ORBCOR
THE NEW ORBIT CORRECTION SYSTEM OF THE PS-COMPLEX

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1. WHAT IS THE ORBCOR PROGRAM?

ORBCOR is an orbit correction program, based on modelling (but it is not a modelling program), and by itself it is an OFF-line program. However, using a number of auxiliary programs and the console-ND500 communication protocol, it can communicate with the actual hardware; reading and possibly changing the corrector strengths, reading the digitized signals of the orbit monitors, etc. Thus, in effect it can also serve as an ON-line program.

ORBCOR is a data-driven program; it is equally applicable to any circular machine or storage ring. The specifics of a particular machine are in the data, the program reads in, not in the program itself.

ORBCOR provides "stationary" orbit correction in the sense, that it corrects the orbit at any momentum but not during ramping. This is not a real restriction, since correcting the orbit at a number of momenta (based on corresponding orbit measurements), a simple program can be implemented which changes the corrector strengths in small steps (almost continuously) during ramping according to the precalculated values (as it is done for example in the NSLS machines (1)).

ORBCOR approximates the extended kicks coming from the correctors having a finite length, with a point-kick applied at the middle of the corrector (2) except in the special case, when the machine functions drastically change over the length of the corrector. In this latter case, N point-kicks have to be specified at suitable locations and ORBCOR will average either the machine-functions (solution-1) or the response-matrix (solution-2) and substitute the N virtual correctors by one equivalent real one.

(1) RAMPCONTROL-program, NSLS Tech-note # , 1984.
(2) S. Krinsky: Closed Orbit Distortion Resulting from an Extended Kick, NSLS Tech Note #14, 1978.
2. RESTRICTIONS AND REQUIREMENTS

ORBCOR was implemented for the PS Division as part of an on-going effort to establish modelling and modelling based control of the different machines in the PS complex.

2.1 Early decision was made (3), (4) about the architecture of the modelling system, as consisting of two main parts:

(a) the mathematical model of the machines manipulated by a modelling program, and
(b) the application-driver programs using the results of the model calculations.

From ORBCOR's point of view it is irrelevant whether the modelling program is AGS, COMFORT, MAD (or else) as long as they all provide an output-file (TWISS-file), containing all the information needed by ORBCOR.

It is also irrelevant for ORBCOR, at what time this file is generated, but care should be exercised that the version of that output-file is generated for the exact machine (lattice, magnet models, magnet strengths, etc), to which the ORBCOR program is going to be applied.

2.2 The computer architecture for the PS control, in which ORBCOR has to be implemented is such (5), (6) that

(a) all operator interface is restricted to the Console ↔ CC,
(b) all hardware interface is restricted to

\[
\text{Console} ↔ \text{CC} ↔ \text{FEC} ↔ \text{hardware},
\]

(c) all modelling and related programs have to run on the ND-500 of PRDEV as batch jobs via the CC ↔ PRDEV link:

\[
\text{Console} ↔ \text{CC} ↔ \text{FEC} ↔ \text{hardware} \\
\uparrow \Updownarrow \Updownarrow \Updownarrow \Updownarrow \\
\text{PRDEV}
\]

(3) F. Perriollat, Proposition pour un service de "Modelling on-line" PS-CO-Note 84-22.
3. WHAT IS THE ORBCOR SYSTEM?

A number of programs, running in the Console Computers (CC) have to be written in order to provide the CONSOLE ↔ ORBCOR-program and HARDWARE ↔ ORBCOR-program communication, thus providing a complete, interactive-like, on-line orbit correction system.

Also, a few auxiliary programs, running in the PRDEV are necessary to provide communication between user and the ORBCOR program within the PRDEV, when ORBCOR is being executed off-line.

Fig.1 shows what are the different parts of the ORBCOR system, in which computer they are running, how do they interact and communicate with the ORBCOR program itself.

A detailed discussion of these programs is given in sec-8 and sec-9.

3.1 CC-programs.

The actual data and command transfer from the CC to the PRDEV will use the communication protocol (6), which is now being developed.

