ATF   REPORT

T I T L E   :   The ATF control system

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SYNOPSIS:

This note describes the control system used for the Accelerator Test Facility (ATF) at KEK. The start-up procedures and available diagnostics are described, and beam control and measurement procedures detailed. The practical operating procedures derived from machine experience are discussed where appropriate. This note is a working document, and will be updated periodically as procedures and control systems change.

KEK   **High Energy Accelerator Research Organization**

The ATF control system

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Some definitions

ATF_Menu : the ATF control program

ATFCC0 : the primary ATF control computer (a DEC Alpha running VMS) … the ATF_Menu program runs here

SET file : a text file containing a saved machine configuration (magnet currents and other selected data)

SAD : (**S**trategic **A**ccelerator **D**esign) a beam optics computation and particle tracking program which is used by the control system for model-based control applications

DR : (**D**amping **R**ing) the damping ring

BT : (**B**eam **T**ransport) injection transport line between linac and DR

EXT : (**EXT**raction) extraction transport line

ICT : (**I**ntegrated **C**urrent **T**ransformer) a beam current monitor

XSR : (**X**-ray **S**ynchrotron **R**adiation monitor) a beam size diagnostic in the DR

OTR : **O**ptical **T**ransition **R**adiation

WS : **W**ire **S**canner

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General procedure and comments to achieve a tuned beam

The general procedure for setting up the machine, starting from a tuned and energy stable beam in the BT line which injects into the damping ring, is to correct the DR orbit, dispersion, and coupling using SAD and then flatten the EXT orbit. These procedures are described in this document and should allow a good emittance measurement. At the start of every shift and experimental run, all machine parameters should be recorded– all magnet currents, orbits, beam currents, what is seen on every display (e.g. XSR) and so on. This includes recording all file names. Always consider the optical needs of an experiment, and the need to create a new optics. The transmission (how current moves through the machine) gives a good indicator of the tuned state. Also, the logbook should be checked at the start of every shift for machine relevant comments, and always take a 'tour' of the machine sections (DR magnets and orbit, EXT magnets and orbit, and so on) to look for problems and check that all magnets are set as they are expected to be. If in doubt, consult the logbook and, if needed, load a known configuration (SET file). Finally, when changing and correcting orbits and dispersion, always look at how good SAD thinks the correction will be, look at the corrected magnet currents, observe exactly what changes, and understand how the beam looks before and after the correction (by storing the orbit before, and then plotting the difference).

Control room displays

Permanent displays in the control room show the beam current in the different parts of the machine. These should be monitored for sudden drops and, in general, for how good the transmission is between various parts of the machine. One monitor shows the machine state and repetition rate. Typically the machine cycles at 1.56 Hz, with 1 bunch per train, and the DR current is typically 1.5 mA, or 4×10^9 electrons per bunch[2] (a bunch stays in the DR for many turns in a second, giving a multi-turn contribution to the current). Another monitor shows radiation levels as a function of time in different parts of the Assembly Hall. A steeply increasing line shows a large radiation gain, probably due to beam loss. The black trace is the EXT line – changing DR beam conditions could cause beam loss here. If the losses are too large the rep rate should be reduced to avoid a radiation trip, which will happen if the integrated radiation dose gets too large. If beam loss is occurring in a certain part of the machine, one solution is to correct the orbit in this region. Also available is a monitor for the gun laser status, showing the laser spectrum and the laser mirror position. To be stable the spectrum should have a good peak at 357 MHz with no sidebands. The INJ and EXT kicker traces are also displayed. There is an ICT (integrated current transformer) display, showing beam intensity as a function of time.

Visual beam displays at screen monitors are available from the ATF_Menu control program on the MONITOR page. All of the screen monitors on this page are available on channel 13 on the large central TV monitor. For example, choosing MS1T shows the beam at the end of the linac after the first of the BT bends; the beam is dispersion dominated here and hence the horizontal size gives a measure of the beam momentum spread. The default channels displayed on the central monitor are 33 (left) and 34 (right). Both of these are beam intensity pickups in the DR – the left one is fast and

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[2] Maximum single-bunch DR currents are around 7 mA, or 2.0E10 electrons per bunch.

can show turn-by-turn data (look for the extra intensity on the injection turn) and the right is a slower measurement. A box under the screen changes the channels, and a legend is displayed on the side. Finally, the beam can be turned off from the BEAM ON/OFF page.

