DAΦNE TECHNICAL NOTE

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Note: **C-7**

PROGRAM LIST FOR THE DAΦNE CONTROL SYSTEM

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INTRODUCTION

In this note I try to make a tentative list of high level programs to serve as a guideline for the development of the Control System software. A list of addressed devices and called subroutines is attached to each program, which can be used to cross-check a corresponding list of high level subroutines and descriptive records of the accelerator equipment [1].

It is assumed that the LINAC is controlled by its own Control System (LCS), and that there is a Timing System (TS), which triggers the pulsed elements in the injection line. LCS can exchange informations with the Main Control System (CS) and TS is set by proper commands by the CS, according to the injection configuration chosen.

The programs are divided into 3 main areas: The Transfer Lines, the Accumulator, and the Main Rings. It is likely that each area has at least one dedicated consolle for direct operation of the machine. A fourth consolle is dedicated to general utility off-line programs and program development.

It should be kept in mind that some of the programs involving measurement on the beam are directly performed by the instrumentation itself. In this case the program takes only care of the presentation of the results on the Control Room screens.

A. TRANSFER LINES

A1. Machine Timing Set

Sets the TS for the whole injection line. Required informations are:

- the pattern of bunches to be stored in each main ring;
- the filling sequence for the bunches in the main rings;
- the number of pulses to be stored in the Accumulator before damping and extraction, or, as an alternative, the threshold current required to stop injection and perform extraction;
- the number of missing pulses required to damp the beam in the Accumulator;
- the delays of each kicker in the Accumulator and main ring referred to the main TS clock;
- the rate (2 Hz max) and delay of pulses delivered to the Linac spectrometer.

The program translates these informations into simple buffers of commands containing the Main Ring bunch number and the machine status (Electron injection into the Accumulator, Positron injection, Electron injection into the Main Ring, Positron injection into the Main Ring, beam to the Linac Spectrometer, Beam to the Test Beam Facility, Stand By, etc.). The commands are transmitted to the TS before each Linac pulse (50 Hz). The TS transforms these informations into the proper commands to be sent to the pulsed elements. The different operation phases can be programmed, stopped or resumed. Timing system settings are saved with their proper names as reference sets in the Database for each Operation Mode (such as "Electron Injection", "Positron Injection" etc.), and can be read, modified and set by the program.

Called devices

1) Main Timing system.

Required data from the System

1) Current Operation Mode.

Required subroutines

1) None.

A2. System Status

Shows a schematic layout of the Transfer Lines, with the option of zooming over selected fractions or operation modes, like electron injection (EI), positron injection (PI), electron extraction (EE), positron extraction (PE), Linac Spectrometer (LS), Beam Test Facility (BTF). Clicking over a particular element opens a dedicated ("expert") window with all available information on the selected item. Variable parameters are evidenced and can be changed from the window, with the possibility of increasing or decreasing the settings in small steps. Current waveforms for the pulsed elements can be displayed. Particular subsets of elements, such as bending magnets, quadrupoles, correctors, vacuum gauges, pumps, strip-lines, beam position monitors, beam current monitors, slits and flags can be presented on dedicated windows with relevant informations on the status of each item in the subset with the possibility of varying its status.

Called devices

1) All magnetic, vacuum and diagnostic elements in the Transfer Lines (R/W);
2) Digital oscilloscope for pulsed elements waveforms.

Required data from the System

1) Complete device records of all magnetic, vacuum and diagnostic elements in the Transfer Line.

Required subroutines

1) Graphic displays of Transfer Lines, with zooming and selection options, and dedicated layouts for magnetic elements, diagnostics and vacuum;
2) Digital Oscilloscope waveform acquisition and display.

A3. Magnet Set

Enables access to a number of reference sets for EI, PI, EE, PE. The reference sets are the currents delivered by all the power supplies in the line (pulsed bending magnets, DC bending magnets, quadrupoles, correctors). The display presents data in a physical form, namely bending radius [m] and deflection angle [mrad] for bending magnets, deflection angles for correctors and normalized gradients (K^2 [m^{-2}]) for the quads. All parameters can be scaled together to match particular energy requirements through a dedicated knob. The program allows reading, modifying, saving and setting a number of reference sets to be fixed during commissioning and first operation. A default reference set is chosen for routine operation.

Called devices

1) All magnetic elements in the Transfer Lines.

Required data from the System

1) Reference sets for EI, PI, EE, PE (R/W);
2) Relevant attributes for all magnetic elements in the Transfer Lines.

Required subroutines

1) None.

A4. Linac beam energy measurement (average and spread)

Performs the necessary operations to present the beam at the center of the hodoscope in the spectrometer line. The field of the pulsed magnet DHPTS001 is trimmed to bring the beam at the center of flag FL1TS001 and the current in the DC magnet DHSTS002 is also trimmed to bring the beam at the center of the hodoscope. Trimmings are performed by the program itself. The beam energy is obtained from the calibration of the DC magnet and the energy spread from the width of the amplitude distribution on the hodoscope. Normal operation, however, requires Linac, Transfer Line and Accumulator energy to be driven by the Main Ring energy setting. The system can therefore be used as a feedback signal at fixed magnet current to trim the whole injection chain energy.

Called devices

1) Hodoscope;
2) Flag FL1TS001;
3) Pulsed Magnet DHPTS001;
4) D.C. magnet DHSTS002.

Required data from the System

1) Relevant attributes of called devices.

Required subroutines

1) Flag Driver (insertion/extraction, analysis of digitized signal from CCD to get beam position with respect to flag center);
2) Pulsed bending magnet driver;
3) D.C. bending magnet driver.

A5. Linac beam emittance and optical functions measurement

Performs all the operations described in DAΦNE Technical Note LC-5, consisting in several beam profile measurements on a special flag with linear response inserted on the beam path, as a function of the gradient in one of the trasfer line quadrupoles (QUATM03). The emittance and optical functions at the center of this quadrupole are calculated from the fit of the measured beam distribution widths with a parabolic function. The measurement is performed separately in the horizontal and vertical planes.