3.1.1 Console → CC → ORBCOR communication link:
OPERCM: Creates and modifies OPERATOR-files from the Console

3.1.2 ORBCOR → CC → Console communication link:
INFOSC: Displays results of the orbit correction on the Console

3.1.3 Hardware → FEC → CC → PRDEV communication links:
PUEMES: Orbit measuring program
CORRCM: Creates (and modifies?) CORRECTOR-files

3.1.4 ORBCOR → CC → FEC → Hardware communication link:
CORRLD: Loads the new currents into the equipment-module of the power-supply

3.1.5 ORBCOR → CC → Graphic Display
DISPLA: Generates graphic displays

3.2 Auxiliary PRDEV programs.

3.2.1 WRDIRF: Converts a standard, sequential TWISS-file into a direct access file

3.2.2 OPERCM: Creates and modifies OPERATOR-files from a PRDEV-terminal

3.2.3 INFOSC: Displays results of the orbit correction on the PRDEV-terminal

3.2.4 ORBCOMP: Calculates the difference orbit from two ORBIT-files, displays the result on a PRDEV-terminal and also writes it on a new ORBIT-file
4. INPUT TO THE ORBCOR PROGRAM

This section deals with the input requirements of the ORBCOR program, and how the needed information is grouped into data sets (data-files), see also Fig.1. The detailed layout of each of these files are given in Appendix-1.

4.1 Modelling information (TWISS-file)

Since ORBCOR is an application-driver, all modelling information of the machine, needed by ORBCOR, has to be provided by the so called TWISS-output-file of the modelling module. The information needed is:

- $Q_x$, $Q_y$: the horizontal and vertical tune of the machine
- $\alpha_p = \frac{R}{\gamma_t^2}$: the momentum compaction factor
- $\beta_c, \phi_c, D_c$: the beta (m), phase/2π (rad), dispersion (m)
- $\beta_m, \phi_m, D_m$: at the point location of the kicks
- same as above for the orbit monitors

Even, when the machine has identical superperiods, ORBCOR can not "propagate" the $\beta, \phi, D$ machine functions from one super period to the whole ring. Either (i) the input of the modelling program has to describe the whole ring - in which case the execution time has to be considered, or (ii) an extension to the modelling program has to be provided, which has access to all the model-information, and thus can propagate the machine functions and provide the necessary input - which might not be very practical.

In addition to the modelling output, the TWISS-file also have to provide unique identifiers of the actual devices to be addressed in the ON-line mode:

- CORNME, an 8 character name of the corrector magnets
- MONNME, an 8 character name of the orbit monitors
- TYPE='PUE ', type designation for monitors (MUST BE GIVEN)
- ='HCOR', OPTIONAL type designation for horizontal
- ='VCOR', and vertical correctors

The format of the TWISS-file was chosen to be the MAD output-file format (7) used as a direct access file. In this case, the records are padded to be 80 character long and a Directory-Table is appended to the standard MAD-file. This table contains the (KEYWORD,NAME,TYPE) for each elements on the TWISS-file in the order of occurrence (see also Appendix-1). The use of the direct access file is justified in sec-6.

4.2.1 SINTRAN commands

A CC program has to assign the operator specified files on the prescribed I/O-units before initiating the execution of the ORBCOR program:

1: Terminal IN/OUT for off-line (PRDEV) execution
2: OPERATOR-file IN
3: TWISS-file IN
4: HCORRECTOR-file IN
5: VCORRECTOR-file IN
6: PRINT-file OUT
7: ORBIT-file IN
8: CALCORB-file OUT for CALC only
9: GRAPHICS-file OUT on demand (not implemented yet)
10: CORSTR-file OUT for GLBL & LOCL only
11: RESULTS-file OUT

4.2.2 Data

A CC program (OPERCM) has to write a data-file (OPERATOR-file) with the following information:

