Optical configurations with variable β^* at different IP locations in ATF2

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SYNOPSIS:

During ATF2 commissioning, it will be important to focus the beam to a proper waist at IP locations both upstream and downstream of the nominal one, where different beam size monitors will be placed with typical resolutions larger than that of the Shintake monitor at the nominal IP. In this note, a method to obtain optical configurations with variable β* at these different IP locations is described, enabling to match the measurement resolutions of these monitors with the linear beam size at the waist, while attempting to retain the overall features of the local chromaticity correction in the final focus optics. During commissioning, it is expected that one will gradually reduce β* after measurements at these different locations.

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Abstract

During ATF2 commissioning, it will be important to focus the beam to a proper waist at IP locations both upstream and downstream of the nominal one, where different beam size monitors will be placed with typical resolutions larger than that of the Shintake monitor at the nominal IP. In this note, a method to obtain optical configurations with variable β* at these different IP locations is described, enabling to match the measurement resolutions of these monitors with the linear beam size at the waist, while attempting to retain the overall features of the local chromaticity correction in the final focus optics. During commissioning, it is expected that one will gradually reduce β* after measurements at these different locations.

1. Introduction

Configurations with variable β* parameters are expected to be important during the commissioning of ATF2 to approach the minimal beam size gradually, with reduced sensitivities to imperfections initially, and optical features closely related to the nominal design, in particular in the chromatically corrected final de-magnifying telescope [1].

Moreover such configurations are also needed to focus the beam to measurable waists at the different IP locations where beam size monitors will be placed, with a tuneable linear beam size matching the corresponding measurement accuracies.

Variable β* configurations can be achieved by adjusting a set of quadrupoles immediately upstream of the final focus section, to change the Twiss parameters of the injected beam. The five sextupoles used in the chromatic correction section must also be re-adjusted slightly, to maintain proper cancellation of the main 2^{nd} order aberrations.

It has been found that such configurations can be achieved with the existing hardware, both for the planned nominal IP and for the locations displaced longitudinally.

In the following, the principle of how variable β* values can be obtained is first recalled. The variable β* configurations obtained at the nominal IP and at two locations upstream and downstream, displaced longitudinally by −54cm and +39cm respectively, are then described. In the last section, some further work needed for the practical implementation of these configurations during commissioning is outlined.

2. The principle of the variable β* parameter

2.1 Beam size dependence at a focal point on focal length and injected beam

The optical system illustrated in Figure 1 is a telescope.

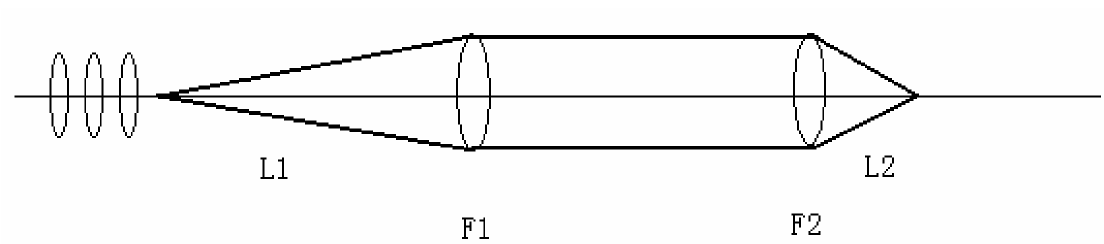

Figure: 1 A one-dimensional telescopic system.

The telescopic system shown in Figure 1 has an optical magnification M given by $M=F_2/F_1=L_2/L_1$ in thin lens approximation. The linear beam size achieved at a given desired focal point location is determined by both the injected beam phase space and by the focal lengths F1 and F2. For the designed ATF2 optics, the focal lengths are already fixed, so readjusting the Twiss parameters of the injected beam is the only way if the telescopic property is to be maintained.

In the ATF2 beam line, the quadrupoles QM12, 13, 14, 15 and 16 can be used upstream of the final focus section for such a re-matching – see Figure 2 where the nominal final focus β-functions are shown.