Machine start-up and gun tuning

Machine start-up begins by opening the laser shutter; this control is found on the RFGUN page. The angle of the laser on the cathode is controlled by moving the second-to-last mirror on a moveable stage in x and y, and the chicane magnets can be adjusted (BH1L to BH4L). The effect of these changes can be seen on the screen in the middle of the chicane, called MS1L, found on channel 11 of the TV monitor after selecting it on the SCREEN page (via MONITOR). The aim is to visually optimise the focus of the beam on the screen by optimising the chicane magnet currents, the mirror settings, and the capture solenoid current (changing the mirror changes the laser focus, and hence solenoid compensation is required). The solenoid, called HELM06, has a nominal current of 105A, and steps of ±5 A should be used. MS2L is a Faraday cup. Next, optimise laser phase in steps of 1 degree, looking at current. A phase plot is available from the RFGUN page. The laser power can be changed using the SET control next to the 'Bunch(es)/Train' controls on the BEAM ON/OFF page. There is an energy spectrometer dipole called BH1L, which bends the beam off the beam-line path in the linac to a screen called MS4L. The nominal current of BH1L is 20A; always press the 'NEW' button after entering the value. Find the beam on MS4L by adjusting the horizontal beam position using BH1L, and the vertical beam position using corrector ZV1L. The intensity of the MS4L image can be adjusted by altering the shutter speed. Now adjust the phase of the gun to optimise the intensity of the beam on MS4L. The gun phase and the first cavity phase (this booster cavity is called L0) can be optimised for emittance, energy spread, and electron yield. Essentially the capture of L0 is optimised using MS4L as a diagnostic. When this is done, remove the screen and turn off BH1L and ZV1L, and the beam is injected into the linac. Getting good orbits in the linac and in the BT/injection region should help attain good BT to DR transmission. Position (and energy) jitter can be optimised by adjusting the phase of klystron number 8 – this is used for linac energy adjustment. The control can be found via the LINAC_RF page.

BPM data

BPM data is accessed via the MONITOR page, which allows selection of various parts of the machine. The BPM display has of 3 subplots: intensity versus BPM number (blue top plot, generally uncalibrated), horizontal orbit in the middle plot and vertical orbit in the lower plot[3]. It is possible to select which BPMs are shown on the plot and used in subsequent orbit correction from the READER CONTROL page. BPMs highlighted in green on this page are displayed and also used in orbit correction. To save an orbit file from the display window, choose 'EXEC. AVERAGE STORED ORBIT INTO MEMORY' at the bottom of the page and then

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[3] A word on coordinate systems: the linac and BT use a locally-right-handed coordinate system in which +X is to the left as looking in the direction the beam is going and +Y is up; the DR and EXT use an "upside-down" right-handed system in which +X is to the right and +Y is down.

'SAVE TO FILE'. The orbit data is written to a file with a pre-defined filename (based on present date and time) in binary format ... be sure to note the filename. There is a converter programme 'CONV Bin to Asc' – from binary to ASCII – which can be found from the main menu on the OTHERS page. There are separate parts for 'LT' (linac and BT), 'DR', and 'EX'. The programme creates a flat text file with columns: BPM number, x position in microns, error of x position as multiple readings are taken, y position in microns, error in y position, intensity from BPMs, error in intensity, number of readings taken, success of measurement. These files are stored on ATFCC0 (atfcc0.kek.jp). To access the data, ftp to this machine[4], change to the proper directory, and get the file. For example:

    cd ATF$DATA:[MONITOR.WORK]
    get EXBPM07MAY18_170855.DAT

An example of the data file is:

```
NO X_POSITION X_SIGMA Y_POSITION Y_SIGMA INTENSITY I_SIGMA NREAD SUCCESS
 1       0.0       0.0       0.0     0.0       0.0     0.0    0    0
 2    -719.8      11.0     161.2    44.4     247.4     6.1    2    1
 3    1750.2      39.4     969.0    19.1    1023.4    70.1   18    1
 4    2326.5     198.6     104.6    44.5    1139.4    74.9   18    1
 5       0.0       0.0       0.0     0.0       0.0     0.0    0    0
 6      -6.2      71.3     225.7    78.3    1331.2   100.9   18    1
 7    1330.7     167.4     353.2    66.9    1161.0    66.4   18    1
 8    2306.1     135.3     236.3    12.0    1502.9   105.6   18    1
 9    1338.1      59.4      -8.3    59.6    1323.9    88.1   18    1
10     738.5      16.6      31.2    29.3     595.7    34.8   18    1
```

Note that the BPMs require relatively constant current to be reliable, and are not good below 2×10^9 electrons per bunch.