<u>Called devices</u>
1) Beam Profile Monitor;
2) Quadrupole QUATM03.

<u>Required data from the System</u>
1) Relevant attributes of called devices.

<u>Required subroutines</u>
1) Beam Profile Monitor driver (insertion/extraction, analysis of CCD digitized signal to measure horizontal and vertical beam position and size).

A6. Beam envelope through the channel

For the injection lines EI and PI, taking as initial values for the emittance and the optical functions the results of the measurement described in A5, the beam envelopes calculated for the current setting of the beamline magnetic elements are displayed and compared with the aperture of the vacuum chamber in the horizontal and vertical planes. A plot of the optical functions is also available on request. The same facilities are also available for the extraction channels EE and PE starting from the theoretical value of emittance and optical functions calculated from the current status of the Accumulator.

<u>Called devices</u>
1) None.

<u>Required data from the System</u>
1) Transfer Line Lattices (EI, PI, EE, PE);
2) Latest beam emittance, energy spread and betatron functions measurements.

<u>Required subroutines</u>
1) Betatron functions and dispersion propagation;
2) Graphic display of arbitrary functions through a magnetic channel.

A7. Beam current along the line

Reads the beam current from all beam current monitors on a single Linac pulse or on the beam extracted from the Accumulator. Striplines can also be used to increase the number of points where the current is detected, even if they do not provide an absolute measurement, by calibrating them against the current monitors. The measurement should be fast enough (50 Hz) to detect Linac current fluctuations on a single detector. The current in each monitor is displayed on the transfer line layout to easily show where current losses occur.

<u>Called devices</u>
1) All beam current monitors in the Transfer Lines;
2) All Striplines in the Transfer Lines.

<u>Required data from the System</u>
1) Relevant attributes of called devices;
2) Transfer Line lattices (EI, PI, EE, PE).

<u>Required subroutines</u>
1) Graphic display of arbitrary function through a magnetic channel.

A8. Beam position along the line

Reads all the strip-lines in the channel during routine operation and (optionally) inserts the flags in the beam path, interrupting the injection procedure, to measure the beam position along the channels. The beam spot on the flags is digitized and the center-of-mass found and translated into beam center position. The information is displayed graphically on the transfer line layout. The beam envelope (as obtained in A6) can be superimposed to the orbit error to evidence possible interference of the beam with the vacuum chamber.

<u>Called devices</u>
1) All striplines in the Transfer Line;
2) All flags in the Transfer Line.

<u>Required data from the System</u>
1) Relevant attributes of called devices;
2) Latest emittance, energy spread and betatron functions measurements;
3) Transfer Line lattices (EI, PI, EE, PE).

<u>Required subroutines</u>
1) Flag driver (insertion/extraction, CCD signal analysis to find beam position with respect to flag center);
2) Betatron functions and dispersion propagation;
3) Graphic display of arbitrary function through a magnetic channel.

A9. Beam trajectory correction

The beam position at all (or at a fraction of) position sensitive detectors is measured (as in A8) and the dipole perturbations in the correctors found with proper algorithms to minimize the distance of the beam from the magnetic center of the transfer line. The correction matrix (whose elements are the displacements induced by a unitary excitation in one corrector in all downstream monitors) can either be calculated from the theoretical model of the transfer line or directly measured by setting each corrector to a known deflection and measuring the displacement in the downstream monitors.

<u>Called devices</u>
1) All striplines in the Transfer Line;
2) All flags in the Transfer Line;
3) All H/V correctors in the Transfer Line.

<u>Required data from the System</u>
1) Relevant attributes of called devices;
2) Transfer Line lattices (EI,PI,EE,PE).

Required subroutines
1) Flag driver (insertion/extraction, CCD signal analysis to find beam position with respect to flag center);
2) Graphic display of arbitrary function through a magnetic channel;
3) Mathematical Library (Matrix inversion, multiplication etc.);
4) Transfer matrix of magnetic elements;
5) Response matrix (displacement at each monitor for unit corrent in each corrector).

A10. Vacuum status

Reads the pressure in the transfer lines from the vacuum gauges and the current in all the pumps and displays the result graphically on a linearized layout. The status of the pumps (on/off) and valves (open/closed) is also shown.

Called devices
1) Vacuum pumps;
2) Vacuum gauges;
3) Isolation valves.

Required data from the system
1) Relevant attributes of called devices;
2) Graphic display of arbitrary function through a magnetic channel.

Required subroutines
1) None.

B. ACCUMULATOR

B1. System Status

Shows a schematic layout of the Accumulator, with the option of zooming over selected fractions of the ring, such as bending arcs and injection and kicker straight sections. Clicking over a particular element opens a dedicated window with all available informations on the selected item. Variable parameters are evidenced and can be changed from the windows, with the possibility of increasing or decreasing the settings in small steps. Current waveforms for the kickers can be displayed. Particular subsets of elements, such as quadrupoles, sextupoles, correctors, vacuum gauges, pumps, strip-lines, beam position monitors, beam current monitors, can be presented on dedicated windows with relevant informations on the status of each item in the subset with the possibility of varying its status.

Called devices
1) All magnetic, RF, vacuum and diagnostic elements in the Accumulator (R/W);
2) Digital oscilloscope for pulsed elements waveforms.

Required data from the System
1) Complete device records of all magnetic, RF, vacuum and diagnostic elements in the Accumulator.

Required subroutines
1) Graphic displays of Accumulator, with zooming and selection options, and dedicated layouts for magnetic elements, diagnostics and vacuum;
2) Digital Oscilloscope waveform acquisition and display.

B2. Magnet and RF set

Enables access to a number of reference sets for electron or positron injection. The reference sets are the currents delivered by all the power supplies in the ring (bending magnets, septum magnets, quadrupoles, sextupoles, correctors and kickers) and the main parameters of the RF system (voltage and frequency). The display presents data in a physical form, namely bending radius [m] and deflection angle [mrad] for bending magnets and septa, deflection angle for correctors, normalized gradients (K^2 [m^{-2}]) for quadrupoles, integrated $\partial^2 B/\partial x^2$ for sextupoles [m^{-2}], deflection angle for kickers, voltage [KV], frequency [MHz] and phase [deg] for the RF. All parameters can be scaled together to match particular energy requirements through a dedicated knob. The program allows reading, modifying, saving and setting a number of reference sets to be fixed during commissioning and first operation. A default reference set is chosen for routine operation.

