

DISPERSION AND BEAM OPTIC PARAMETER MEASUREMENTS IN THE TRANSPORT LINE (E-WEG) FROM DESY II TO PETRA III

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Abstract

The transport line E-Weg extends from the extraction septum in DESY II to the injection septum in PETRA III, and transports electrons at a beam energy of 6.0 GeV. It consists of 3 parts. The first part is in the DESY tunnel, the second part is a long drift space in a slanted tube and the third part is in the PETRA III tunnel. The vertical plane difference between the accelerators is 1.28 m. The optics was derived from initial values at Übergabepunkt (UGP) from a previous optics. The total length of the transfer line is about 203 m. Ten screen monitors are used to estimate the profiles of the beam spot for the optics measurements, while 8 BPMs, mostly adjacent to the screens, are used to compare and control the orbits. Two scrapers are installed on either side of the long drift space to trim the beam dimensions in transverse plane. Two FCTs are used to measure the beam current and the transfer efficiency. The transverse dispersion and beta functions are measured by extracting the beam from DESY at different energies and analysing the beam profiles at the screen as well as positions at BPMs. The details of such measurements are reported in this paper.

INTRODUCTION

The E-Weg is designed to deliver an electron beam from DESY II to PETRA III[1-3], a 6 GeV synchrotron light source with a horizontal beam emittance of 1.3 nm.rad with 1% emittance coupling. It consists of 3 parts such as, a part of it is in DESY tunnel, the long drift space is in a slanting tube and the third part is in PETRA III tunnel. The vertical plane difference between the tunnels are 1.28m, the DESY tunnel is in lower respect to PETRA III. The E-Weg optics was derived from the initial values at UGP (transfer point) from previous optics. The UGP is at the entrance of the first quadrupole magnet in the transfer line. Most of the references were available from this point. The total length of the E-Weg is 203.37m. It consists of 12 quadrupoles, 7 horizontal bending magnets, 5 horizontal correctors, 7 vertical correctors, and one vertical bending magnet. There are 10 screen monitors to provide the beam profiles of the intercepted beam spot. In addition there are 8 BPMs mostly adjacent to the screen monitors to compare and control the transverse orbits. For trimming of the beam profiles in transverse plane two scrapers are installed on either side of the long drift space. Two current transformers (FCT) are in use for measuring the beam current in the transport line.

The extracted beam from DESY II with a theoretical horizontal emittance of 350nm.rad and vertical emittance

of 35nm.rad considering coupling of 10%, passes through the magnetic fringe fields of quadrupole QD43, sextupole SD43, dipoles B43 and B44 of DESY II booster ring in operation. So the extracted electron beam gets kicks from these magnets before reaching at UGP. From an old optics printouts[4] information about the effect of these magnets on E-Weg was implemented to match the optics at UGP and then whole E-Weg was further modified to take the requirements of PETRA III injection point ($\beta_x = 19$ m; $\eta_x = 0.4$ m, $\beta_y=9.31$ m) with E-Weg parameters at point of injection ($\beta_x = 12.981$ m; $\beta_y=10$ m). The present optics used is shown in the Fig.1.

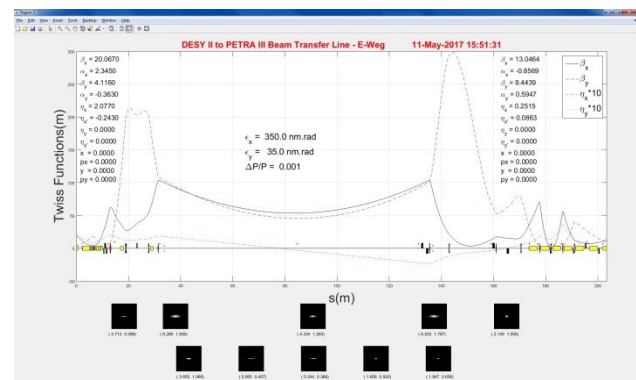


Figure 1: The theoretical transverse betatron and dispersion functions of the E-Weg with tune values $\mu_x = 1.7167$, $\mu_y = 1.5620$.

