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CHROMATICITY CORRECTION IN THE TRISTAN PHASE I
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Abstract

The TRISTAN main ring now under construction has four insertions. Besides the normal modes in which the four insertions have the same optics, the TRISTAN main ring will be operated in somewhat more complicated configurations with insertions having different optics. This report will consider chromaticity corrections using six families of sextupoles for the TRISTAN main ring with two different insertion types; opposite insertions have the same optics. The strength of correcting sextupoles is determined mainly using the W-correction method. The program PATRICIA is used to track the trajectories of test particles over 800 turns. The results show that the correction scheme adopted allows adequately large amplitudes of betatron and synchrotron oscillations.

KEYWORDS: storage ring, chromaticity correction

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§1. Introduction

In the TRISTAN main ring$^{1)}$, it is possible to install two different types of insertion in order to suit the different requirements of the physical experiments. Because ℓ_{int}, the distance from the interaction point to the nearest quadrupole, and β^*, beta functions at the interaction point are different in the two insertion types, they make different contributions to natural chromaticity. Hence, the chromaticity correction is somewhat complicated.

This report will discuss whether or not it is possible to correct the chromaticity by using an arrangement of six families of sextupoles in the whole ring and how to determine the strengths of the correcting sextupoles.

The chromaticity corrections for three possible operating modes in the TRISTAN main ring were performed. The results obtained show that the trajectories of particles with initial amplitudes of 11 σ in both transverse planes and with a synchrotron oscillation of 8 σ_e remain stable over 4 times the damping time. These results demonstrate that six families of sextupoles are flexible enough for chromaticity correction of the TRISTAN main ring with two types of insertion.

§2. Lattice optics

The lattice parameters of TRISTAN version 11 with low-β mode and mini-β mode are given in Ref. (2). The version described here, the TRISTAN version 11 B (V11B)$^{3)}$, has two different types of insertion to be installed in the ring. Compared with version 11, the main differences are as follows:

(1) Two of the four insertions have $\ell_{int} = \pm 2.7$ m, $\beta^*_y = 0.05$ m, $\beta^*_x = 0.8$ m. They will be referred to as the mini-β insertions, in which the first insertion quadrupole magnet will be replaced by a superconducting magnet. The other two have $\ell_{int} = \pm 4.5$ m, $\beta^*_y = 0.1$ m, $\beta^*_x = 1.6$ m. They will be referred to as the low-β insertions.

(2) For the requirements of the chromaticity correction, the insertions and the dispersion suppressors have been rematched. In the dispersion suppressors, five variable quadrupoles are used. Calculations using the program MAGIC show that we can match the normal cell of the phase advance 54°, 60° and 90° into the two different types of insertion without any additional aperture, and the beta functions in both planes are quite smooth.

(3) The condition of the strict periodicity of the beta functions in the RF section is given up in order to keep sufficient flexibility for adjusting the phase advance. This enables the working point to be adjusted over a wide range, while keeping the rest of the optics unchanged. To permit good injection and reduction of chromatic perturbation and orbit sensitivity to β^*, the detuned optics are retained. The ratio of horizontal and vertical beta function at the interaction points can be held constant while β^*_x and β^*_y are increased by as much as a factor 3.

(4) The quadrupoles in each type of insertion are controlled independently, resulting in a total of 25 families of quadrupoles to be used in the whole ring.

Some parameters of this version (V11B) are given in Table 1.

§3. Chromaticity correction scheme

The uncorrected chromaticities in the V11B are - 95.2 and - 63.8 in the vertical and horizontal plane, respectively. The low-β insertions make a larger contribution to the natural chromaticity than the mini-β insertions. The difference in the chromaticity between the two insertion types will make the chromaticity correction somewhat complicated. Hence, the arrangement and strengths of the correcting sextupoles have to be adjusted carefully in order to compensate this difference and reduce some undesirable effects of the correcting sextupoles.

(1) Constraints for the chromaticity correction scheme.