Called devices
1) All magnetic elements in the Accumulator.

Required data from the System
1) Reference sets for EM (Electron Mode), PM (Positron Mode) (R/W);
2) Relevant attributes for all magnetic elements in the Accumulator.

Required subroutines
1) None.

B3. Lattice parameters

Calculates the theoretical lattice parameters, starting from the current status of the machine. The optical functions are displayed graphically on a linearized machine layout, as well as the trajectory of the stored and injected beams under the action of the kickers and the envelopes for the injected beam first turn with the last measured Linac beam emittance and energy spread. Calculated and shown are the emittance, energy spread, uncorrected and corrected chromaticities, damping times, momentum compaction, betatron tunes, synchrotron frequency, synchrotron integrals.

Called devices
1) None.

Required data from the System
1) Accumulator Lattice;
2) Relevant attributes of magnetic and RF elements;
3) Latest Linac beam emittance, energy spread and betatron functions measurements.

Required subroutines
1) Mathematical Library (Matrix inversion, multiplication etc.);
2) Transfer matrix of magnetic elements;
3) Total machine matrix;
4) Optical functions calculation from total matrix;
5) Betatron functions and dispersion propagation;
6) Beam trajectory through a magnetic channel;
7) Synchrotron radiation integrals;
8) Momentum compaction;
9) Beam emittance;
10) Beam energy spread;
11) Horizontal and vertical uncorrected chromaticity;
12) Chromaticity correction with 2 sextupole families;
13) Horizontal and vertical betatron tune;
14) Synchrotron frequency;
15) Graphic display of arbitrary functions through a magnetic channel.

B4. Accumulator matching

Starting from the current configuration, calculates and sets the quadrupoles, sextupoles and kickers as a function of desired betatron tunes, chromaticities, stored beam position at the septum at injection, extracted beam position and angle at the septum. Optionally, each of the mentioned parameters can be increased/decreased in small steps to optimize injection/extraction efficiency.

Called devices
1) All magnetic elements in the Accumulator.

Required data from the System
1) Accumulator Lattice ;
2) Relevant attributes of magnetic elements.

Required subroutines
1) Mathematical Library (Matrix inversion, multiplication etc.);
2) Transfer matrix of magnetic elements;
3) Nonlinear equation system solution;
4) Horizontal and vertical uncorrected chromaticity;
5) Chromaticity correction with 2 sextupole families;
6) Injection kickers set.

B5. Closed orbit display (first turns)

Reads the signal from the 4 short strip-lines during the first revolutions. The measurement can be triggered by the TS on specified delays to record and display beam position after the desired number of beam turns in the ring.

Called devices
1) Short striplines.

Required data from the System
1) Relevant attributes of called devices.

Required subroutines
1) Graphic display of arbitrary functions through a magnetic channel.

B6. Closed orbit display (stored beam)

Reads and displays the stored beam position at all available beam position monitors (8) and short striplines (4). Injection is stopped during the measurement.

Called devices
1) Button beam position monitors;
2) Short striplines.

Required data from the System
1) Relevant attributes of called devices.

Required subroutines
1) Graphic display of arbitrary functions through a magnetic channel.

B7. Dispersion measurement

The beam position is measured at all available monitors and striplines as a function of the RF frequency. The result is plotted on a frequency scale to show non-linear terms and the first order dispersion calculated from the slope at the center frequency using the theoretical value of the momentum compaction. The result is compared with the expected values of the optical function. Injection is stopped during this measurement, which cannot be performed when the Main Rings are in operation, since the two RF systems are locked to each other.

Called devices
1) Button beam position monitors;
2) Short striplines;
3) RF cavity.

Required data from the System
1) Relevant attributes of called devices.

Required subroutines
1) Mathematical Library (Matrix inversion, multiplication etc.);
2) Polynomial fit;
3) Transfer matrix of magnetic elements;
4) Total machine matrix;
5) Dispersion function calculated from total matrix;
6) Dispersion propagation;
7) Synchrotron radiation integrals;
8) Momentum compaction;
9) Graphic display of arbitrary functions through a magnetic channel.

B8. Closed orbit correction

The program reads the stored beam position as in B6 and finds the optimum correction currents to obtain any desired pattern of displacements from the ideal trajectory in all position sensitive detectors, using a proper algorithm (which takes into account the maximum deflection delivered by each corrector). The correctors are set to the calculated values and the orbit is measured again to take into account the non-linearities of the machine. If needed, the whole procedure is iterated until the required accuracy is satisfied. Injection is stopped during the measurement. The correction matrix (whose elements are the displacements induced by a unitary excitation in one corrector in all monitors) can either be calculated from the theoretical model of the Accumulator or directly measured by setting each corrector to a known deflection and measuring the displacement in the monitors.

Called devices
1) Button beam position monitors;
2) Short striplines;
3) H/V correctors.

Required data from the System
1) Relevant attributes of called devices;
2) Accumulator lattice.

Required subroutines
1) Mathematical Library (Matrix inversion, multiplication etc.);
2) Transfer matrix of magnetic elements;
3) Total machine matrix;
4) Optical functions calculation from total matrix;
5) Betatron functions and dispersion propagation;
6) Response matrix (displacement at each monitor for unit current in each corrector);
7) Graphic display of arbitrary function through a magnetic channel.

B9. Localized orbit bumps

It is particularly useful to displace the beam from the ideal trajectory at some selected positions (e.g. at the kickers, injection or extraction septum), without moving the beam position in the rest of the ring. The program accepts as input the position along the ring where the beam must be displaced and the desired displacement and angle. It then finds the best combination of correctors to be used in order to get the desired displacement with the minimum perturbation on the machine. The corrector currents are found from the machine model (it is a non linear problem if there are active sextupoles between the excited correctors) and set. The new positions are measured and compared with the input values and the procedure iterated, if necessary, until the desired accuracy is obtained. It is very useful to change beam position and angle at a given point in small steps through dedicated knobs.