IRING 4 char identifier of the machine
Pact, Pimp beam momentum [GeV/c] where the orbit was measured and where the correction is to be implemented
CORR 4 char identifier of the command (GLBL, LOCL, CALC)
XYX =1 if correcting HORIZONTAL-plane
=2 if correcting VERTICAL-plane
IGRAH=0 do not write GRAPHICS-file
=1 write GRAPHICS-file
IOFLG =1 corrector type designation is marked on the TWISS-file not marked, all correctors are listed on the CORRECTOR-file ATTENTION: the PS ring uses exclusively IOFLG=2
IREST=0 do not reset corrector strengths to 0 before correction, thus correcting the measured orbit
=1 reset corrector strengths to 0 before correction, thus correcting the bare orbit
ITER number of correctors to be used (1 < ITER < 200) ITER = 4 is used for LOCL
BMPNME 8 char name (as it appears on the TWISS-file++) of the element, where the LOCL "bump" is desired
XYO, XYPO desired displacement [mm] and slope [mrad] at the "bump"
NAME(i), i=1,ITER, 8 char name (as they appear on the TWISS-file++) of the correctors to be used in the CALC-mode
ANG(i), i=1,ITER, corresponding kicks [mrad]

+ Later this information should come from the current in the magnets
++ In case of mismatch of the names, see ERROR-handling in Appendix-2
4.3 Corrector assignment and information (CORRECTOR-file)

There has to be a certain flexibility in

(a) specifying which magnets are to be considered as correctors
(diverging the machine modelling from the corrector assignment
and avoiding the necessity of running the modelling program
every time, when different magnets are to be considered as
correctors),

(b) disabling correctors,

(c) recognizing and properly treating the situation when the
corrector can not be treated as a point kick (like in the PS,
where two combined functions dipoles, each \( \pm 4.4 \) m long and
having a D-F or F-D section, separated by \( \pm 1.6 \) m, has a
common backleg-winding powered by one power-supply).

That flexibility is provided via the CORRECTOR-file, which contains

a. CORNME 8 char corrector-magnet name, exactly matching that on
the TWISS-file (see footnote ++ on page-7)

b. PSNAME 16 char name for the power supply, the corrector is on
c. disable-flag = 0 or 1 if the corrector is enabled or disabled

The CORRECTOR-file can list all of the (horizontal or vertical) correctors
defined on the TWISS-file, or only a subset of it. All correctors, however,
which are not listed on the CORRECTOR-file will be disabled by ORBCOR. If the
TWISS-file does not contain the KEY = 'HCOR' or 'VCOR' designation, than it is
assumed that only those devices, listed on the CORRECTOR-file are correctors.
In either case, there must not be any device on the CORRECTOR-file, which does
not appear on the TWISS-file (care should be exercised to correctly match the
names -- may be extracting them from the modelling input?).

The correctors can be listed in any order, but the ones on the same power
supply have to be consecutive on the CORRECTOR-file, even though they might
not be consecutive in reality.

The device information, mentioned in 4.2 are also included in the CORRECTOR-
file:

d. present-corrector-strength [Amp]

e. maximum-achievable-corrector-strength [Amp]

f. conversion-factor from [Amp] to [Tesla * m]

Information (a)-(c) is "user-defined", while (d)-(f) are "device-related" and
accessible via the device-name (PSNAME in this case). They have to be combined
by a program and made available in the PRDEV. This program can reside either
in the CC or in the PRDEV, as long as the user of the ORBCOR program does not
have to use a PRDEV-terminal in addition to the Console.

Notice, that the PSNAME provides the means for ON-line execution of ORBCOR;
they have to be valid device-names by which those devices can be exceeded. For
OFF-line runs, only the indication of independent of identical power-supply is
important.

This file will be written and sent to the PRDEV by a CC-program (CORRCM).

+ The corrector strength can be in any unit, thus for example for the
EPA where orbit correction is envisioned by displacing quadrupoles, it can be
translated by the conversion factor to mm.
4.4 ORBIT-file

The measured orbit (in mm), a disable/enable indicator and the monitor-name, MONNME, which must match the names on the TWISS-file, will be provided by an independent orbit measuring program. Measured orbits have to be written and stored on data-files for OFF-line analysis and comparison with other orbits at any time.

This file will be written and sent to the PRDEV by a CC program (PUEMES).

5. WHAT DOES THE ORBCOR PROGRAM DO?

Presently ORBCOR can be used in 3 different modes (see the detailed algorithms in Appendix-3 and ref. (8))

More modes can easily be implemented later.