Making a difference orbit is a useful method for viewing changes in orbit when making magnet changes or doing corrections (for example changing DR RF frequency for making dispersion measurements, or changing corrector or quad settings). To do this, save an orbit to memory and then select 'POS - MEMORY'. The difference between the present orbit (POS) and memory is then plotted. The top-left selector changes the number of turns to wait before taking BPM data. A high number (500,000) is good, as this lets the beam fully damp. If this number is changed, it's advisable to turn beam off and retake BPM pedestal data. This ensures the offset is correct in the current monitor. The pedestal data control may be found via 'OPEN WINDOW ADC & PEDESTAL' on the BPM display window.

DR tunes

Select 'Turn-by-Turn' from the MONITOR page to control the beam exciter and measure the DR tunes. The nominal tunes are approximately 15.3 and 8.7. Be sure to turn off the beam exciter afterwards. An appearance of the horizontal tune on the vertical display indicates a coupled beam. Make sure the turn selected is very high – 500,000 is standard, as this is a fully damped turn.

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[4] From outside KEK, ftp access to this machine requires a VPN connection.

Save machine configuration

On main magnet pages, select 'Open Save Window'. This brings up the save parameters page. Select 'SAVE SETTING DATA to FILE' to create a text file on ATFCC0 in the directory 'ATF$SET_DATA'. Filenames are based on the date and time of the save, e.g. "`ATF$SET_DATA:SET07NOV26_1724.DAT`". Example output is:

```
! MAGNET BRANCH 1
!   name          set     mon    onoff    vol
!-----------------------------------------------------------------
     BA1L         0.000   0.000   0     0.000
     ZH1L         0.000   0.000   0     0.000
     ZH2L         0.000   0.000   0     0.000
     ZH3L         0.000   0.000   0     0.000
     ZH4L         0.000   0.000   0     0.000
     ZH5L         0.000   0.000   0     0.000
     ZH6L         0.000   0.000   0     0.002
     ZH7L         0.000   0.000   0     0.000
     ZH8L         0.000   0.000   0     0.000
```

This file contains, among other things, the currents of all magnets; the `set` value is the power supply set-point (in Amperes) of the named magnet. Note that the machine state is somewhat unreliable, and using established decks for calculation is generally recommended. Save the machine state at the start of every shift, so it can be recovered if the machine goes bad. Set-points for a group of magnets can be loaded from a file by selecting 'FILE' on the appropriate magnet control page and choosing the file required . Computer codes exist to turn the magnet currents in the SET file into an instantaneous MAD deck, and turn a MAD deck into a SET file. This is available from the authors.

Magnet setting and KL conversion

Control pages for magnets in various parts of the machine can be selected from the MAGNET page (i.e. 'DR STR (V)' for vertical correctors in the DR). The 'file' column on each display shows the values from the selected SET file; the 'WROTE' column shows the present set points. A previously saved set of magnet currents can be loaded by choosing 'FILE'; clicking on 'SET' then sets the magnets to the 'file' values. It's good practice to save the present settings before loading a pre-defined file. Clicking on a magnet's name brings up a page from which the currents can be changed; the current can be reset to its starting value by selecting 'RESET'. On the MAGNET page, clicking on different parts of the picture will display a schematic layout of the selected area; the display also shows the orbit. On this display, magnets can be selected by clicking on them.

KL conversion and Twiss file creation

To convert magnet currents to normalized integrated strengths (and vice versa), go to the 'SAD Calc.' page and select 'MAGNET K <-> I CALCULATION'. Enter the magnet name and the beam energy. Then enter KL (or current) into the appropriate box and convert to current (or KL). For example, choosing ZV9R, 1.28 GeV, and

0.0016 mrad gives 5 A (the power supply limit for this magnet). Note the ATF always works in terms of normalized integrated strength.

A SAD optics computation for either DR or EXT can be requested via the 'SAD Calc.' page. Select 'DATA TRANSFER', which will bring up a page with two windows, one for DR and one for EXT. In the appropriate window, select 'SAVE to SAD' (to use the present magnet setpoints) or 'SAVE to SAD (Current FILE Data)' (to take the setpoints from a SET file). A text file will be created containing an "optics dump" (Twiss parameters, etc.):

```
ATF$SAD_DATA:DR_OPTICS_DUMP.SAD (for DR)
ATF$SAD_DATA:EXT_OPTICS_DUMP.SAD (for EXT)
```

Note that SAD will compute the periodic Twiss parameters for the DR at the entrance to the extraction kicker and use them as the initial Twiss parameter values for computing the EXT optics.

