

CLOSED ORBIT CORRECTION OF THE NSLS VUV RING\*

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Summary

We describe the results obtained from the orbit correction system in the NSLS VUV storage ring which consists of 24 PUE stations and 16 horizontal and vertical correction dipoles. The data were obtained by the PUEREAL module of the RING control program which provides automatic switching of the signal from individual electrodes of the PUE stations and provides a readout at harmonic of the RF frequency. The closed orbit is then calculated and corrected by measured displacements of the PUE's from the adjacent quadrupoles. The ORBIT module of the RING program was used to minimize the RMS orbit deviations choosing the most effective correctors and calculating their strengths. For the horizontal case, the correction was accomplished using 3 correctors in two iterations starting with RMS values  $X = 2.9$  mm to  $X = 0.9$  mm. Vertically three iterations and 6 correctors were required to correct the RMS value from  $Z = 6.8$  mm to  $Z = 0.8$  mm.

Orbit Measuring System

The orbit measuring system in the VUV ring consists of 24 sets of pick up electrodes (PUE), and 16 horizontal and 16 vertical correctors. A quadrant of the ring is shown on Fig. 1.

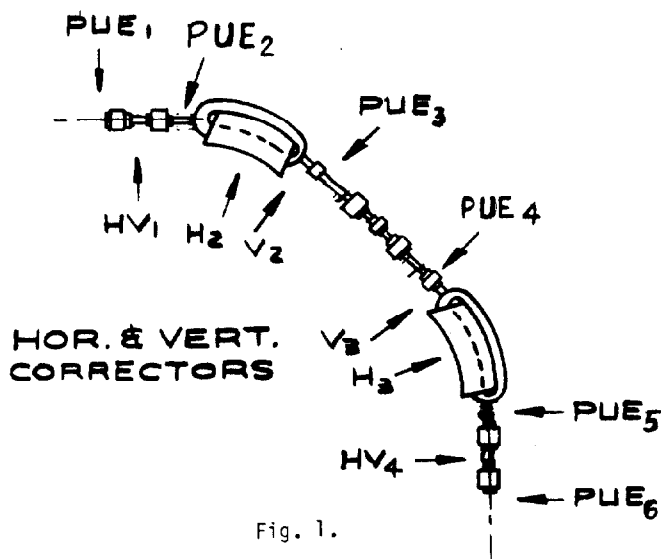


Fig. 1.

Each of the PUE stations consists of four circular electrodes 18 mm in diameter, mounted on an SMA type RF vacuum feed through connector as shown in Fig. 2. The two upper and two lower electrodes and their connections are preassembled on circular disks, pretested and welded into carefully machined recesses in the vacuum chamber.

The signals induced on these electrodes are sampled sequentially by means of a system of coaxial switching relays. They are then detected by a Hewlett Packard model 8555 spectrum analyzer used as a fixed frequency receiver tuned to a harmonic of the electron

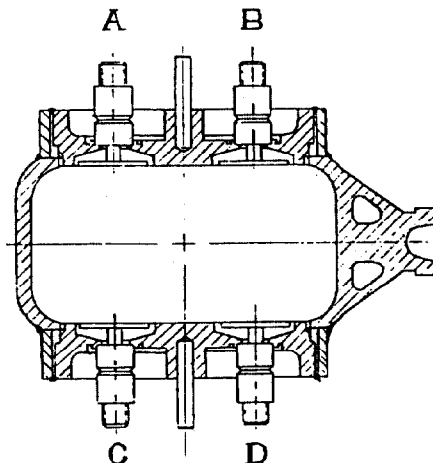


Fig. 2.

bunch frequency. This instrument has good frequency and gain stability, adjustable bandwidth, and a linear detector, all features which are needed for this application. The DC output of the spectrum analyzer which is proportional to the electrode signal voltage at the selected frequency is processed by an analog to digital converter and the value is stored in a  $\mu$ -processor dedicated to the PUE system. The RF signal on a pick up electrode is a few hundred microvolts per milliamp of beam in the storage ring. The system sensitivity allows position measurements to be made on stored currents of a fraction of a mAmp.