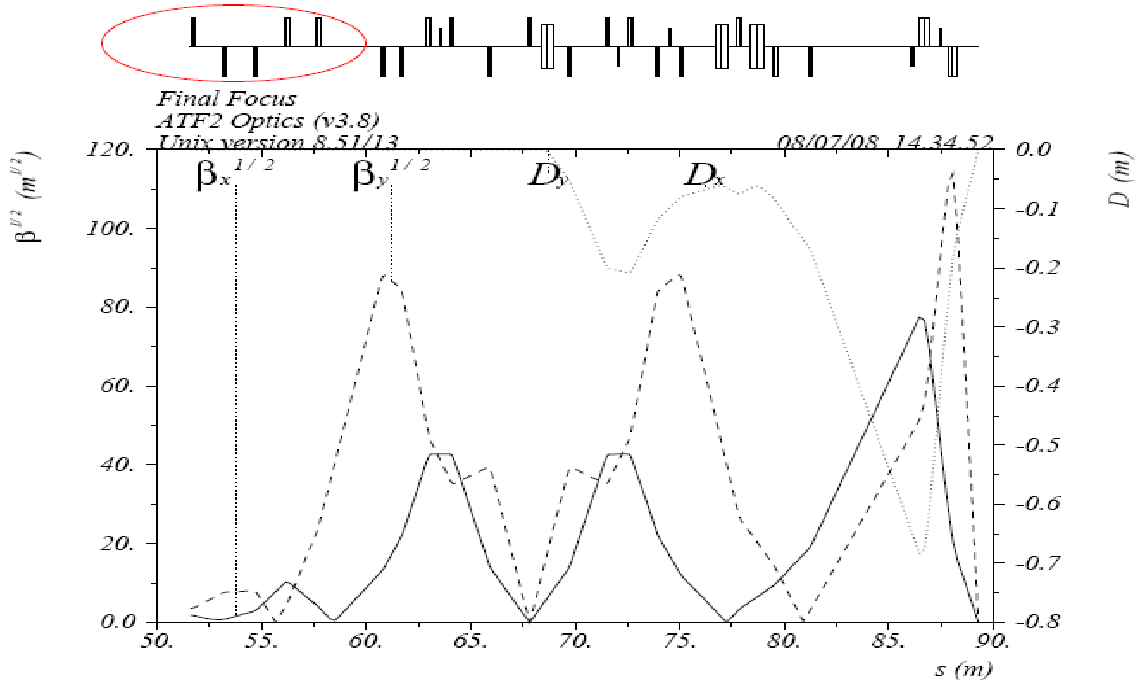

Figure 2: β-functions for the nominal ATF2 final focus optics. The quadrupoles used to re-match the Twiss parameters at the entrance of the de-magnifying telescope are highlighted.

3. Beam size for variable β* parameters at nominal IP

3.1 Matching procedure

The ATF2 line transports electrons with energies close to 1.3 GeV. To obtain and study the variable optics, the MAD [2] tracking module is used. The β functions in both transverse planes are changed at the interaction point by successively applying the following fitting conditions:

- fit QM12, QM13, QM14, QM15, QM16 to obtain the wanted $\beta_{x,y}$ and to maintain $\alpha_{x,y}$=0 and D_x=0 at the interaction point,
- fit the sextupoles SD0, SF1, SD4, SF5, SF6 to cancel T_{122}, T_{126}, T_{166}, T_{342}, and T_{346}, which are the largest second order terms.

3.2 Results

Nominal ATF2 parameters are β_x = 0.004m and β_y = 0.0001m. By matching the above listed quadrupoles and sextupoles, a broad range of increased or decreased β_y values can be obtained around the nominal value - see Figure 3. The corresponding magnet strengths are listed in Table 1.

The minimum beam size which is achieved is σ_y = 23nm. It is obtained by tracking and fitting a Gaussian to the core of the distribution (see Figure 4) when β_y is about four times smaller than nominal. For this value, the linear beam size would be 17nm in the absence of higher order aberrations. For larger than nominal β_y values, the aberrations become negligible and the beam size from tracking then matches the linear one.