Orbit bumps

Closed orbit bumps can be made manually by setting corrector strengths in the BT, DR, or EXT parts of the machine. There is a 'fast bump' programme, which is useful for quickly making bump "knobs" in the DR or EXT that are capable of making mm-sized bumps quite easily with 4 magnets. Find it from the 'SAD Calc' page … select 'DR FAST LOCAL BUMP'. First enter the beam energy and run SAD to compute the optics by selecting 'RUN DR' or 'RUN EXT'. Next, select the correctors to be used the kind of bump required (e.g. 'Dy' is a y-position bump) in the programme interface. Clicking on 'Get steering names and ratio' will compute the currents needed for a 1mm closed bump. The bump can then be applied by clicking the '+' or '-' arrow-shaped buttons, which applies proportional increments of the computed bump currents. Go easy: it's very easy to exceed the current limit of 5A in the correctors. Extraction region orbit bumps in the DR persist into the EXT, which then needs to be corrected by hand, or by computing a correction offline. Bumps create dispersion, which also needs to be corrected. Note the dispersion correction routine in the DR will assume all correctors are available, and so invariably remove all set bumps, although an option exists to remove correctors from the algorithm in order to preserve the bumps. Finally, it's useful to store the orbit in memory before making a bump and then plot 'POS-MEMORY' as the bumps are being applied in order to see the effect of the bump clearly and to ensure that the bump closes as expected. It's also useful to save the orbits before and after making the bump (and write down the file names).

Orbit correction in DR

The orbit correction procedure in the DR begins with reading the DR BPMs by choosing "EXEC AVERAGE STORED ORBIT TO MEMORY", and then "Save to file" in the DR BPM display. Now go to "SAD programmes", choose "DR orbit correction", select the saved file as 'file A' using the button at the bottom of the orbit correction window, and copy file A to SAD buffer 1 (choose "FILE A", "COPY" and click on "SAD buffer 1"). Plot the contents of SAD buffer 1 on the orbit display to verify that the orbit information has copied into the buffer successfully, and then press 'CALC' to run the SAD orbit correction programme. The results appear on the

control room SAD terminal, with the points showing the measured orbit and the lines are the fit to this orbit by SAD. If the fit is good, the correction will probably be good as SAD uses this fit to compute the corrector strengths. The data points and the fit should be printed now if hard copy is needed. An orbit that has no BPM data will be flat. Now press enter on the SAD terminal to copy the computed magnet settings back to the control system. Check that the magnet currents do not exceed the 5A corrector limit and press "SET" to copy the values to the magnet power supplies. Pressing "RESET" will undo the magnet settings. To save the post-correction orbit, push "save to file", convert to ASCII and copy the orbit file from the VMS control computer. The DR correction algorithm minimises the sums of squares of BPM deviations, and stops when a chosen tolerance is reached. Using too tight a tolerance will cause SAD to give unreliable results; however the tolerance is rarely changed in practice. In general, good corrected orbits to aim for are around ±1mm in the DR (this criteria also applies to the EXT). The injection/ extraction region has a limited aperture, and beam can be lost when correcting the orbit. The goal is small measured orbit deviations, a good SAD fit, corrector currents within limits, and no beam loss when applying the settings (watch intensity over time on the ICT monitor). The number of correctors used for orbit correction can be changed, and is a good variable to play with if satisfactory orbit correction cannot be achieved. Iteratively correcting the orbit using 60 (max), 30, 20 or 10 correctors works in practice.

If the orbit around the DR looks like a Betatron oscillation, try a single-corrector orbit correction. Do this using SAD, and SAD will choose the most responsive corrector automatically. This corrector can then be adjusted manually to optimise the orbit.

The injection orbit (BT line) can be displayed but is less important in practise, as the DR beam is damped and loses all memory of what happens during injection over the damping time of the ring. Steering in the BT is not usually necessary, unless orbit correction in the DR causes a reduction in injection efficiency and a slight drop in BT to DR transmission. In this case, manual touch-up of the injection trajectory using correctors at the end of the BT may be necessary.