Called devices
1) Button beam position monitors;
2) Short striplines;
3) H/V correctors.

Required data from the System
1) Relevant attributes of called devices;
2) Accumulator lattice.

Required subroutines
1) Mathematical Library (Matrix inversion, multiplication etc.);
2) Transfer matrix of magnetic elements;
3) Local response matrix (displacement at selected monitor for unit current in nearby correctors);
4) Graphic display of arbitrary function through a magnetic channel.

B10. Tune measurement

The fractional part of betatron tunes is measured with a network analyzer connected to the feed-back striplines. The network waveform is displayed and the peak corresponding to the betatron frequencies measured and converted into betatron tune. The two planes can be measured independently or together. The measurement can be performed also during injection, by detecting the frequency of spontaneous oscillations by means of a FFT.

Called devices
1) Network analyzer connected to feedback long striplines;
2) Fast Fourier Transform analyzer.

Required data from the System
1) Integer part of betatron tunes.

Required subroutines
1) Network analyzer driver;
2) Fast Fourier Transform driver.

B11. Betatron functions measurement

This program is expected to be particularly useful during the commissionig stage. The betatron functions at the center of the quadrupoles are measured from the betatron tunes variation induced by a small variation in the current supplied to a quadrupole family. Being the quads powered in series, the measurement assumes equal betatron functions in the quads of the same family: this limitation can be overcome by a small additional coil or by shunting individual quads. The same measurement can be performed at the correctors if it will be possible to power the coils in the quadrupole configuration. The result of the measurement is displayed and compared graphically with the theoretical values calculated from the current setting of the ring. Injection is stopped during the measurement.

<u>Called devices</u>
1) Network analyzer connected to feedback long striplines;
2) Accumulator quadrupoles;
3) (Accumulator correctors).

<u>Required data from the System</u>
1) Relevant attributes of accumulator quadrupoles (and correctors);
2) Accumulator lattice.

<u>Required subroutines</u>
1) Network analyzer driver;
2) Mathematical Library (Matrix inversion, multiplication etc.);
3) Transfer matrix of magnetic elements;
4) Total machine matrix;
5) Betatron functions calculation from total matrix;
6) Betatron functions propagation;
7) Graphic display of arbitrary functions through a magnetic channel.

B12. Chromaticity measurement

The chromaticity is measured by fitting the dependence of the betatron tunes on the RF frequency. Injection is stopped during the measurement.

<u>Called devices</u>
1) Network analyzer connected to feedback long striplines;
2) RF cavity.

<u>Required data from the System</u>
1) None.

<u>Required subroutines</u>
1) Network analyzer driver;
2) Polynomial fit of measured data.

B13. Beam size measurement

The image of the beam is focused on a CCD camera at the synchrotron radiation ports for electrons and positrons from the bending magnets. The CCD signal is scanned and displayed separately as intensity profiles in the horizontal and vertical planes. The beam sizes are taken as the widths of the distributions and the emittance calculated from the theoretical optical functions. The CCD camera can also be triggered, in order to detect fast beam size variations, such as changes during damping after injection or beam instabilities.

Called devices
1) Synchrotron radiation monitor Image Analyzer.

Required data from the System
1) Accumulator lattice.

Required subroutines
1) Image Analyzer driver;
2) Mathematical Library (Matrix inversion, multiplication etc.);
3) Transfer matrix of magnetic elements;
4) Total machine matrix;
5) Betatron functions calculation from total matrix;
6) Betatron functions propagation.

B14. Bunch length measurement

The bunch length is measured on the synchrotron radiation port with a fast (<≈ 30 ps) solid state photodiode and analyzed with a sampling oscilloscope. The bunch shape is presented on the screen, together with the relevant waveform parameters.

Called devices
1) Digital oscilloscope.

Required data from the system
1) Relevant RF parameters.

Required subroutines
1) Digital oscilloscope waveform acquisition and display.

B15. Damping time measurement

The beam is kicked by one of the injection/extraction pulsed magnets. A coherent oscillation is excited, which is rapidly trasformed into an incoherent enlargement of the beam size. In the synchrotron light measurement setup a slit is positioned on the radiation spot center and the intensity of the signal after the slit is recorded on a digitizing oscilloscope. The waveform is transmitted to the CS and the damping time measured. Being the synchrotron radiation port near the injection/extraction straight section, the dispersion is small, and the horizontal betatron damping time is measured. Rotating the slit by 90º, one can measure also the vertical betatron damping, by exciting the beam in the vertical direction by means of a sinusoidal excitation in the feed-back strip lines: when the excitation is rapidly switched off, the damping time is measured in the same way as in the horizontal case. Injection is stopped during the measurement.

Called devices
1) Synchrotron radiation monitor electronics (Slit movements);
2) Accumulator kickers;
3) Waveform generator;
4) Digital oscilloscope.

Required data from the system
1) None.

Required subroutines
1) Digital oscilloscope waveform acquisition and display.

B16. Injection/extraction efficiency

The charge on each Linac pulse is measured on the current monitor (WCM) in the Transfer Line nearest to the injection point, and all the pulses are summed up to find the total charge delivered to the Accumulator. This number is compared to the stored current before extraction. The same procedure is performed on the extracted beam on a single measurement on the WCM. A stored current measurement after each injection pulse is also performed during an injection/extraction cycle and displayed on a plot to observe saturation effects.

<u>Called devices</u>
1) Current monitors in Transfer Line (single pulse) and Accumulator (stored beam).

<u>Required data from the System</u>
1) Relevant attributes of called devices.

<u>Required subroutines</u>
1) None.

B17. Beam lifetime measurement

The stored current value is measured with a current monitor at required time intervals together with average residual gas pressure in the ring, beam emittance and bunch length. The time behaviour is plotted on the screen. The measured value of the lifetime is compared with the calculated contributions of gas bremsstrahlung, gas scattering and intrabeam scattering. Injection is stopped during the measurement. If the measurement is performed at low current the current could be measured with higher sensitivity with a spectrum analyzer connected to a stripline in the "sum" configuration.