Also, part of the orbit measuring system are the different modules of the NSLS control program RING\*\*. PUEREAL<sup>3</sup> is the module for orbit measurements, ORBIT is for orbit correction and simulation and PLRING is to generate color graphic displays.

Orbit Measurement

The PUEREAL program instructs the  $\mu$ -processor to sequentially switch to each of the 4 electrodes of each of the 24 PUE stations to read and store the digitized signals. (A dwell time of 200 msec per electrode allows for coaxial relay switching and receiver settling, and permits data acquisition for a complete orbit in 20 sec.) The program then calculates the horizontal and vertical displacements for the  $i$ -th PUE as

$$X_i = K \frac{(A+C) - (B+D)}{A+B+C+D} + \Delta X_i; \quad Y_i = K \frac{(A+B) - (C+D)}{A+B+C+D} + \Delta Y_i$$

where A,B,C,D are the digitized signals from the corresponding electrodes (see Fig. 2.). K is a calibration factor (found to be well approximated by a constant up to ~ 10 mm displacements) and  $\Delta X_i, \Delta Y_i$  are

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\*\*The RING<sup>1</sup> program is an adaptation of PEP's SCORE<sup>2</sup> Program.

the H and V position offsets of the electrodes found by careful mechanical survey. As a preliminary validity test, the readings from those PUE stations where the sum  $\Sigma_i = A+B+C+D$  differs from the average  $\bar{E}$  by more than 15% or where the cross difference  $\Delta_i = (A+D) - (B+C)$  (which should be zero) is larger than 15% of  $\bar{E}$  were rejected.

#### Closed Orbit Corrections and Orbit Simulations

Another program module, ORBIT<sup>1</sup>, was used to perform the correction of the closed orbit using a specified number of correctors. ORBIT computes the betatron functions,  $\alpha$ ,  $\beta$ ,  $\phi$ , using a model of the machine lattice and the magnets, and using the present value of magnet strengths. The program chooses the most effective N correctors\*, calculates the necessary kick at each of them and calculates the corrected orbit, guiding the operator to choose and implement the most suitable solution. ORBIT also has the capability of ignoring correctors and PUE stations (when the corrector strength or the measured displacement exceeds a maximum value).

ORBIT can be used (i) on-line, calculating all the magnet strengths from the digital setpoints in corresponding  $\mu$ -processors and from the measured calibration factors and also calculating and implementing the new solutions, or (ii) off-line reading the "present" magnet strengths from data files.

The orbit measurement and preliminary data analysis requires more time than the orbit correction itself, since repeated execution of the ORBIT program is required to decide what is the most desirable solution (how many correctors to use). Therefore, we chose the option that ORBIT reads the orbit data measured and written onto a data file by PUEREAL as opposed to the option when ORBIT activates PUEREAL every time it is executed. This method also has the advantage of being able to correct the H & V orbits measured at the same time.

The ORBIT program may also be used to make a local orbit change or simulate the effect of powering selected correctors. These options were used to test the credibility of the PUE data. One such test was the comparison of the calculated and measured responses on all PUE's of the individual correctors.

#### Fourier Analysis of the Orbit

Further confirmation of the validity of the orbit data came from Fourier analysis<sup>5</sup>. Let  $g(k \cdot \Delta S)$ ,  $k = 1, \dots, N$  be the sampled orbit, where  $\Delta S = L/N$  is the sampling interval,  $L$  is the circumference of the ring,  $N$  is the number of samples. The Fourier transform of  $g$  can be calculated in polar coordinates as  $G(n/NT) = A_n e^{i\psi_n}$ ,  $n = 1, \dots, N/2$  where  $A_n$  is the amplitude and  $\psi_n$  is the complex phase corresponding to the  $f = (n-1)/NT$  frequency.