Dispersion correction in DR

To perform dispersion correction in the DR, use the DR dispersion correction programme from the SAD programmes menu. This programme needs to take three sets of orbit data – one nominal orbit, and two off-energy orbits (plus and minus some small energy deviation). Change the DR RF frequency to change the energy ($dp/p = -1/\text{alpha\_c} * df/f$). Care should be taken when changing the RF frequency to keep the stored beam current constant, as the BPMs are strongly current dependent. For the nominal orbit, choose 'exec' and then 'save to file'. The nominal orbit should be placed in 'STANDARD' using the buttons in the SAD dispersion correction programme and copy to SAD. Now do an RF ramp (on main menu, choose delta-f ramp) and choose a frequency change, for example plus and minus 3 KHz. The orbit should be taken at each frequency setting. Now put the +3 kHz orbit in file A and the -3kHz orbit in file B (to do this, select file A and choose most recent file, and same for file B). Then, in the SAD programme, perform a 'file A – file B' operation and store the result in SAD buffer 1. The nominal orbit should go in SAD buffer 2.

The calculation also needs the machine working point. The Nominal machine tunes are horizontally close to 15.3 and vertically close to 8.7. If desired, adjust DR quads to get 15.182 and 8.432 i.e. close to nominal tune. The tune monitor beam exciter should be turned on to take a tune measurement, and turned off again afterwards. Also, the DR frequency shift should be turned off (ramp off).

The SAD dispersion correction programme needs to store tune and the total delta-frequency (6 kHz in this running example) and the desired correctors to be used. The correctors can be selected, and the chosen ones apply to both orbit correction and dispersion correction. Now run the SAD programme, and measured dispersion appears on SAD computer for the horizontal and vertical directions (the y-axis of the plots is called "E"). The data points are the measured dispersion and the line is the SAD fit. The expected DR dispersion should be around 0.1 to 0.2 cm. If the dispersion is higher, e.g. 4cm, on SAD display, reduce corrector number, for example to 10, in SAD programme. In this case, the 10 most effective ones are chosen. Generally, if the fit is bad, the new magnet settings should not be used. In this case, do not press set, but change some calculation parameters (number of correctors, tolerance) and re-compute. The goal is the data points less than about 10mm in y and about -5mm to 10mm in x. This is close to design. Another way of judging dispersion correction is to look at the XSR monitor (second port, with lower dispersion, at end of BH1R at the end of one of the arcs), and aim for a small beam size by comparing the beam size before and after correcting the dispersion. Aiming for 10 microns on the XSR is a good practical goal. Note the XSR display is in channels, which should be multiplied by 1.2 to get microns (note this calibration can change). A tilted beam will mean the vertical beam size shown is not quite the true size, so watch the beam tilt on the XSR. Dispersion correction will tend to untilt the beam, and coupling can be estimated from the beam tilt on the display. The XSR can be printed at this stage to obtain a hard copy. Press enter on the SAD computer to copy values back to control system. Now on the magnet current display, check all new currents are less than the maximum of 5A (the new ones are in the file column). Press 'set' in the DR correction window to make currents in magnets. Note this changes DR magnets, and so the dispersion, and hence the dispersion should be re-measured if further calculations are to be made. If the dispersion correction is bad, and dispersion is large, retry with different delta-frequency (say 1,2 or 5 kHz) or different number of correctors (10, 20, 30, 60). Also manually tuning the dispersion (plot difference between memory at nominal and actual orbit at some change in RF frequency) and tuning correctors by hand can be useful. The dispersion correction changes the orbit, so keep an eye on the DR orbit if making many goes at correction, and correct if needed. The expected DR physical emittance is 20 pm, so if correcting dispersion and the measured DR dispersion is around this number, tuning is good. Generally, this number is easy to get (although may need coupling correction) and beyond it is harder.

DR coupling correction

The DR coupling correction is performed by choosing two DR horizontal steers in one of the arcs, separated by one integer; for example ZH22R and ZH24R. Measure the vertical orbit at plus and minus some current around nominal for each magnet. For example, if the nominal current is 0.22A, consider plus and minus 0.2A, which is 0.02A and 0.42A. Ensure the DR current does not drop when changing corrector, or