<u>Called devices</u>
1) Stored current monitor;
2) Vacuum gauges;
3) Residual gas analyzer;
4) Synchrotron radiation monitor;
5) Digital oscilloscope.

<u>Required data from the system</u>
1) Relevant attributes of called devices;
2) Beam energy;
3) Relevant attributes of RF cavity;
4) Accumulator aperture (physical, dynamic);
5) Accumulator lattice.

<u>Required subroutines</u>
1) CCD camera driver;
2) Mathematical Library (Matrix inversion, multiplication etc.);
3) Transfer matrix of magnetic elements;
4) Total machine matrix;
5) Betatron functions and dispersion calculation from total matrix;
6) Betatron functions and dispersion propagation;
7) Digital oscilloscope waveform acquisition;
8) Gas bremsstrahlung lifetime;
9) Gas scattering lifetime;
10) Intrabeam scattering (Touschek) lifetime.

B18. Synchrotron frequency measurement

The beam synchrotron frequency is measured with a spectrum analyzer and result transferred to the CS and displayed together with the relevant lattice and RF parameters (RF voltage, RF frequency, momentum compaction).

<u>Called devices</u>
1) Spectrum analyzer.

<u>Required data from the system</u>
1) Beam energy;
2) Relevant attributes of RF cavity;
3) Accumulator lattice.

<u>Required subroutines</u>
1) Spectum analyzer driver;
2) Mathematical Library (Matrix inversion, multiplication etc.);
3) Transfer matrix of magnetic elements;
4) Total machine matrix;
5) Dispersion calculation from total matrix;
6) Dispersion propagation;
7) Synchrotron radiation integrals;
8) Momentum compaction.

B19. Vacuum status

Reads the pressure in the Accumulator from the available vacuum gauges and the current in all the pumps and displays the result graphically on a linearized layout. The status of the pumps (on/off) and valves (open/closed) is also shown.

<u>Called devices</u>
1) Accumulator vacuum pumps;
2) Accumulator vacuum gauges;
3) Accumulator isolation valves.

<u>Required data from the system</u>
1) Relevant attributes of called devices.

<u>Required subroutines</u>
1) Graphic display of arbitrary function through a magnetic channel.

B20. Feed-back systems status

The relevant parameters on the status of the feed-back systems (longitudinal and transverse), such as gain, power, phase relation between pick-up and kicker are presented on the CS screens.

<u>Called devices</u>
1) Transverse feedback electronics;
2) Longitudinal feedback electronics.

<u>Required data from the System</u>
1) Relevant attributes of called devices;
2) Accumulator lattice.

<u>Required subroutines</u>
1) Mathematical Library (Matrix inversion, multiplication etc.);
2) Transfer matrix of magnetic elements;
3) Total machine matrix;
4) Optical functions calculation from total matrix;
5) Betatron phase propagation.

C. MAIN RINGS

C1. System Status

Shows a schematic layout of the Main Rings, with the option of zooming over selected fractions of the machine, such as bending arcs, injection and RF straight sections, "matching" straights, interaction regions (IR). Due the complexity of the machine, the possibility of dedicated layouts (magnets, vacuum, diagnostics, injection, detectors) is also useful. Clicking over a particular element opens a dedicated window with all available informations on the selected item. Variable parameters are evidenced and can be changed from the windows, with the possibility of increasing or decreasing the settings in small steps. Current waveforms for the kickers can be displayed. Particular subsets of elements, such as bending magnets, quadrupoles, sextupoles, splitters, wigglers, correctors, experimental solenoids, solenoidal compensators, RF systems, vacuum gauges, pumps, strip-lines, beam position monitors, beam current monitors, can be presented on dedicated windows with relevant informations on the status of each item in the subset with the possibility of varying its status.

<u>Called devices</u>
1) All magnetic, RF, vacuum, diagnostic and machine related detector elements in the Main Rings (R/W);
2) Digital oscilloscope for pulsed elements waveforms.

<u>Required data from the System</u>
1) Complete device records of all magnetic, RF, vacuum, diagnostic and machine related detector elements in the Main Rings.

<u>Required subroutines</u>
1) Graphic displays of Main Rings, with zooming and selection options, and dedicated layouts for magnetic elements, diagnostics and vacuum;
2) Digital Oscilloscope waveform acquisition and display.

C2. Magnet and RF set

Enables access to a number of reference sets for the various operation modes and for each ring. The reference sets are the currents delivered by all the power supplies in the rings (bending magnets, septum magnets, splitters, quadrupoles, sextupoles, correctors, experimental and correction solenoids, kickers), the rotation of the quadrupoles in the IR and the main parameters for the RF systems (voltage, frequency, phase shift between the two cavities). The display presents data in a physical form, namely bending radius [m] and deflection angle [mrad] for bending magnets, septa and splitters, longitudinal field [T] for solenoids and correctors, normalized gradients (K^2 [m^{-2}]) for quadrupoles, integrated $\partial^2 B/\partial x^2$[$m^{-2}$] for sextupoles, deflection angle for kickers, voltage [KV], frequency [MHz] and phase [deg] for the RF). All parameters can be scaled together to match particular energy requirements through a dedicated knob. The program allows reading, modifying, saving and setting a number of reference sets to be fixed during commissioning and first operation. A default reference set is chosen for each kind of routine operation ("day-one", single beam, one experiment, two experiments).

<u>Called devices</u>
1) All magnetic elements in the Main Rings.

<u>Required data from the System</u>
1) Reference sets for all operation modes (R/W);
2) Relevant attributes for all magnetic elements in the Main Rings.

<u>Required subroutines</u>
1) None.

C3. Lattice parameters

Calculates the theoretical lattice parameters for each ring, starting from the current status of the machine. The optical functions and beam envelopes are displayed graphically on a linearized machine layout. The status of the interaction region, crossing angle, parasitic crossings, solenoid compensation, vertical separation etc. can be shown separately. Calculated and displayed are the emittance, energy spread, uncorrected and corrected chromaticities, damping times, momentum compaction, betatron tunes, synchrotron frequency, synchrotron integrals.

