the QC1 quadrupoles close to IP's is 10 ~ 30 μm for the long rage and 10 ~ 20 pm for the short range (less than few hours). This is amounts to the vertical COD of more than 0.1 mm. The COD changes gradually and the COD correction is performed when exceeding some threshold. Correction intervals change from day to day. In the worst case it is required at every filling time and in the best case it is stable as long as one day. Horizontal displacement of, the QC1 quadrupoles estimated from the tilt measurement [1] is smaller by an order than the vertical one.

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