TRANSVERSE OPTIC PARAMETERS MEASUREMENTS

Transverse Dispersion Measurements

The dispersion function can be calculated from the centroid shift of the beam spot at screens (Beam Profile Monitors) by extracting the beam from DESY II at different energies. The centroid shift will be $\Delta z = \eta_z \times \Delta P/P$, where $z = (x, \text{horizontal or } y, \text{vertical})$ and η is the dispersion function of the respective plane at that location with the relative momentum spread of $\Delta P/P$. It is possible to change the energy of the extracted beam from DESY II with $\Delta P/P \sim 0.001$ or 0.002 i.e. 6 to 12MeV at an energy of 6GeV. With $\Delta P/P \sim 0.001$, this will give a centroid shift (0.099, 0.59)mm at 72m screen and (1.59, 1.12)mm at 119m screen location as per the theoretical expectations. It is seen that the quadrupoles also change the focussing strength due to energy change that affects the dispersion function too. But the change of dispersion function due to quadrupole strength change is neglected. A change of 1000 turns at DESY extraction makes an

energy change of 90.8MeV for the measurements. In practice ± 20 turns from the working point is considered for dispersion measurements.

Beam Optics Parameters Measurements

Consider a beam in the two-dimensional phase space $(x; x')$ and assume the distribution is Gaussian with the density function given by [5],

$$\rho(x, x') = N \exp\left[\frac{-(\sigma_{22}x^2 - 2\sigma_{12}xx' + \sigma_{11}x'^2)}{2|\sigma|}\right],$$

with symmetric beam matrix, $\sigma = \begin{pmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{12} & \sigma_{22} \end{pmatrix}$. The task is

to find the emittance $\varepsilon = \sqrt{|\sigma|}$. When a profile monitor intercepts the entire beam, only the spatial width at that point, $\sqrt{\sigma_{11}}$ is determined.

However, the other matrix elements may be inferred from beam profiles taken under various transport conditions downstream of the given point if the transformation of the beam matrix between those points is understood.

If a beam has matrix σ^0 at some point, s_0 , and matrix σ^1 at some other point, s_1 , downstream, the transformation of the beam between s_0 and s_1 may be characterized by a *transfer matrix* \mathbf{R} :

$$\mathbf{R} = \begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix}, \text{ such that } \sigma^1 = \mathbf{R}\sigma^0\mathbf{R}^T.$$

Where \mathbf{R}^T is transpose of matrix \mathbf{R} . The total transfer matrix of a series of beam line components is just the product of the matrices of the individual components. Since the matrix element that we can measure at a given point is σ_{11}^1 .

We will write out the expression for this element as a function of σ^0 :

$$\sigma_{11}^1 = R_{11}^2\sigma_{11}^0 + 2R_{11}R_{12}\sigma_{12}^0 + R_{12}^2\sigma_{22}^0 \quad [1]$$

The elements of σ^0 can be deduced from a set of three measurements of σ_{11} obtained from beam conditions described by three different transfer matrices. In practice more than three independent width measurements are taken and the data subjected to least-squares analysis.

The simplest example in principle is measurement of the beam width at several locations along the beam line, s_i , separated only by drift spaces. Call the position of the first monitor s_0 and the beam matrix at this point σ^0 . The next monitor downstream is at point s_1 , where the beam matrix is σ^1 . The transfer matrix for a drift of length $L_1 = s_1 - s_0$ is

$$\mathbf{R}_L = \begin{pmatrix} 1 & L_1 \\ 0 & 1 \end{pmatrix}, \text{ We find } \sigma_{11}^1 = \sigma_{11}^0 + 2L_1\sigma_{12}^0 + L_1^2\sigma_{22}^0$$