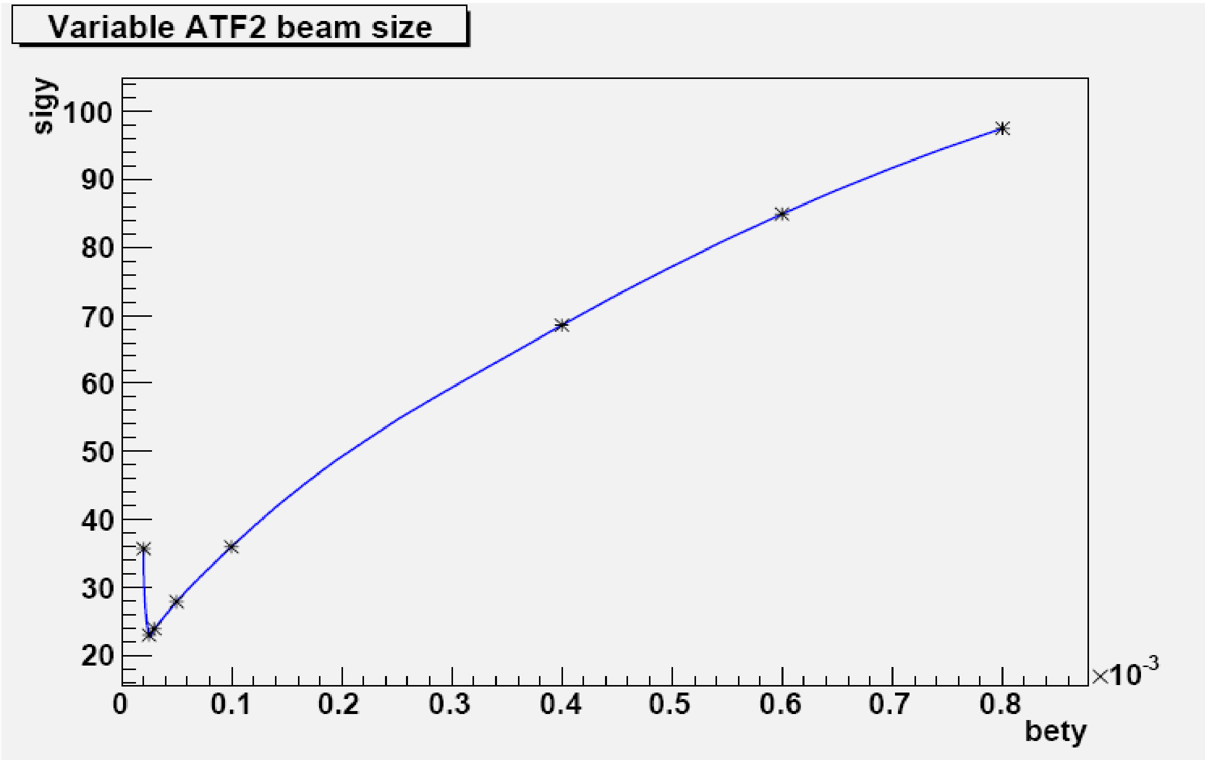

Figure 3: Variable beam size at the interaction point. β_y and σ_y are in units of metres and nanometres, respectively.