In the chromaticity correction for V11B, we try to adhere to following constraints:

(i) Six families of sextupoles are used in the whole ring rather than twelve.

(ii) The arrangements of the sextupoles are made as similar as for the normal low-β and mini-β mode, in other words, the sextupoles are arranged in mirror symmetry with respect to the center of the arc. Such a configuration is very simple and convenient for varying the operational mode, because there is no need to change the hardware.

(iii) The chromaticity correction method adopted here is still based on the W-correction, which attempts to correct the strong first-order chromatic effects arising from the insertion doublet.

(iv) Since the beam-beam interactions apparently cause the particles to have very large transverse amplitude but the momentum distribution remains Gaussian and falls off very rapidly$^{4)}$, we give more attention to the stability of particles with larger transverse amplitudes and with synchrotron oscillations only within the bucket height (corresponding to 7 σ_e).

(2) The possibility of chromaticity correction for the V11B using six families of sextupoles.

Strictly speaking, the superperiodicity of the main ring becomes 2 when two different types of insertion are incorporated. But it may be assumed that the complete lattice still has fourfold symmetry approximately, because the normal arc, dispersion suppressor and RF section are strictly symmetric with respect to the center of the arc. The difference between the two types of insertion is only a slight perturbation on the whole ring.

It is well known that the severity of chromatic effects is approximately proportional to ℓ_{int}/β^*_y, which are 54 and 45 in the mini-β and low-β insertion, respectively. Although there are some differences between them, their chromatic characteristics are very similar.

Because the luminosity is not sensitive to β^*_x, the difference in the chromatic perturbations between the low-β and mini-β insertions can be reduced by slightly changing β^*_x without additional aperture. This will tend to equalize the sextupole strengths needed in the two insertion types.

According to first order chromatic theory$^{5)}$, the very large chromatic perturbations arising from the insertion doublet oscillate at twice the betatron frequency and propagate into the main lattice through the RF section without change, except in phase. The perturbations at any given point in the main lattice are just functions of the phase advance between the insertion doublet and that point. By adjusting the phase advance between the insertion doublet and the first sextupole in the octant with the low-β and the mini-β insertions separately, the strong chromatic perturbations from both the low-β insertion and mini-β insertion may be reduced towards the main lattice, and the sextupole strengths needed can also be reduced. Linear chromatic perturbation theory has shown that it is also very important to adjust the first sextupole strength in order to confine the chromatic errors within a short distance in the main lattice. The conditions which make the chromatic perturbations minimum at the first sextupole have been discussed in Ref. (5).

As a consequence, it is possible to use six families of sextupoles to correct the chromaticity for the TRISTAN main ring with two types of insertion.

§4. Chromaticity correction procedure

The calculations for the correcting sextupoles are based on keeping the conditions of making the W-value zero at both the interaction point and the symmetry point of the arc. Table 2 gives the strengths of the correcting sextupoles for the low-β octant and for the mini-β octant, respectively. Because the chromatic perturbations in the two types of insertion are similar, the results show that only a very small difference exists in the required sextupole strengths.

If necessary, the difference in the strengths between the two insertion types may be further reduced by slightly changing β^*_x.

In principle, we can initially set the strengths of the sextupoles either for the low-β or for the mini-β octant, or their mean value. Then, we modify the strengths around those chosen in order to suit the chromaticity correction for the TRISTAN main ring with two types of insertion.

The program MAGIC can be used to calculate the variation of the beta functions throughout a ring, which is convenient for study of the dependence of chromatic perturbations arising from the insertion doublet on the phase advance. By carefully adjusting the phase advance between the insertion doublet and the first sextupoles in each octant seperately, it is possible to get favourable phase shifts which make:

i) The chromatic errors in both planes decrease towards the centre of the main arc, at which position they will be rather small.

ii) The particles with large transverse initial amplitudes remain stable over at least one damping time.

iii) The necessary strengths of the correcting sextupoles are as low as possible.