5.1 GLBL-mode

In this mode, ORBCOR minimizes the orbit displacement around the ring by adjusting the strengths of the most effective N orbit correctors using the MICADO algorithm. The following steps are performed:

(a) the orbit to be corrected is calculated as

\[ \mathbf{v} = \mathbf{v}_{\text{meas}} - \mathbf{v}_{\text{syn}} \left[ -\theta_0 \right], \]

where \(\mathbf{v}\) stands for \(x\) or \(y\), \(\mathbf{v}_{\text{syn}} = \mathbf{D} \Delta p/p\) is the synchrotron component of the measured orbit (horizontal only) due to the \(\Delta p/p\) relative momentum error of the beam, and \(\theta_0 = (A) \theta_0\) is the component of the measured orbit due to the present \(\theta_0\) kicks on the correctors, where \(A\) is the response-matrix (see Appendix-3). This latter term has to be considered only if the corrector strengths are to be set to zero before correction (IRESET=1).

(b) the new corrector strength, \(\theta_0\), is calculated to minimize the \(r\) residual orbit displacement (MICADO):

\[ | \mathbf{r} | = | \mathbf{v} + (A) \theta_0 | = \min \]

5.2 LOCL-mode

In this mode, ORBCOR achieves a desired displacement and slope at an operator-specified element of the machine (one, contained in the TWISS-file) by recalculating the strengths of the 4 closest correctors (two on each side of the specified point).

5.3 CALC-mode

In this mode, ORBCOR calculates the \(\Delta v\) orbit change, corresponding to a \(\Delta \theta\) change in the corrector strength. The resulting orbit change is also written on the calculated-ORBIT-file in the same format as the ORBIT-file, thus it can serve as input ORBIT-file for an other execution or ORBCOR.
5.4 Other modes

Any other mode can easily be included into the program. Two of the proposed modes are:

5.4.1 HARM-mode
This would be a harmonic correction mode, where
   a. the program would fit the measured orbit with harmonics up to the n-th
      (n could be either operator specified or fixed),
   b. correct for certain, operator specified harmonics by first choosing the
      appropriately situated correctors and then calculating both, the residual
      orbit and the corrector strength.

5.4.2 HELP-mode
In this mode, ORBCOR could provide some information in a convenient form to help the user
   a. to locate an element by name (HELP would return the superperiod, the
      element is in and the seq-# in the defined lattice),
   b. to find the name of the i-th element in the defined lattice,
   c. to print and/or display all elements in a given superperiod or the
      whole ring.

6. OUTPUT FROM THE ORBCOR PROGRAM.

6.1 PRINT-file

ORBCOR unconditionally writes a detailed report on a ASCII data-file, which can be printed on operator request. At every execution of the program, the same file is being overwritten. An example of the output format for each of the 3 modes (GLBL, LOCL, CALC) are given on Figs.5-7.

6.2 Calculated orbit (ORBIT-file)

The calculated orbit in the CALC-mode is written on a data-file in the standard ORBIT-file format. This will make possible the comparison (by the ORBCOMP auxiliary program) of an expected and a measured orbit, or the finding of equivalent or corrector set to a given or corrector set (by calculating first the orbit corresponding to a set of klicks and then globally correcting this orbit while disabling one or more of the original correctors). It also provides a way for testing the program.

6.3 Calculated corrector strengths (CORSTR-file)

The calculated new or corrector strengths (in the GLBL and LOCL-mode) have to be written on a data-file for the ON-line option. The file is automatically rewritten at every execution of the program, and it is up to the operator to get and use it via the CORRLD CC-program.

For each corrector whose strength was modified, the power-supply-name (PSNAME) and the new value of the current in Amp is written on the file.
6.4 RESULTS-file

This file is used by the INFOSC program to display the results of the orbit correction on the Console or on the PRDEV-terminal

It is a subset of the results, written on the PRINT-file:

For all 3 modes:
    IRING, Pact, Pimp, CORR, IXY ............. as specified on the OPERATOR-file For GLBL only:
    ITER, IRESET .............................. as specified on the OPERATOR-file
    CORNMEi, PSNAMEi ....................... as specified on the CORRECTOR-file i=1,ITER
    θi,before [mrad], θi,after [mrad & Amp]  .... as calculated
    RMS orbit before & after correction [mm] .... as calculated
    ΔP/P ...................................... as calculated