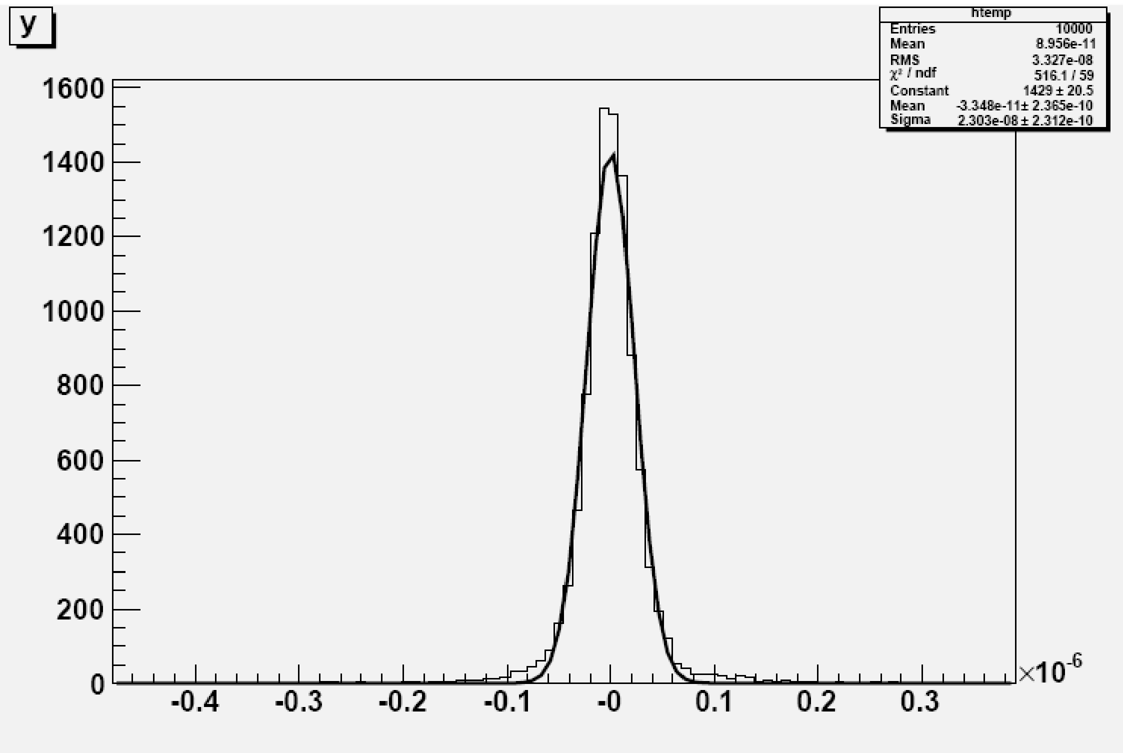

Figure 4: Minimum vertical beam size with a Gaussian fitting the core, corresponding to β_y reduced by a factor 4 and β_x at the nominal value.

β_y (m)	2.00E-05	2.50E-05	5.00E-05	1.00 E-04	4.00E-04	6.00E-04
σ_y(nm) - linear	15.2	17	24	34	68	83.3
σ_y(nm) - tracking	35.72	23	27.9	36	68.52	84.89
KLQM12(m^{-1})	3.10E-01	3.14E-01	3.28E-01	0.336	3.08E-01	3.70E-01
KLQM13(m^{-1})	9.28E-01	9.28E-01	9.26E-01	0.91	8.55E-01	8.63E-01
KLQM14(m^{-1})	-1.37E+00	-1.35E+00	-1.29E+00	-1.12	-6.07E-01	-9.62E-01
KLQM15(m^{-1})	6.64E-01	5.47E-01	3.79E-02	-0.32	-5.83E-01	-2.97E-01
KLQM16(m^{-1})	8.59E-01	7.91E-01	6.19E-01	0.58	7.02E-01	-1.90E-01
KLSD0(m^{-2})	4.36E+00	4.36E+00	4.37E+00	4.31	4.55E+00	4.65E+00
KLSF1(m^{-2})	-2.60E+00	-2.60E+00	-2.61E+00	-2.59	-2.66E+00	-2.67E+00
KLSD4(m^{-2})	1.51E+01	1.51E+01	1.51E+01	14.9	1.56E+01	1.59E+01
KLSF5(m^{-2})	-9.64E-01	-9.61E-01	-9.57E-01	-0.79	-9.99E-01	-7.69E-01
KLSF6(m^{-2})	8.45E+00	8.46E+00	8.51E+00	8.56	8.51E+00	8.74E+00

Table 1: Magnet strengths, linear β_y values and beam sizes for variable β_y configurations. The 5th column in red corresponds to nominal parameters. The tracking used $\delta_E/E = 10^{-3}$.