After careful adjustment, the phase advance between the interaction point and the first sextupole has been determined and it tends to give a working point around $\nu_x \approx 33.7$ and $\nu_y \approx 39.7$. The linear lattice obtained has a slightly different phase advance in the two insertion types and the values obtained are:

i) mode I (see note below)
In low-β insertion $\Delta\mu_x = 1.809 \times 2\pi$ $\Delta\mu_y = 2.426 \times 2\pi$
In mini-β insertion $\Delta\mu_x = 1.809 \times 2\pi$ $\Delta\mu_y = 2.424 \times 2\pi$

ii) mode II
In mini-β insertion (1) $\Delta\mu_x = 1.805 \times 2\pi$ $\Delta\mu_y = 2.419 \times 2\pi$
In mini-β insertion (2) $\Delta\mu_x = 1.818 \times 2\pi$ $\Delta\mu_y = 2.429 \times 2\pi$

iii) mode III
In low-β insertion (1) $\Delta\mu_x = 1.805 \times 2\pi$ $\Delta\mu_y = 2.419 \times 2\pi$
In low-β insertion (2) $\Delta\mu_x = 1.813 \times 2\pi$ $\Delta\mu_y = 2.429 \times 2\pi$

which indicate that the arc is not exactly centred in the phase advance.

It is well known that some non-linear chromatic effects, such as the variation of the tunes, of the amplitude functions, and of the dispersion with momentum error, particularly at the interaction region, must be taken into account. This can be done by using the information produced by the program PATRICIA6), which can calculate the magnitudes of various harmonics in the expansion of the tunes in terms of momentum error and the contribution of individual sextupoles to each of these harmonics. By carefully adjusting the strengths of the most effective sextupoles, the contributions of the harmonics which are close to 2ν may be reduced. So the non-linear chromatic effects will be reduced.

All the above adjustments should be performed while keeping the linear chromaticities nearly zero.

The stability of the betatron oscillation in the corrected machine has also been investigated by means of the program PATRICIA, which tracks the trajectories of test particles over 4 times the damping time.

The chromaticity corrections for several cases, with two types of insertion and with the same type of insertion but different parameters at the interaction point, have been studied, and the results are as follows:

i) mode I

low-β insertions (superconducting quadrupole off)

$\ell_{int} = \pm 4.5$ m $\beta^*_x = 1.6$ m $\beta^*_y = 0.1$ m

mini-β insertions (superconducting quadrupole on)

$\ell_{int} = \pm 2.7$ m $\beta^*_x = 0.8$ m $\beta^*_y = 0.05$ m the stability limits: 11 σ_x, 11 σ_y, 8 σ_e

ii) mode II

mini-β insertions (1) (superconducting quadrupole on)

ℓ_{int} = ± 2.7 m β^*_x = 0.8 m β^*_y = 0.05 m

mini-β insertions (2) (superconducting quadrupole on)

ℓ_{int} = ± 2.7 m β^*_x = 1.1 m β^*_y = 0.07 m

the stability limits: 11 σ_x, 11 σ_y, 7 σ_e

iii) mode III

low-β insertions (1) (superconducting quadrupole off)

ℓ_{int} = ± 4.5 m β^*_x = 1.6 m β^*_y = 0.1 m

low-β insertions (2) (superconducting quadrupole off)

ℓ_{int} = ± 4.5 m β^*_x = 2.0 m β^*_y = 0.16 m

the stability limits: 11 σ_x, 11 σ_y, 7 σ_e

These results show that an arrangement of six families of sextupoles can be used for correcting the chromaticity in the TRISTAN main ring with two types of insertion.

The stable regions found by tracking the particles for mode I are given in Fig. 1. It shows that the trajectories of particles with transverse initial amplitudes of at least 10 σ in both planes and with a synchrotron oscillation amplitude of 8 σ_e remain stable. The variations of the tunes, β and η at the interaction point with momentum error Δp/p in the two types of insertion are shown in Figs. 2 to 4. Figure 5 shows the phase-space diagrams up to 800 turns (∿ 4 times the damping time) for mode I. For other modes, the results obtained are almost the same. Table 3 gives two sets of sextupole strengths by which almost the same stability limits can be obtained. The detailed arrangement of the correcting sextupoles is given in Table 4.