For LOCL only:
    BPMNME, XYO, XYPO ..................... as specified on the OPERATOR-file
    β, ω, D  machine functions at the "bump" location as found on the TWISS-file
    XYP, XYPP present value of the displacement and slope [mm & mrad] as calculated
    CORNMEi, PSNAMEi ....................... as specified on the CORRECTOR-file i=1,ITER
    θi,before [mrad], θi,after [mrad & Amp]  .... as calculated

For CALC only:
    ITER, (NAMEi, ANGi, i=1,ITER) ........ as specified on the OPERATOR-file
    Calculated orbit [mm]

6.4 GRAPHICS-file

This file has to provide the necessary data for the CC display program (DISPLA), such that no calculations should be duplicated. A few of the proposed displays are:

a. H & V measured orbit
b. Calculated orbit together with the used correctors
c. H or V orbit and correctors before and after correction

The first two cases should be available both, as

a. v [mm] vs. s [m], and
b. v / fβ vs. ϕ [rad].

7. EXECUTION TIME

A large portion of the execution time of ORBCOR is spent on the reading of the TWISS-file. By separating the modelling part from the orbit correction, we reduced the execution time on the calculations but introduced an additional considerable time in reading-in the modelling data.

Typical examples for the execution time are given in row-b of Table-1 for horizontal and vertical GLBL orbit correction using TWISS-files with (i) 160
elements total and (ii) 733 elements total. The number of monitors and correctors are the same for the 160 and for the 733 elements, but there are 30 more horizontal then vertical correctors. In each case, the execution-time in sec and the CPU-time in internal units are given. The numbers without the bracket refer to the time used by the TWISS-file handling, while the numbers in bracket refer to the rest of the execution time.

These times were obtained by reading as little as possible and avoiding formatted reading whenever possible. As a point of interest The corresponding times are given in row-c with formatted read of all information on the TWISS-file.

<table>
<thead>
<tr>
<th></th>
<th>t [sec]</th>
<th>CPU [a.u.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>160 elmts</td>
<td>a)</td>
<td>4 (+4)</td>
</tr>
<tr>
<td>40 mon</td>
<td>b)</td>
<td>4 (+4)</td>
</tr>
<tr>
<td>50 corr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>733 elmts</td>
<td>a)</td>
</tr>
<tr>
<td>40 mon</td>
<td>b)</td>
<td>15 (+4)</td>
</tr>
<tr>
<td>50 corr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>160 elmts</td>
<td>a)</td>
</tr>
<tr>
<td>40 mon</td>
<td>b)</td>
<td>3 (+3)</td>
</tr>
<tr>
<td>20 corr</td>
<td>c)</td>
<td>11 (+3)</td>
</tr>
<tr>
<td>733 elmts</td>
<td>a)</td>
<td>10 (+4)</td>
</tr>
<tr>
<td>40 mon</td>
<td>b)</td>
<td>11 (+4)</td>
</tr>
<tr>
<td>20 corr</td>
<td>c)</td>
<td>34 (+4)</td>
</tr>
</tbody>
</table>

Considerable time can be saved if the TWISS-file is a random-access file and records corresponding to only those elements, one is interested in, can be read (instead of sequentially reading the file and pulling out the relevant records).

As a test, both TWISS-files (with 160 and 733 elements) were converted using the WRDIRF-program to fixed-lengths-record (80 ASCII characters) random-access file without any format change, and a number of records were appended at the end containing a table of the KEYWORD, NAME and TYPE of each element (see Appendix-1). This table is used by the "random"- version of the program to convert pointers (NAME or TYPE) to sequence-#, thus allowing direct read by the record-. The execution times with the random-version of ORBCOR are given in row-a. The gain compared with row-b is significant, reducing the overhead to at least comparable with the rest of the execution time.