While β_y cannot be reduced below a quarter of its nominal value without the beam size becoming dominated by higher-order aberrations, much larger increases than shown in Table 1 can easily be obtained, e.g. up to a factor 1000. All magnet strengths remain within their specified range in all these cases.

Similar results can be obtained when β_x is changed as well.

4. Variable β* parameters at displaced IP locations

4.1 IP configuration for commissioning

During commissioning, three types of monitors are planned to measure the beam size at and near the IP. The Shintake monitor [3] will be placed at the nominal IP, downstream of the last final doublet quadrupole QD0. Its resolution ranges more than 300 nm. For initial commissioning, a carbon wire-scanner with a diameter of 7 microns will be available +39cm downstream of the IP, with a resolution down to about 2 microns. A novel kind of monitor, based on a nano-pattern deposition on a thin film, the "Honda-monitor" [4], is also projected -54cm upstream of the IP, with a resolution in the 0.3-1 micron range.

4.2 Matching procedure and results for the displaced IP at -54cm

4.2.1 Matching procedure

The following procedure is used to obtain a focal point at -54cm:

1) Use QM12-16 to obtain $\beta_x=4\times\beta_{x,nominal}$ $\beta_y=4\times\beta_{y,nominal}$ at the nominal IP. As discussed on Section 2.1, the magnification reduces with the focal length of

the final doublet, hence the necessity to initiate the procedure by increasing the β parameters at the nominal IP.

2) With the values obtained, fit QD and QF in the final doublet to obtain $\alpha_{x,y}$=0,
   - first at the nominal IP,
   - then in several successive steps, each of about -10cm, all the way to the location at -54cm.
3) Fit SD0, SF1, SD4, SF5, SF6 to obtain T_{126}=0, T_{122}=0, T_{346}=0, T_{342}=0, T_{166}=0.

The final result at -54cm is then close to the nominal parameters. For example in the above, $\beta_{x,y}$ = 0.005, 0.00011m and a tracked beam size of about σ_y = 39nm were obtained. The required QM12-16 and QD0, QF1 integrated magnet strengths are shown below in units of m^{-1}:

KLQM12 = 3.438185E-01
KLQM13 = 8.779989E-01
KLQM14 = -1.182823E+00
KLQM15 = 4.439885E-02
KLQM16 = -1.750061E-01
KLQD0FF= -2.204962E+00
KLQF1FF = 8.173861E-01

While the original specification of the power supplies for the final doublet quadrupoles QD0 and QF1, respectively (with 150 and 100 amps, respectively) would have enabled only maximum integrated strengths of -1.53 and 1.02 m^{-1} for these two magnets, which is too weak for QD0, a new and stronger power supply configuration is now being secured [5].

4.2.2 Increasing β_y at the waist at -54cm

Increasing β_y at the waist at -54cm is readily achieved following the matching procedure described in Section 3.1. For instance factors ten, twenty, forty, sixty, or eighty times the nominal β_y = 0.0001m parameter can easily be obtained. A few examples are listed below, with the corresponding β functions shown in Figures 5-7.

1) Factor 10 : β_x =0.004m, β_y=0.001m → $\sigma_{y,linear}$ = 108nm and $\sigma_{y,tracked}$ = 112nm
2) Factor 20 : β_x = 0.004m, β_y=0.002m → $\sigma_{y,linear}$ = 153nm and $\sigma_{y,tracked}$ = 155nm.
3) Factor 80 : β_x =0.004m, β_y = 0.008m → $\sigma_{y,linear}$ = 306nm and $\sigma_{y,tracked}$ = 305nm.

It has been checked that factors beyond 80 could also be obtained by re-matching QM12-16, if larger linear vertical beam sizes were desired at the displaced IP at -54cm. However, in this case, the basic features of final focus optics would no longer be preserved, making it probably less relevant.