Conclusion

Although two types of insertion are installed in the TRISTAN main ring, the chromaticity correction can still be performed with six families of sextupoles. By adjusting the phase advance in both planes between the insertion doublet and the first sextupoles in the octants with the low-β and the mini-β insertions respectively, the chromatic perturbations can be confined within a short distance in the main bending arcs.

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Table 1

General parameter of TRISTAN main ring V11B

Beam energy	E_0	= 30 GeV
Circumference	C	= 3018 m
Average radius of curved section	R	= 480.34 m
Number of interaction regions	N	= 4
Revolution frequency	f_{rev}	= 99.33 kHz
Synchrotron oscillation frequency	f_s	= 10.058 kHz
Damping time	τ_x	= 2.08 ms
	τ_y	= 2.08 ms
	τ_E	= 1.04 ms
Partition number	J_x	= 1.00005
	J_E	= 1.99995
Natural energy spread	σ_E/E_0	= 0.164×10^{-2}
Natural horizontal emittance	ε_{xo}	= 0.1798×10^{-6} m·rad
Bucket height	$\Delta E/E$	= 1.089×10^{-2}
Betatron oscillation tune	ν_x/ν_y	= 33.75/39.75
Phase advance per normal cell	$\mu_x = \mu_y$	= 60°
Natural chromaticity	ξ_x	= - 63.8
	ξ_y	= - 95.2
Beta function at colliding point		
Low-β insertion	β^*_x/β^*_y	= 1.6 m/0.1 m
Mini-β insertion	β^*_x/β^*_y	= 0.8 m /0.05 m

Table 2

Sextupole strengths ($\frac{1}{B\rho}B''\ell$, m^{-2}) for low-β and mini-β octants

	SF1	SF2	SF3	SD1	SD2	SD3
mini-β	-0.35328	-0.54409	-0.65332	0.26017	1.31206	1.34275
low-β	-0.34778	-0.55564	-0.74410	0.28227	1.33005	1.40528

Table 3 Sextupole parameters

(I)

Name	No.	Strength ($\frac{1}{B\rho}$ $B''\ell$, m^{-2})
SF1	40	-0.33399
SF2	40	-0.51628
SF3	40	-0.74671
SD1	40	0.27570
SD2	40	1.28064
SD3	40	1.41507

(II)

Name	No.	Strength ($\frac{1}{B\rho}$ $B''\ell$, m^{-2})
SF1	40	-0.34817
SF2	40	-0.54659
SF3	40	-0.70140
SD1	40	0.27113
SD2	40	1.38115
SD3	40	1.31564

Table 4 Lattice layout

Name	Length (m)						
Low-β insertion	97.4728	L4.5	QC1H	L1.0	QC2H	L7.9	QC3H
and RF section		L5.0	QC4H	LRF	QC5H	LRF	QC6H
		LRF					
		3	[QRDH	LRF	QRFH	LRF]	QRDH
		LRF	QRFH	LBF			
Dispersion suppressor	61.63	BXW	L.55	2	[QS3H	LBF	BX
		L.55	QS4H	LBF	BX	L.55]	QS5H
		L.55	SD1	L.55	BX	LBF	QS6H
		L425	SF1	L425	BX	L.55	QS7H
		L.55	SD2	L.55	BX	LBF	
Normal cell	193.44	4 [cell (SF2, SD3) cell (SF3, SD1) cell (SF1, SD2)]					
Wiggler cell	24.7171	QW4H	L425	SF2	L425	BX	L.55
		QW3H	L.55	SD3	L.55	BX	LBF
		QW2H	L425	SF3	L425	L1.6	QW1H
		L4.5					
(Wiggler cell)*	24.7171						
(Normal cell)*	193.44						
(Dispersion suppressor)*	61.63						
RF section and	97.4728	LBF	QRFH	LRF	QRDH	3	[LRF
Mini-β insertion		QRFH	LRF	QRDH]	LRF	Q6H2	LRF
		Q5H2	LRF	Q4H2	LC4	Q3H2	L11.4
		Q1H2	L.8	QSH2	L2.7		
Cell (SF, SD)		QFH	L425	SF	L425	BX	L.55
		QDH	L.55	SD	L.55	BX	LBF