Several different L_i forms a set of equations from which the elements of σ^0 are extracted. Now considering the case of taking profiles at three longitudinal positions s_0, s_1

and s_2 such that s_1 and s_2 are separated by drift spaces with lengths of L_1 and L_2 from s_0 .

$$\sigma_{11}^1 = \sigma_{11}^0 + 2L_1\sigma_{12}^0 + L_1^2\sigma_{22}^0, \text{ and}$$

$$\sigma_{11}^2 = \sigma_{11}^0 + 2L_2\sigma_{12}^0 + L_2^2\sigma_{22}^0$$

We can solve for other elements of beam matrix at s_0 from the above two equations and with little algebra we find,

$$\sigma_{22}^0 = \frac{L_2(\sigma_{11}^1 - \sigma_{11}^0) - L_1(\sigma_{11}^2 - \sigma_{11}^0)}{L_1L_2(L_1 - L_2)}, \text{ and}$$

$$\sigma_{12}^0 = \frac{(\sigma_{11}^1 - \sigma_{11}^0 - L_1^2\sigma_{22}^0)}{2L_1}.$$

Knowing all the matrix elements of beam matrix at s_0 , $\sigma^0 = \begin{pmatrix} \sigma_{11}^0 & \sigma_{12}^0 \\ \sigma_{12}^0 & \sigma_{22}^0 \end{pmatrix}$ the beam optics parameters at s_0 is then easily calculated as follows,

$$\varepsilon = \sqrt{\sigma_{11}^0\sigma_{22}^0 - (\sigma_{12}^0)^2} \quad [2]$$

$$\beta = \frac{\sigma_{11}^0}{\varepsilon}; \quad \alpha = -\frac{\sigma_{12}^0}{\varepsilon}; \quad \gamma = \frac{\sigma_{22}^0}{\varepsilon}$$

Where ε is the beam emittance and α, β, γ are Twiss parameters at position s_0 .

The α, β and γ at point s_0 are transported to α, β and γ at point s_i , as follows,

$$\begin{bmatrix} \beta \\ \alpha \\ \gamma \end{bmatrix}_{s_i} = \begin{bmatrix} R_{11}^2 & -2R_{11}R_{12} & R_{12}^2 \\ -R_{11}R_{21} & 1 + 2R_{12}R_{21} & -R_{12}R_{22} \\ R_{21}^2 & -2R_{21}R_{22} & R_{22}^2 \end{bmatrix} \begin{bmatrix} \beta \\ \alpha \\ \gamma \end{bmatrix}_{s_0} \quad [3]$$

With some calculations the betatron functions are determined at different azimuthal positions s_1 and s_2 .

RESULTS AND DISCUSSIONS

A Java client program was developed to measure the beam positions in the E-Weg using the available 8 Beam Position Monitors (BPMs) placed side by side of Beam Profile Monitors. This program is also capable of changing the extracted beam energy by changing the extraction turn number of DESY II dipole ramping cycle taking ± 20 turns from mid of normal working of 6.0GeV. The orientation of profile monitors and sign of position monitors are ensured for correct interpretation of dispersion function. The measurements are carried out for several times, but the results of such an experiment is shown in Fig.2 with measured and corresponding theoretical values. Some of the values are plotted zero as the resolution of the BPMs unable to measure the difference. The list of theoretical and measured transverse dispersion functions at 8BPMs positions in the E-Weg are also listed in Table 1.