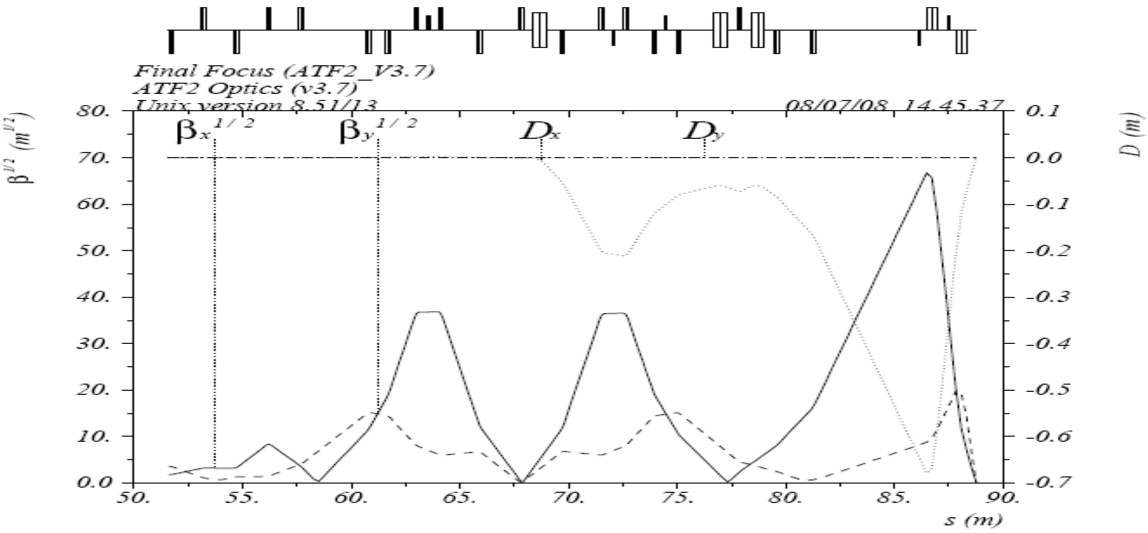

Figure 5: β functions with nominal β_x and ten times $\beta_{y,nominal}$ at the waist at -54cm.

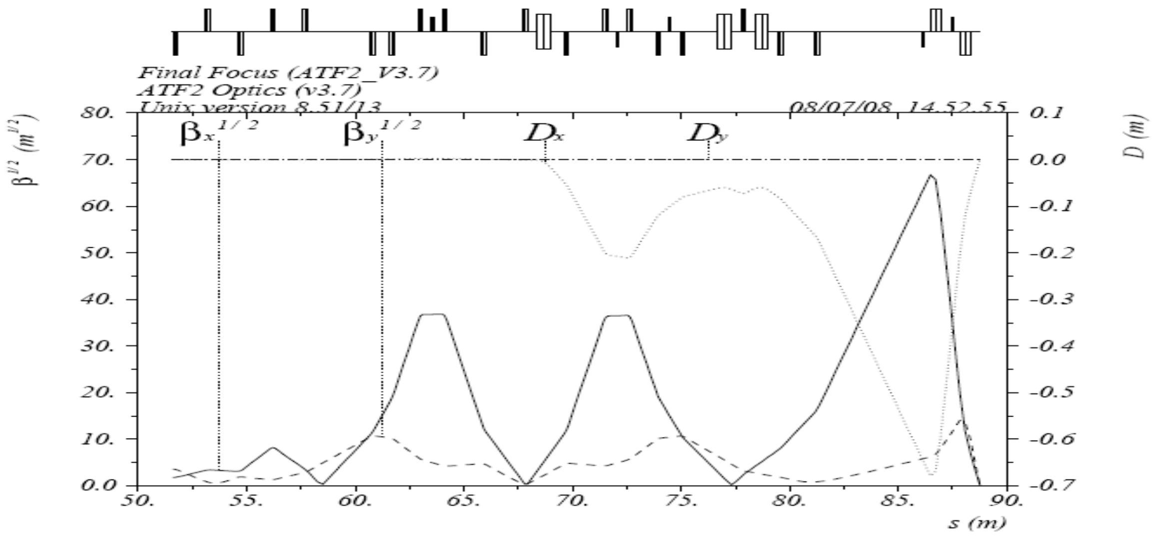

Figure 6: β functions with nominal β_x and twenty times $\beta_{y,nominal}$ at the waist at -54cm.