<u>Called devices</u>
1) None.

<u>Required data from the System</u>
1) Main Rings Lattices;
2) Relevant attributes of magnetic and RF elements.

<u>Required subroutines</u>
1) Mathematical Library (Matrix inversion, multiplication etc.);
2) Transfer matrix of magnetic elements;
3) Total machine matrix;
4) Optical functions calculation from total matrix;
5) Betatron functions and dispersion propagation;
6) Beam trajectory through a magnetic channel;
7) Synchrotron radiation integrals;
8) Momentum compaction;
9) Beam emittance;
10) Beam energy spread;
11) Horizontal and vertical uncorrected chromaticity;
12) Chromaticity correction with 2 sextupole families;
13) Horizontal and vertical betatron tune;
14) Synchrotron frequency;
15) Solenoid compensation;
16) Parasitic crossings;
17) Graphic display of arbitrary functions through a magnetic channel.

C4. Collider matching

Calculates from the machine model and sets the magnetic elements as a function of desired betatron tunes, betatron functions at crossings, crossing angle, chromaticities, experimental solenoid field, emittance. Optionally, each of the mentioned parameters can be increased/decreased in small steps. Special items can be addressed, which change the status of a subset of elements to vary the value of one or more physical parameters at the same time: as an example, the variation of the crossing angle (at fixed other parameters) requires moving the currents in the splitter, the dedicated corrector and the quadrupoles in the matching sections. This program should be developed in a modular way, so that options of varying machine parameters can be easily implemented.

<u>Called devices</u>
1) All magnetic elements in Main Rings.

<u>Required data from the System</u>
1) Main Rings Lattices ;
2) Relevant attributes of magnetic elements.

<u>Required subroutines</u>
1) Mathematical Library (Matrix inversion, multiplication etc.);
2) Transfer matrix of magnetic elements;

3) Nonlinear equation system solution;
4) Horizontal and vertical uncorrected chromaticity;
5) Chromaticity correction scheme;
6) Synchrotron integrals;
7) Emittance calculation;
8) Solenoid correction;
9) Compensation of crossing angle;
10) Injection kickers set.

C5. Closed orbit display (first turns)

Reads the signal from the striplines during the first revolutions. The measurement can be performed (because the bunch injected from the Accumulator is sufficiently short) also on BPMs if a fast electronic system is implemented. The measurement can be triggered by the TS on specified delays to record and display the beam position after the desired number of beam turns in the ring.

<u>Called devices</u>
1) Short striplines;
2) (Button beam position monitors).

<u>Required data from the System</u>
1) Relevant attributes of called devices.

<u>Required subroutines</u>
1) Graphic display of arbitrary functions through a magnetic channel.

C6. Closed orbit display (stored beam)

Reads and displays the stored beam position at all available beam position monitors and striplines.

<u>Called devices</u>
1) Button beam position monitors;
2) Striplines.

<u>Required data from the System</u>
1) Relevant attributes of called devices.

<u>Required subroutines</u>
1) Graphic display of arbitrary functions through a magnetic channel.

C7. Dispersion measurement

The beam position is measured at all available monitors and striplines as a function of the RF frequency. The result is plotted on a frequency scale to show non-linear terms and the first order dispersion calculated from the slope at the center frequency using the theoretical value of the momentum compaction. The result is compared with the expected values of the optical function.

<u>Called devices</u>
1) Button beam position monitors;
2) Short striplines;
3) RF cavity.

<u>Required data from the System</u>
1) Relevant attributes of called devices.

<u>Required subroutines</u>
1) Mathematical Library (Matrix inversion, multiplication etc.);
2) Polynomial fit;
3) Transfer matrix of magnetic elements;
4) Total machine matrix;
5) Dispersion function calculated from total matrix;
6) Dispersion propagation;
7) Synchrotron radiation integrals;
8) Momentum compaction;
9) Graphic display of arbitrary functions through a magnetic channel.

C8. Closed orbit correction

The program reads the stored beam position as in C6 and finds the optimum correction currents to obtain any desired pattern of displacements from the ideal trajectory in all position sensitive detectors, using a proper algorithm. The correctors are set to the calculated values and the orbit is measured again to take into account the non-linearities of the machine. If needed, the whole procedure is iterated until the required accuracy is reached. Injection is stopped during the measurement. The correction matrix (whose elements are the displacements induced by a unitary excitation in one corrector in all monitors) can either be calculated from the theoretical model of the transfer line or directly measured by setting each corrector to a known deflection and measuring the displacement in the monitors.

<u>Called devices</u>
1) Button beam position monitors;
2) Striplines;
3) H/V correctors.

<u>Required data from the System</u>
1) Relevant attributes of called devices;
2) Main Rings lattices.

<u>Required subroutines</u>
1) Mathematical Library (Matrix inversion, multiplication etc.);
2) Transfer matrix of magnetic elements;
3) Total machine matrix;
4) Optical functions calculation from total matrix;
5) Betatron functions and dispersion propagation;
6) Response matrix (displacement at each monitor for unit current in each corrector);
7) Graphic display of arbitrary function through a magnetic channel.

C9. Localized orbit bumps

It is particularly useful to displace the beam from the ideal trajectory at some selected positions (e.g. at I.P. or injection septum), without moving the beam position in the rest of the ring. The programs accepts as input the position along the ring where the beam must be displaced and the desired displacement and angle. It then finds the best combination of correctors to be used in order to get the desired displacement with the minimum perturbation on the machine. The corrector currents are found from the machine model (it is a non linear problem if there are active sextupoles between the excited correctors) and set. The new positions are measured and compared with the input values and the procedure iterated, if necessary, until the desired accuracy is obtained. It is very useful to change beam position and angle at a given point in small steps through dedicated knobs.

Called devices
1) Button beam position monitors;
2) Striplines;
3) H/V correctors.

Required data from the System
1) Relevant attributes of called devices;
2) Main Rings lattices.