Drift Length

Name	Length (m)	Name	Length (m)	Name	Lengths (m)
L4.5	4.50	L1.0	1.0	L2.7	2.7
L7.9	7.9366136	LC4	5.0	L11.4	11.4366136
LRF	6.0736219	L.55	0.55	L425	0.425
LBF	0.3	L.8	0.8	L1.6	1.647043

( )* represent mirror symmetry

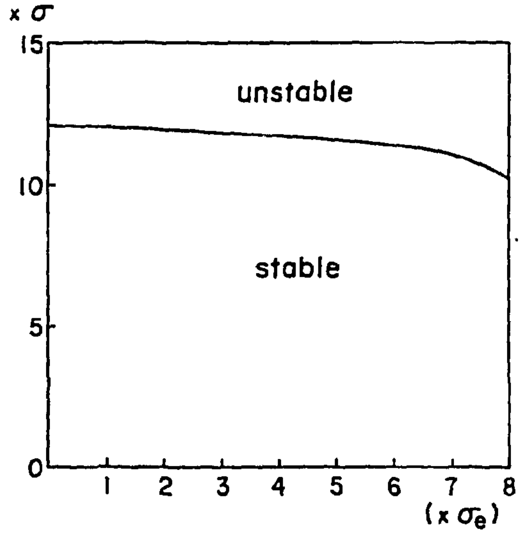


Fig. 1 Stability limit vs. transverse and longitudinal oscillation amplitudes.

σ number of standard deviations of transverse amplitude

σ_e number of standard deviations of momentum deviation

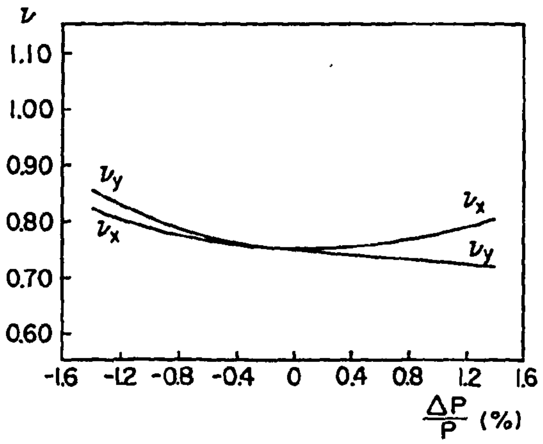


Fig. 2 Variation of non integral part of the tunes with momentum.

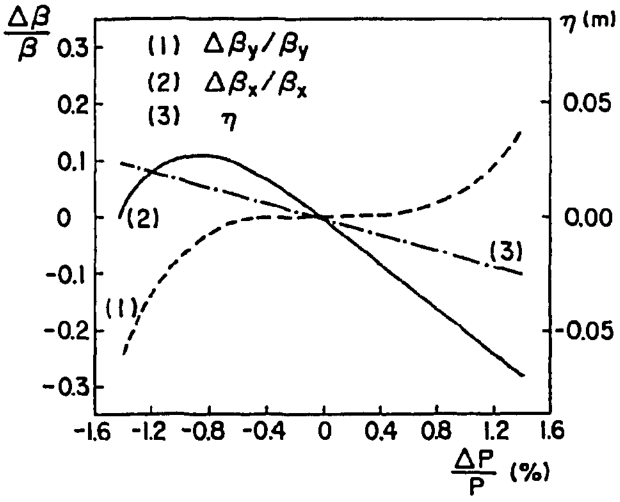


Fig. 3 Variation of β functions and η function with $\frac{\Delta p}{p}$ in the mini-β insertion.