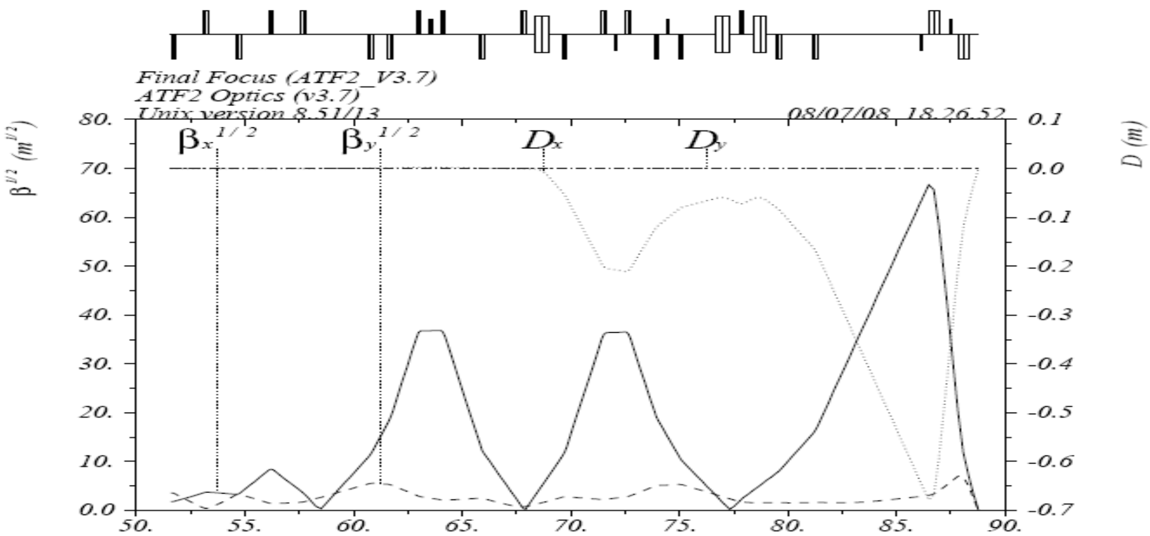

Figure 7: β functions with nominal β_x and eighty times $\beta_{y,nominal}$ at the waist at -54cm.

4.3 Matching procedure and results for the displaced IP at +39cm

4.3.1 Matching procedure and results

The following procedure can be used to obtain a focal point at +39cm with a $\beta_{x,y}$ parameters increased by factors of 10 and 800, respectively :

1) Fit QD and QF in the final doublet to obtain $\alpha_{x,y} = 0$ at + 39cm, using the nominal values for QM12-16. The integrated quadrupole strengths needed are KLQD0FF = -1.117399E+00 m^{-1} and KLQF1FF = 7.030126E-01 m^{-1}.
2) Fit QM12-16 to obtain β_x =0.04m, β_y=0.08m, $D_x = \alpha_{x,y} = 0$ at + 39cm.
3) Fit SD0, SF1, SD4, SF5, SF6 to obtain T_{126}=0, T_{122}=0, T_{346}=0, T_{342}=0, T_{166}=0.

The resulting beam sizes are $\sigma_{x,linear}$ = 8.9 μm, $\sigma_{x,tracked}$ = 8.9 μm, $\sigma_{y,linear}$ = 962nm and $\sigma_{y,tracked}$ = 968nm. The corresponding β functions are shown in Figures 8.

800 is the largest factor which can be achieved while preserving the overall features of the final focus optics. It was checked that larger factors can also be achieved if this last condition is relaxed. However, as explained in Section 4.2.2, this would probably be of lesser interest.