The measured orbits were sampled at 32 equidistant points around the ring (linearly interpolating between the measured points). These data then were analysed with a fast Fourier transformation program (FFT)<sup>6</sup>. On the other hand, ORBIT was used to generate a random orbit which in turn was analysed the same way by Fourier transformation. In some cases, when the orbit proved to be difficult to correct with implementable corrector strengths, Fourier analysis was used to

determine if the measured orbit exhibited some "unphysical" features. In many such cases, we found that the contribution of higher harmonics was larger than for a "random" orbit with the same RMS-value. The  $A_n$  coefficients for (a) calculated random, (b) measured uncorrected, and (c) corrected measured orbits are shown in Fig. 3 for the vertical case. The similarity of the "random" and measured uncorrected orbits are convincing.

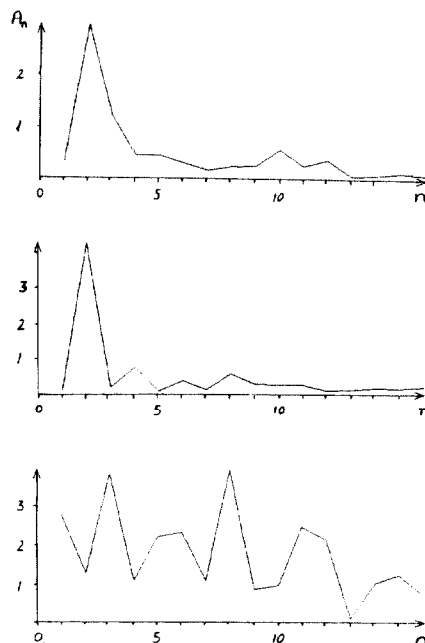


Fig. 3.

#### Results

We were able to store beam with all horizontal correctors set to zero, thus measuring the H closed orbit of the "bare" machine. ORBIT was then used on the horizontal bare orbit predicting the decrease of the RMS value from the measured  $X_{\text{bare}} = 2.9$  mm to  $X_{\text{calc-1}} = 1.0$  mm using  $\theta_1 = -0.5$  mrad. After implementing the change, the orbit was measured with an RMS value of  $X_{\text{meas-1}} = 1.6$  mm. Using ORBIT on this orbit again, we implemented a solution using  $\theta_1 = -0.6$  mrad,  $\theta_8 = -0.1$  mrad,  $\theta_7 = 0.8$  mrad and  $\theta_{12} = -0.2$  mrad, with the prediction of  $X_{\text{calc-2}} = 0.7$  mm. The final measured orbit showed  $X_{\text{meas-2}} = 0.9$  mm.

Figures 4a 4b and 4c show the horizontal bare and final corrected orbits and the used corrector strengths, respectively. As an illustration of the man-program interface, Fig. 6 shows the operator screen for one of the ORBIT runs.

The beam was stored with one vertical corrector powered whose effect the ORBIT program calculated and deducted from the measured orbit, thus arriving to the vertical bare orbit (see Fig. 5a). Then an iteration, similar to the horizontal case was carried out. The first chosen solution of ORBIT used 3 correctors with  $\theta_2 = -1.0$  mrad,  $\theta_3 = -0.4$  mrad and  $\theta_{10} = 1.2$  mrad bringing the orbit from an RMS value of from  $Y_{\text{bare}} = 6.8$  mm to  $Y_{\text{calc-1}} = 0.9$  mm, with the implemented measured orbit showing  $Y_{\text{meas-1}} = 1.7$  mm. In the second step with 2 additional connections;  $\theta_4 = -0.4$