Required subroutines
1) Mathematical Library (Matrix inversion, multiplication etc.);
2) Transfer matrix of magnetic elements;
3) Local response matrix (displacement at selected monitor for unit current in nearby correctors);
4) Graphic display of arbitrary function through a magnetic channel.

C10. Tune measurement

The betatron tunes are measured with a network analyzer connected to the feed-back striplines. The network waveform is displayed and the peaks corresponding to the horizontal and vertical frequencies measured and converted into betatron tunes.

Called devices
1) Network analyzer connected to feedback striplines.

Required data from the System
1) Integer part of betatron tunes.

Required subroutines
1) Network analyzer driver.

C11. Betatron functions measurement

This program is expected to be very useful during the commissioning stage. The betatron functions at the center of the quadrupoles are measured from the betatron tunes variation induced by a small variation in the current supplied to the quadrupole. The same measurement can be performed at the correctors if it will be posible to power the coils in the quadrupole configuration. The result of the measurement is displayed and compared graphically with the theoretical values calculated from the current setting of the ring.

Called devices
1) Network analyzer connected to feedback striplines;
2) Main Ring quadrupoles;
3) (Main Ring correctors).

Required data from the System
1) Relevant attributes of accumulator quadrupoles (and correctors);
2) Main Rings Lattices.

Required subroutines
1) Network analyzer driver;
2) Mathematical Library (Matrix inversion, multiplication etc.);
3) Transfer matrix of magnetic elements;
4) Total machine matrix;
5) Betatron functions calculation from total matrix;
6) Betatron functions propagation;
7) Graphic display of arbitrary functions through a magnetic channel.

C12. Chromaticity measurement

The chromaticity is measured by fitting the dependence of the betatron tunes on the RF frequency.

Called devices
1) Network analyzer connected to feedback striplines;
2) RF cavity.

Required data from the System
1) None.

Required subroutines
1) Network analyzer driver;
2) Polynomial fit of measured data.

C13. Beam current measurement

The average beam current is measured by a current monitor and displayed both in numerical and graphical form, as a function of time. The charge in any individual bunch can be also measured by gating a longitudinal pick-up, calibrated against the current monitor, in coincidence with the Timing System.

Called devices
1) Beam current monitor;
2) Longitudinal pick-up;
2) Timing System.

Required data from the System
1) Relevant attributes of current monitor;
2) Relevant attributes of longitudinal pick-up.

Required subroutines
1) None.

C14. Beam size measurement

The image of the beam is focused on a CCD camera at the synchrotron radiation ports for electrons and positrons from the bending magnets (or wigglers). The CCD signal is scanned and displayed separately as intensity profiles in the horizontal and vertical planes. The beam sizes are taken as the widths of the distributions and the emittance calculated from the theoretical optical functions. The size of any any individual bunch can be also measured by gating the signal in coincidence with the Timing System.

Called devices
1) Synchrotron radiation monitor Image Analyzer;
2) Timing System.

Required data from the System
1) Main Rings Lattices.

Required subroutines
1) Image Analyzer driver;
2) Mathematical Library (Matrix inversion, multiplication etc.);
3) Transfer matrix of magnetic elements;
4) Total machine matrix;
5) Betatron functions calculation from total matrix;
6) Betatron functions propagation.

C15. Bunch length measurement

The bunch length is measured with a fast solid state photodiode and analyzed with a sampling oscilloscope. The bunch shape is presented on the screen, together with the relevant waveform parameters. The length of any individual bunch can be also measured by gating the signal in coincidence with the Timing System.

Called devices
1) Digital oscilloscope;
2) Timing System.

Required data from the system
1) Relevant RF parameters.

Required subroutines
1) Digital oscilloscope waveform acquisition and display.

C16. Damping time measurement

The beam is kicked by one of the injection pulsed magnets. A coherent oscillation is excited, which is rapidly trasformed into an incoherent enlargement of the beam size. In the synchrotron light measurement setup a slit is positioned on the radiation spot center and the intensity of the signal after the slit is recorded on a digitizing oscilloscope. The waveform is transmitted to the CS and the damping time measured. Rotating the slit by 90º, one can measure also the vertical betatron damping, by exciting the beam in the vertical direction by means of a sinusoidal excitation in the feed-back strip lines: when the excitation is rapidly switched off, the damping time is measured in the same way as in the horizontal case.

Called devices
1) Synchrotron radiation monitor electronics (Slit movements);
2) Main Rings kickers;
3) Waveform generator;
4) Digital oscilloscope.

Required data from the system
1) None.

Required subroutines
1) Digital oscilloscope waveform acquisition and display.

C17. Injection efficiency

The stored current in the Accumulator is measured on the current monitor (WCM) before extraction and at all current monitors in the transfer line from the accumulator to the main ring. A "bunch killer" system should be envisaged to correct for possible overflows of the Linac bunch in more than one bucket in the Accumulator. After injection, the current stored in the main ring is compared to the value measured before the injection pulse. The measurements are displayed in such a way to show where beam losses occur. The transfer line striplines can also be used, by calibrating them against the current monitors.

Called devices
1) Current monitors in Accumulator (stored beam), Transfer Line (single pulse) and Main Rings (stored beam).

Required data from the System
1) Relevant attributes of called devices.

Required subroutines
1) None.

C18. Beam lifetime measurement

The stored current value is measured at required time intervals together with the average residual gas pressure in the ring, and the time behaviour plotted on the screen. The measured value of the lifetime is compared with the calculated contributions of gas bremsstrahlung, gas scattering and intrabeam scattering.

Called devices
1) Main Ring current monitors (stored beam);
2) Main Ring vacuum gauges;
3) Residual gas analyzer;
4) Synchrotron radiation monitor;
5) Digital oscilloscope.

Required data from the system
1) Relevant attributes of called devices;
2) Beam energy;
3) Relevant attributes of RF cavity;
4) Main Rings aperture (physical, dynamic);
5) Main Rings lattices.