BPM reading could be false. For the first corrector, to go 0.02A, store orbit as file A, go to 0.42A, store orbit as file B, and return magnet to nominal value. Store file A – file B in Sad buffer 1. Now repeat for the other corrector, and store file A – file B in SAD buffer 2. Note the delta-I can be different for each of the two correctors, and should be as large as possible, but no current loss. Now go to SAD programmes, and select 'SAD DR coupling correction'. Set which magnets have been used, delta-I's (note this is the total step in current, so twice the plus/minus value) and which family of trim skew quad coils (attached to sextupoles, hence names SD and SF, with differing phase). Now run SAD. The SAD calculation works by looking at the vertical orbit induced from a change in the horizontal orbit, and hence the coupling. This is returned as skew quad settings (actually skew trim coils attached to sextupole poles in DR). When SAD is finished, the fitted vertical orbit change is displayed on the SAD computer. Now press enter to transfer values back to control system, check the strengths (maximum is 8.5A in this coils) and set to make the currents in the magnets. The DR beam can be viewed on the XSR (x-ray SR monitor on the SAD computer) to see if the vertical beam size is reduced (sigma is shown on left hand side, and remember to apply the 1.2 channels to microns conversion factor). A good coupling correction means the beam is less tilted after the correction. In practice, the SD family is generally more effective, but tends to need values over the current limit. Hence use SF as a general rule. Another way to correct the coupling is trying to remove any spikes in the vertical tune display leaking from the horizontal tune by scanning the skew quads. This leakage arises from coupling. If coupling correction is not effective, not setting the new skew strengths means a new dispersion correction (which often un-tilts the beam) is not beneficial, as the machine state will not have changed since the last dispersion correction. So one way is to set the new skew settings (despite the correction not being good) and retry the dispersion correction.

Measuring DR emittance

The DR emittance is measured using the XSR monitor in the damping ring. When making this measurement, it's advisable to ensure the DR dispersion and coupling is corrected (e.g. beam is not tilted in XSR monitor). Start the XSR programme on the SAD computer ('xsr start'), and get the horizontal and vertical beam sizes from the fit. The unit of the beam size is channels, which needs multiplying by 1.2 to get microns (however the channel to beam size mapping is adjustable). The DR emittance is computed by measuring the beta function at the XSR by using a quadrupole scan to measure tune shifts, and extracting the emittance from the beta function. Open the 'Interferometer V' in the monitor window, and press 'Beta calc'. The programme needs the absolute tune at five different trim currents of three DR quads (QM3R, QM4R and QM5R) – the programme tells which to use. Note three frequencies can be used (instead of five), but frequencies must be symmetric. The ring has 2-fold symmetry; do not change the main currents on the quads but only the trims on the correct single quads. Note this is a different window to the main quad settings, so be careful to only adjust the trims on the local magnets. Make sure they are all set to 'use' to ensure the calculation uses the correct magnets. Turn on the turn-by-turn tune (TbT) monitor, turn on the beam exciter and change the necessary quadrupole. Pressing 'get will transfer the data from the TbT tune monitor to the fitting programme automatically. Next, press 'save" to save optics to SAD, and then 'calc' to perform the SAD calculation. The results of the fit, and the beta function, will appear on the SAD computer. If the fit is good, the beta function will be reliable, and

generally around 1.5m to 2.5m is close to design and acceptable. This value can now be used for DR emittance extraction. If the current drops when making the current changes in the trims, try using a smaller range of currents (it's an adjustable parameter). Another explanation for an unreliable result is the working point could be close to a resonance. The design beta function is around 2.5m in this region, giving a guide to the expected result and allowing a quick estimate of the DR emittance. The measured emittance is very sensitive to the beam tuning – for example a slightly tilted beam with a vertical size of 12 channels (multiplied by 1.2 for microns) gives an emittance of 70pm. If the data is saved, it may be possible to untilt the beam manually offline and improve the measurement. The design DR emittance is 20pm and, in practice, the best tuning is a flat beam on the XSR with a size of about 7-8 microns. An advisable experimental procedure is to measure the beta function several times and take a mean and standard deviation.

EXT tuning

The ATF has no orbit correct algorithm for the extraction line and so the orbit needs to be fixed by altering the correctors by hand, watching the BPM display. The EXT correctors cannot alter the orbit at the start and the extraction kicker (from the MAGS menu) timing should be altered. Adjust the horizontal and vertical orbit by hand to minimise and attain a flat orbit at the wire scanning stations. The magnet panel available from the MAGS window picture is useful as this shows the orbit and the magnets are clickable. If changing the horizontal orbit affects the vertical orbit, there is some stray coupling.