\*The program uses the original MIKADO<sup>4</sup> subroutines

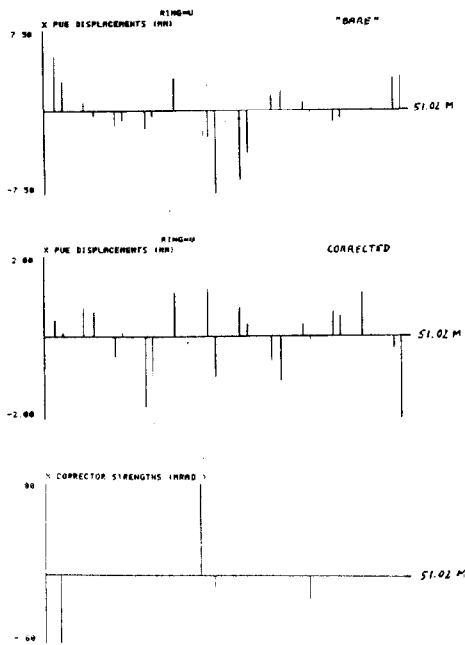


Fig. 4.

mrad and  $\theta_{15} = -0.2$  mrad the calculated and measured RMS values were:  $Y_{\text{calc-2}} = 1.0$  mm and  $Y_{\text{meas-2}} = 1.2$  mm. We decided to further improve the orbit. Using 1 additional corrector:  $\theta_7 = 0.3$  mrad, both the calculated and measured orbits had  $Y_{\text{calc-3}} = Y_{\text{meas-3}} = 0.8$  mm. The final measured orbit is shown on Fig. 5b.

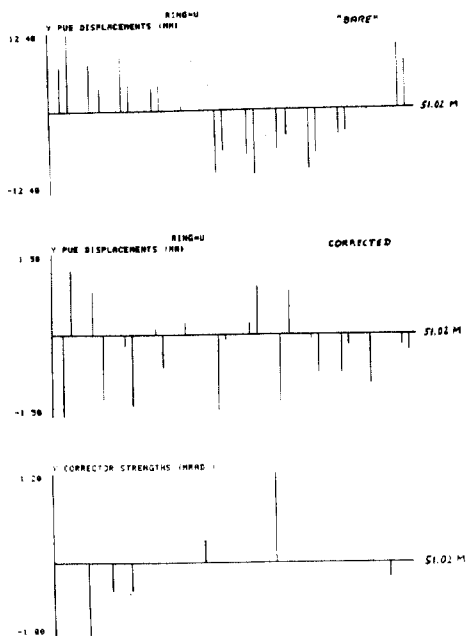


Fig. 5.

The reproducibility of the position measurements is .2 mm. It is difficult to determine the real measurement error which is due to multiple reasons; signal jitter, non-linearity of the detector, quantization error in the analog-to-digital conversion and survey error.

Orbit correction is performed on the VUV ring periodically, in case of need.

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RINGS (B,U,X) = U  MOM. COMP. FACTOR X LENGTH = 1.73
ENERGY (IN GEV) = 0.6050
PLANE (1/HOR. 2/VERT.) = 1 CORRECTION (LOCL, GLOB, CALC) = GLOB
START WITH CORRECTORS = 0 (0/NO 1/YES)? 0  NUMBER OF CORRECTORS TO USE = 1
X-TUNE= 3.160, Y-TUNE= 1.300  PUE DISPLACEMENTS FROM 1/FILE OR 2/MICRO? 1
CORRECTOR STRENGTHS BEFORE/AFTER CORRECTION (MRAD)
ID. = 1
BEFORE = .0
AFTER = -.5
PUE DISPLACEMENTS BEFORE/AFTER CORRECTION (MM)
BEFORE = 5.0 2.7 .8 -.5 -1.4 -.9 -1.6 -.8 3.0 -2.4 -7.5 -6.3 -3.8 1.3
        1.8 .7 -.3 -1.1 -.8 -.2 2.9 3.1
AFTER = .3 -.1 .7 .8 .6 1.9 -.1 -.2 .7 .3 -2.6 -1.1 -.8 .3
        -.1 .1 -.7 -.0 .2 1.5 -.2 -2.0
RMS BEFORE = 2.94678  RMS AFTER = .962828
CHANGE BEAM ENERGY BY DEL/E= -7.578670E-04
DISPLAY DISPLACEMENTS AND CORRECTOR STRENGTHS (0/NO 1-4/MON.)?

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Fig. 6.

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