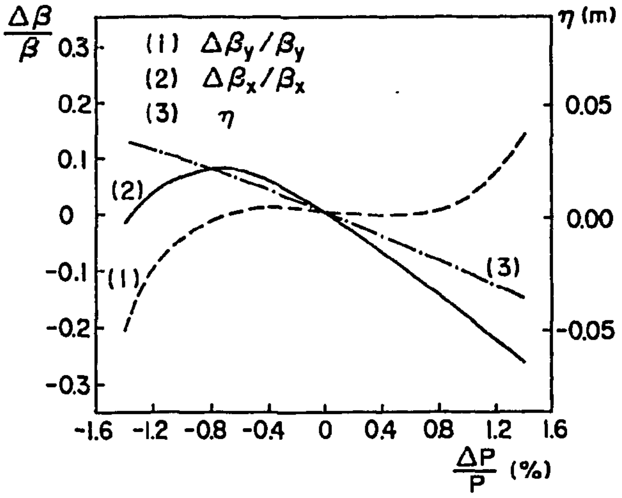
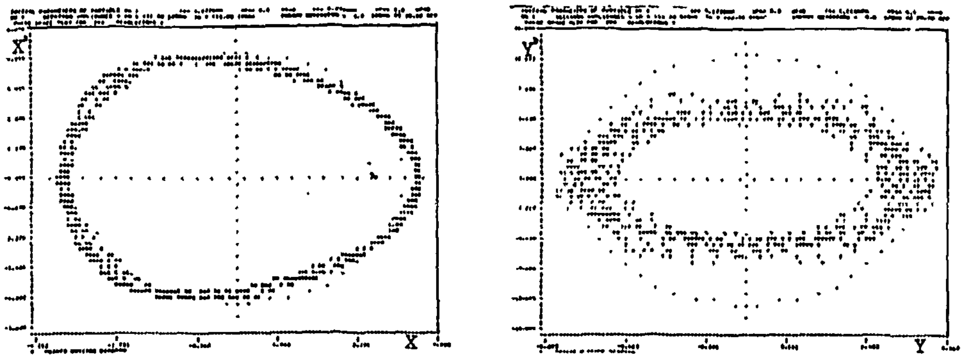
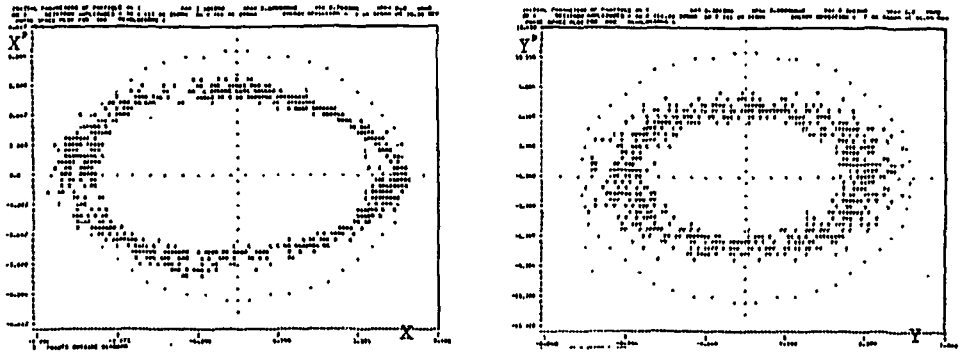


Fig. 4 Variation of β functions and η function with $\frac{\Delta p}{p}$ in the low-β insertion.



$\Delta P/p = 0$ $\Delta P/p = 0$



$\Delta P/p = 7\sigma_e$ $\Delta P/p = 7\sigma_e$

Fig. 5 Phase space diagram given by the program PATRICIA. Particles have 11 standard deviations of transverse amplitude and 0 and 7 momentum deviations.