The dispersion is measured as in the DR – vary the RF frequency in the ring and save the orbit differences (and nominal), and run SAD to correct. This works just like the DR dispersion correction, except the orbit is taken at 5 different points of DR RF frequency: -4 kHz, -2 kHz, 0, +2kHz and +4 kHz (this range can be changed and can be reduced if correction does not work). The DR frequency shift should be turned off afterwards ('ramp off'). Go to the SAD calculation, 'EXT dispersion measure correct' and then 'EXT dispersion calculation for BPMs' and load the orbit files (the five points should the five files next to them). To calculate the offset, storing the orbit with ramp off and then plotting the difference with ramp on visualise the offset. The flattest orbit (which may not be at a ramp of 0 kHz) is the offset. Now run the dispersion calculation, which will fit to the dispersion at each wire scanner and give quadratic curve and numerical values at each wire scanner. It's good practise to write down the dispersion at each wire scanner, as they are needed for the wire scanner measurement. Note how the dispersion curves with frequency have a linear part corresponding to linear dispersion and a quadratic part for the first contribution to non-linear dispersion. Now go to Dispersion correction programme. The dispersion values are loaded in, but shown at the position of the BPMs (and not the wire scanners). Press Save to save the linear optics to SAD (it's changed by the correction algorithm), and wait until the data has been transferred. Press 'Calc and load', which runs SAD and returns the skew quad settings QS1X and QS2X to the FILE option of those magnets, and QF3X and QF4X settings, again to the 'FILE' option of those magnets. Note if CALC is pressed, just the measurement is made, with no skew quads changed, compared to if 'CALC and LOAD' is pressed, when the correcting skew quad settings are copied back and loaded into the control system. To see the corrected EXT dispersion, a new measurement should be performed. Push 'load from file'

option on these magnets to load the correcting settings. In practice, dividing the strength by 2 is suggested, as the SAD correction tends to overestimate the magnet settings. Also, the current limits of the skew quad magnets are easily exceeded (4 A, as they are air cooled magnets). Note the dispersion correction in the EXT is very difficult as the goal is very tight – about 10mm vertical dispersion at the diagnostic straight is the maximum tolerable for good emittance measurement. If the dispersion correction proves difficult, make some delta-frequency in the DR, and plot position-ref and position, where ref is orbit without delta-frequency. This difference is related to dispersion so adjust QF3X, QF4X, QD3X and QD4X to reduce it empirically. The EXT dispersion is a biggest tuning factor in a successful emittance measurement and if the dispersion is badly corrected or measured, a good emittance measurement is difficult. A further technique to dispersion correction is to construct the response matrix of the skew quads – measure the dispersion at the baseline currents and at plus/minus some values. This gives a matrix equation (response matrix formalism), which can be inverted to give skew quad currents that zero the dispersion.

Wire scanning

The ATF is equipped with a set of five wire scanner stations in the extraction line diagnostic straight, which allow a two- or four- dimensional measurement of the emittance. Each station consists of a movable stage with a vertical wire, a horizontal wire and several wires at angles to the beam. A photon detector is placed after the last wire scanner station to record the photon rates as a function of wire position. To use these scanners, click on monitors, and then select the wire scanners (e.g. MW1X etc). A screen comes up with the y, x, and plus/minus 10 degree wire readouts (relative to the x wire). The first task is to find the beam with the wires - the expected range in mm of where the beam is expected to be from design is shown on the sidebar. The range and step of each wire can be altered, and the start/stop button allows the wire scan to begin. These controls are used to find and make an effective measurement of the beam. This initial scan can be slow, as it needs a large range and a small step size to avoid missing the beam. Clicking on the axes can rescale them, but retake data to ensure plot is correct if changing vertical scale. Check each beam is roughly where it should be, as the wires can be mixed up. Generally the +10 and -10 degree wires give a larger beam size than the y wire – it's crucial to ensure the identification is clear. The scale is signal, and a very low signal possibly means the additional carbon wire is being moved through the beam. The data can be saved from this screen for later analysis. A correction factor needs to be applied to the data, as the wires are inclined to the beam. For the x wire, this inclination angle is +45 degrees, and so the x projection of the fitted beam size is found by multiplying by cos(45). Similarly, the y wire is inclined by -45 degrees, and so the multiplicative factor is cos(-45)=cos(45). The U wire is also inclined at 45 degrees, but with a -10 degree tilt, so the multiplicative factor is cos(35). These factors are not applied to the raw data in data files, but are applied to the stated x and y beam sizes on the wire scanner control software. The MW2X scanner has a reflected geometry, but the factors remain the same due to the even symmetry of cos(x). Note the tilted wires are only needed for the full 4D emittance calculation; the x and y are enough for 2D. A tilted beam can mix beam size up between the wire scanners. A quick wire scan can be done to get an idea of EXT beam sizes. Finally, the diagnostic straight quads are called QDnX, and the skews in the diagnostic section (designed to correct the coupling) are called QKnX.