Table 1: List of Dispersion Functions

$-\Delta E(\text{GeV})$	On Energy(GeV)	$+\Delta E(\text{GeV})$	$\Delta E/E(\%)$	
6.0457	6.0475	6.0493	0.5953	
	Theoretical $\eta(\text{m})$		Measured $\eta(\text{m})$	
Name	η_x	η_y	η_x	η_y
M000	1.8802	0	-0.5216	0.0308
M020	1.9107	-0.0266	0.3603	0.0356
M119	-1.4793	-1.1492	0.0077	0.2602
M144	-0.4561	-0.9784	-0.8741	-0.6193
M161	0.4727	-0.6235	-1.1326	-0.5737
M169	1.2715	0.2927	0	0
M178	1.6634	0.5213	1.0812	0.189
M185	0.3395	0.3439	0.8062	-0.0808

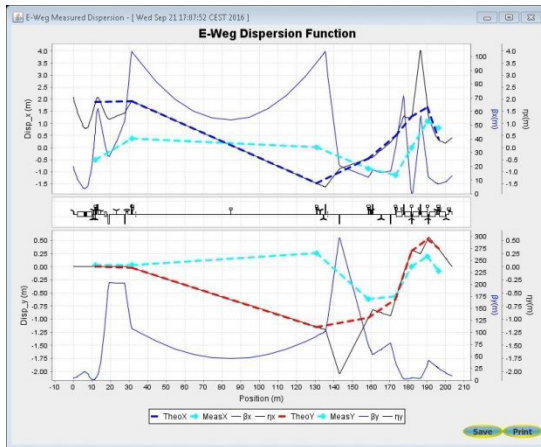


Figure 2: The measured transverse dispersion functions are plotted along with theoretical values.

There are only 3 beam profile monitors which are separated by drift spaces of 55.68m (SM072) and 102m (SM119) from first (SM019), used for beam emittance measurements. The beam profiles are measured using MATLAB utility fitting tools and one of them is shown in Fig.3[6].

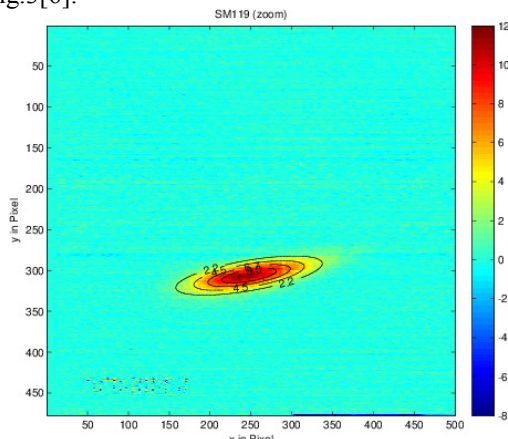


Figure 3: Beam profile measurements using MATLAB at SM119.

The measured beam sizes (σ) are tabulated in Table 2, which are further used to calculate the emittances and betatron functions (theoretical values are written in brackets for reference) at s_0 , s_1 , and s_2 using afore discussed equations 2 & 3.

Table 2: List of Betatron Functions

Monitor	$\sigma_x(\text{mm})$	$\epsilon_x(\text{nm.rad})$	$\beta_x(\text{m})$	α_x
SM019	5.253482	357	77.3(103)	0.828(0.958)
SM072	4.337361		53(54)	-0.386(-0.023)
SM119	6.9486		135(96)	-1.396(-0.89)
Monitor	$\sigma_y(\text{mm})$	$\epsilon_y(\text{nm.rad})$	$\beta_y(\text{m})$	α_y
SM019	0.98797	12.5	78(107)	1.05(1.177)
SM072	0.74694		45(45)	-0.45(0.005)
SM119	1.344465		144(92)	-1.70(-1.03)

CONCLUSIONS

The electron beam transfer line E-Weg, delivers beam from DESY II to PETRA III at 6.0GeV. This transfer line is optimised for better injection efficiency. Still the errors in the initial conditions of beam from DESY II, misalignments of magnets, resolution of BPMs and other factors are not ignored that will detriment the beam quality. Attempts are made to fix the optics of E-Weg from beam size measurements from beam profile monitors. We measured the beam optics parameters with the available beam monitoring systems which are not 100% agreement with theory, which may be further investigated. The measured horizontal emittance of 357 nm.rad and vertical emittance of 12.5nm.rad shows coupling of 3.5%.

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