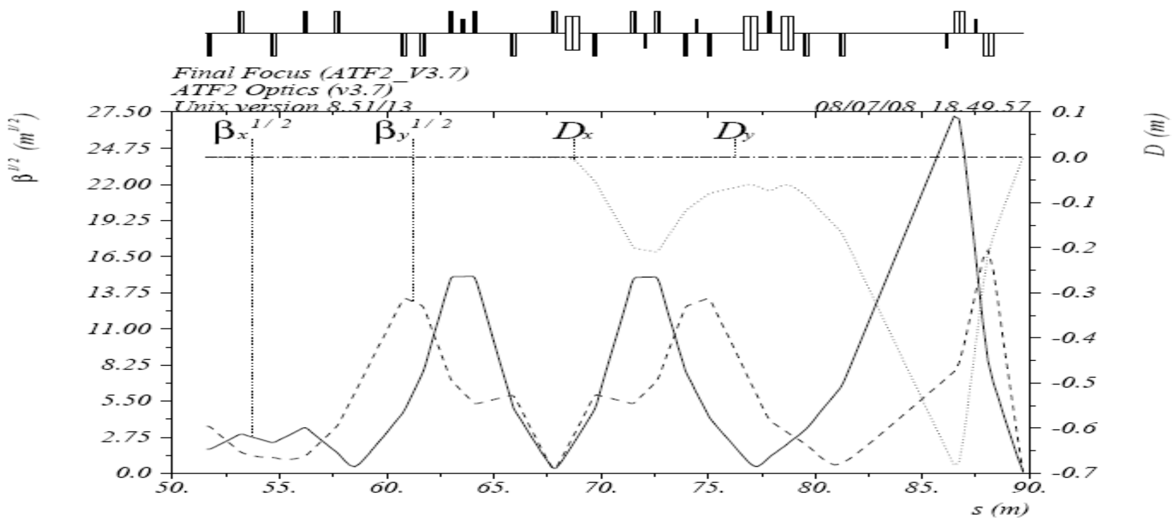

Figure 8: β functions with 10 times $\beta_{x,nominal}$ and 800 times $\beta_{y,nominal}$ at the waist at +39cm.

Conclusion and further work

At displaced IP location at -54cm, β_y can be as large as is needed for the linear beam size to match the resolution of the planned Honda-monitor, while preserving the basic features of the FFS optics. This is not quite the case for the other displaced IP at +39cm, where the wire-scanner will be located, since a linear beam size reaching only about half the its resolution is possible if the basic features of the FFS optics are to be kept. Larger beam sizes are of course possible at both displaced IPs if this requirement is relaxed.

Smaller values can also be achieved, down to about a factor four, which may be useful for final spot size minimisation. This is the topic of a specific R&D proposal, aiming to demonstrate the capability of lowered $\beta_{x,y}$ values, both from the point of view of the optical design optimisation and from that of the experimental tuning in the presence of errors [6].

All these configurations can be achieved with the existing hardware (magnets and power supplies), though for the -54cm IP location, the specification for the QD0 power supply had to be revised.

During the commissioning it will be important to be able to load such configurations easily in the control room and to check that indeed waists have been achieved at the desired locations. For this purpose, linear combinations of QD0 and QF1 can be computed to enable to independently vary α_x and α_x. Measuring the beam sizes as a function of each of these knobs will then yield parabolas which, in the presence of magnet imperfections such as quadrupole strength errors and sextupole horizontal misalignments, or input betatron mismatch, will not generally be centred. From the observed offsets, QD0 and QF1 can then readily be used to calculate the appropriate correction to absorb such accumulated effects. Such linear combinations need to be computed separately for small adjustments around each of the desired IP location, as linear behaviour can certainly not be expected over the large displacements between each IP location.

In each case, the procedure for correction and practical implementation must be studied in simulation, using a representation of the expected errors and input mismatches, including also cross-plane coupling effects and imperfectly cancelled dispersion. Orthogonality with other optical correction knobs should be checked, as well as the useful range around each IP location over which the linear approximation is sufficient.

For practical implementation in the control room, a set of easy to use graphical interfaces enabling to toggle between the different IP locations and with a choice of pre-computed optical configurations yielding appropriate values of the β parameter will be important. For final spot size minimisation at the nominal IP, a quasi-continuous set of β_y parameter values will also be needed to empirically find the one giving the smallest spot size in the presence of the errors and applied correction procedures (so-called β_y -scan).

Acknowledgements

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