Required subroutines
1) Image Analyzer driver;
2) Mathematical Library (Matrix inversion, multiplication etc.);
3) Transfer matrix of magnetic elements;
4) Total machine matrix;
5) Betatron functions and dispersion calculation from total matrix;
6) Betatron functions and dispersion propagation;
7) Digital oscilloscope waveform acquisition;
8) Gas bremsstrahlung lifetime;
9) Gas scattering lifetime;
10) Intrabeam scattering lifetime.

C19. Synchrotron frequency measurement

The beam synchrotron frequency is measured with a spectrum analyzer and result transferred to the CS and displayed together with the relevant lattice and RF parameters (RF voltage, RF frequency, momentum compaction).

Called devices
1) Spectrum analyzer.

Required data from the system
1) Beam energy;
2) Relevant attributes of RF cavity;
3) Main Ring lattices.

Required subroutines
1) Spectum analyzer driver;
2) Mathematical Library (Matrix inversion, multiplication etc.);
3) Transfer matrix of magnetic elements;
4) Total machine matrix;
5) Dispersion calculation from total matrix;
6) Dispersion propagation;
7) Synchrotron radiation integrals;
8) Momentum compaction.

C20. Vacuum status

Reads the pressure in the rings from the available vacuum gauges and the current in all the pumps, and displays the result graphically on a linearized layout. The status of the pumps (on/off) and valves (open/closed) is also shown.

Called devices
1) Main Rings vacuum pumps;
2) Main Rings vacuum gauges;
3) Main Rings isolation valves.

Required data from the system
1) Relevant attributes of called devices.

Required subroutines
1) Graphic display of arbitrary function through a magnetic channel.

C21. Feed-back systems status

The relevant parameters on the status of the feed-back systems (longitudinal and transverse), such as gain, power, phase relation between pick-up and kicker are presented on the CS screens. The program must deliver to the longitudinal multibunch feedback systems all the required information (synchrotron frequency, momentum bunch, number of injected bunch etc.) to optimize its performance.

Called devices
1) Transverse feedback electronics;
2) Longitudinal feedback electronics.

Required data from the System
1) Relevant attributes of called devices;
2) Main rings lattices.

Required subroutines
1) Mathematical Library (Matrix inversion, multiplication etc.);
2) Transfer matrix of magnetic elements;
3) Total machine matrix;
4) Optical functions calculation from total matrix;
5) Betatron phase propagation.

C22. Luminosity measurement

The luminosity is measured through the counting rate of single beam-beam bremsstrahlung photons in a counter placed downstream the splitter magnet on an ideal line starting from the I.P and propagating in the direction of the outgoing beam. The counter gives a signal, whose intensity is proportional to the energy of the photons, and it is calibrated by comparing the measured energy spectrum to the theoretical one. The measurement is very fast at the foreseen luminosity of DAΦNE, and the background coming from the bremsstrahlung on the residual gas atoms is negligible. However, in order to check also low-luminosity conditions, such as single bunch operation during commissioning, the background can be subtracted either by storing a bunch in one of the rings, which does not cross the corresponding bunch in the other one, or by separating the beams at the I.P. The program should be able to perform all routine and commissioning operations, such as reading the scalers at given time intervals, calibrate the system at low stored current, display the luminosity in graphical form in order to optimize beam superposition. It may be used, if necessary, as a correction signal for an orbit feed-back to keep the luminosity always at its best value.

<u>Called devices</u>
1) Luminosity monitor electronics;
2) Interaction region vertical correctors.

<u>Required data from the System</u>
1) Relevant attributes of called devices.

<u>Required subroutines</u>
1) Scaler Driver;
2) ADC Driver;
3) Beam energy.

C23. Measurement of the coupling at the I.P.

Due to the presence of solenoidal fields and rotated quadrupoles, the coupling factor at the I.P. can be minimized by changing the rotation angle in the low-β quads and the field in the solenoidal compensator. Once the beam superposition is optimized, it is possible to further optimize the luminosity by changing the coupling at the I.P. The coupling value is then calculated from the measured luminosity, beam current and emittance and from the model values for the betatron functions at the I.P.

<u>Called devices</u>
1) Luminosity monitor electronics;
2) Interaction region vertical correctors;
3) Solenoid compensators;
4) Interaction region quadrupoles rotation.

<u>Required data from the System</u>
1) Relevant attributes of called devices;
2) Main Rings lattices.

<u>Required subroutines</u>
1) Scaler Driver;
2) ADC Driver;
3) Beam energy;
4) Mathematical Library (Matrix inversion, multiplication etc.);
5) Transfer matrix of magnetic elements;
6) Total machine matrix;
7) Optical functions and dispersion calculation from total matrix;
8) Betatron functions and dispersion propagation;
9) Synchrotron radiation integrals;
10) Beam emittance;
11) Beam energy spread.

C24. Detector solenoid compensation

The coupling effect of the detector solenoid is compensated by means of the field in the solenoidal compensators and the rotation of the low-β quadrupoles, as a function of the field in the central solenoid and the beam energy.

<u>Called Devices</u>
1) Main Detector Solenoid;
2) Solenoidal Compensator;
3) Rotation of low-b quadrupoles (Actuator).

<u>Required data from the System</u>
1) Pre-programmed correction file.

<u>Required Subroutines</u>
1) None.

C25. Measurement of beam-beam tune shifts

The tune shifts and tune spread are detected by the tune measurement system (C10) by comparing the waveforms of interacting and separated beams. The result is also compared with the value calculated from the measured values of luminosity, stored current, emittance and the theoretical betatron functions.

Called devices
1) Network analyzer connected to feedback striplines;
2) Luminosity monitor electronics;
3) Interaction region vertical correctors.

Required data from the System
1) Integer part of betatron tunes;
2) Relevant attributes of called devices;
3) Main Rings lattices.

Required subroutines
1) Network analyzer driver;
2) Scaler Driver;
3) ADC Driver;
4) Beam energy;
5) Mathematical Library (Matrix inversion, multiplication etc.);
6) Transfer matrix of magnetic elements;
7) Total machine matrix;
8) Optical functions and dispersion calculation from total matrix;
9) Betatron functions and dispersion propagation;
10) Synchrotron radiation integrals;
11) Beam emittance;
12) Beam energy spread.