To make an emittance measurement, set up at least 3 wire stations (the more the better), make x and/or y measurements about 4 or 5 times, and compute the mean and standard deviation (for example, with Excel or Mathematica). The beam sizes generally should not vary too much from station to station. Note if a vertical measurement is all that's needed, just do the y wire, and 3, 4 or 5 stations to save some time. Save the data at every wire scanner. Now, in the wire scanner analysis window, transfer the linear system to the SAD computer, press "EXT 5 wire", fill in beam size data in x and y, enter the standard deviation in the box, fill in the dispersion info (computed by SAD during the EXT dispersion correction procedure, measure the energy spread, or use the design value of 8.E-4, and push 'SAVE TO SAD" to save the linear system. The stations used in the calculation are coloured green. Then make the calculation, and the SAD computer will show the results of the fit in terms of fitted phase space ellipses at each wire scanner (with a dashed ellipse showing another possible ellipse within the specified errors), the ellipses in normalised co-ordinates, the fitted Twiss parameters at every wire scanner and the physical emittance. The ellipses need to overlap for a consistent measurement, and dispersion (which is subtracted from the beam sizes) is the biggest cause of non-consistency. Resolution of wires is about 10um. Save the results of the fit. Note, when doing the wire scanning, make sure the wires of all stations apart from the one being used are moved out of the way ("go to stay position"). This avoids interference with the measuring wire.

A tilted beam at the wire scanner can be cured by scanning the skew quads (QKnX) in the extraction line. This is a difficult process. The suggested range of skew quad settings are plus and minus 4.5 A.

To copy off wire scanner files from the control computer, save the data in the wire scanner programme (complete with time stamp) and ftp off the VMS machine. The directories are atf$data:[wire_scan] for scanner data and atf$data:[saddata.5ws] for the 5 wire scanner reconstruction data. Format is stage position [mm], photon signal, current. "Y wire" is raw data and "Y wire all" is current normalised data.
Example data is:

```
! stage position[mm], gamma signal[ADC count], beam charge[ADC count]
! Y wire
 0.740120E+02, 0.332320E-01, 0.427300E+03
 0.740005E+02, 0.507955E-01, 0.358300E+03
 0.739895E+02, 0.806840E-01, 0.374300E+03
 0.739800E+02, 0.376359E-01, 0.377300E+03
 0.739705E+02, 0.576264E-01, 0.437300E+03
```

The beam size measurements, along with the instantenaous linear optics in the diagnostic straight gained from the set file, can also be used to reconstruct the twiss parameters at a given point.

Optical transition radiation (OTR) monitor (SLAC)

There is an OTR monitor installed in the extraction region, immediately after ZV1X. This exploits the radiation emitted when a charged particle beam crosses a boundary between two materials with different optical properties. A lense and a camera points at the OTR screen (which is labelled at MS1X on the control system) to image the transverse properties of the beam. To fully insert the target screen, select screen MS1X. This moves the screen into the beam. Now load the SLAC OTR monitor

control (from the monitor's screen). This presents three controls – voltage to the lense, voltage to the VMOVER and voltage to the HMOVER (the mover voltage bottons work in the opposite sense to the arrows). A smaller VMOVER voltage moves the screen into the beam from below (a maximum voltage of 1.8 V is the screen fully retracted from below, and 0.55 V means the screen is fully up into the beam), and with no beam on the target a horizontal groove (the tench or ditch) should be visible. Ensure the focus is crisp on the trench and the trench can be seen. With no beam make a 'get dark' to find the background excitation of the camera. Now the mover voltages should be adjusted to find the beam, using the beam position information from ML1X, and the beam can be steered horizontally using BS1X (septum current). Previous runs have shown that (x,y) at ML1X of (2500 um, -150 um) correspond to (HMOVER,VMOVER) of (2.780 V, 0.805 V). The beam, once found, should the focused by adjusting the the focusing voltage. Note the beam size is in channels, which is uncalibrated to metres at the present time.

Appendix: Directories for data on VMS control computer

BPM:	`atf$data:[monitor.work]`
wire-scanners:	`atf$data:[wire_scan]`
set data:	`atf$data:[setdata]`
5 wire-scanner file:	`atf$data:[saddata.5ws]`