Other advantages of having a random access file are the easy handling of mismatched corrector or monitor names and the absence of the need to list correctors and monitors on the CORRECTOR and ORBIT files in the same order as on the TWISS-file. This later allows easy recognition of magnets which are fed by the same power supply but which are physically separated from each other by other elements (e.g. "bump"-magnets).
8. SPECIFICATIONS FOR THE CC-PROGRAMS

In this section, the specifications of the CC-programs mentioned in sec-3 are given. The separation of these programs is arbitrary and is rather functional than factual; that is they can be implemented as one CC-program performing all the separate tasks.

Care should be exercised
1) to prevent screen-scrolling when part of the information is "running-off" the screen,
2) to carefully design the screen-formats to display every important information with enough explanation on the limited area of the screen,
3) to use cursor-control to help and guide the operator and make his/her work easier,
4) to offer default answers whenever possible.

8.1 Orbit measuring program (PUEMES).

This program will
a) measure the orbit at an operator specified momentum,

b) test the raw-data (digitized signals) to flag suspicious PUE's;

set the "disable-flag" based on
(i) the analysis of the raw-data
(ii) operator selection
(iii) default-file

c) write the H & V orbits in standard format on an ORBIT-file (see Appendix-1). Care should be exercised, that the PUE names on the ORBIT-file and the TWISS-file should be identical. Also, it is a good practice to write the date, file-name, comments, etc. in the 1-st two records.

As an example for an orbit measuring program see (9).

8.2 OPERATOR-file manipulating program (OPERCM).

This program will create or modify the OPERATOR-file, which serves as "operator input" for the ORBCOR program.

The program has to:

a) clear the console-screen (or part of it) and display the designed screen-format with a short indication of the items to be specified by the operator (as an example, see Figs.2),

(9) Eva Bozoki: Orbit measurements through the use of the PUEREAL program, BNL-32899, 1983
b) fill the displayed screen-format with the values from the input-file,

c) accept new values where desired.

As an example for this program see its implementation on the PRDEV (sec-9.1) and also (10).

8.3 Results-reporting program (INFOSC)

This program will display the most important results and messages on the Console, which were written by the ORBCOR program on the RESULTS-file. As an example, see its implementation on the PRDEV (sec-9.2).

8.4 CORRECTOR-file manipulating program (CORECM).

This program has to access and combine information related to the orbit-corrector-magnets and then write the collected data on the CORRECTOR-file. It also has to provide a way of modifying the content of a given CORRECTOR-file.

The input/output-file-names have to be operator specified, either accepting them from the program or providing them via 'open-file' statements in perform-macros.

The procedure is as follows:

a) The list of names of the correctors for which information is to be provided and which will serve as a pointer to further information on that magnet has to come from a system-table. Care should be exercised, that the names match those, on the TWISS-file!

b) By the corrector-name, the following information has to be looked-up from a system-table:
   (i) the [Tesla x m] / [Amp] calibration-factor for the magnet
   (ii) the name of the corresponding power-supply

c) Using the power-supply-name as a pointer, the following further information has to be read from the corresponding equipment-module:
   (i) present current [Amp] provided by the power-supply,
   (ii) maximum current, which can be provided by the power-supply.

d) Set "disable-flag" based on certain criteria. This is the only information which might have to be modified for an existing CORRECTOR-file.
8.5 Corrector-strength changing program (CORRLD).

This program will load the new corrector strengths (calculated by ORBCOR) into the equipment-module of the power-supply.

The corrector-names and the new corrector-strengths in [mrad] are read from the CORSTR-file.

The corresponding [Tesla * m] / [Amp] calibration factor is looked up from a system-table.

The corresponding power-supply-name is looked up from a system-table.

The new value is then loaded.

8.6 Graphic display program (ORBGRAPH).

To be specified later
9. THE MINIMUM ORBCOR SYSTEM ON THE PRDEV

For OFF-LINE use of ORBCOR and for testing until the CC-programs and the CC-PRDEV communication are not available, OPERCM and INFOSC (see Fig. 1) were implemented on the PRDEV. These two programs are interactive and serve to communicate the operator's request and choice to ORBCOR as well as to inform the operator about the results of the calculations performed in ORBCOR.

In order to facilitate the comparison of two measured or a measured and a calculated orbit, and create difference orbit files (which could serve as input to and analysed by ORBCOR) in the standard ORBIT-file format, an auxiliary program, ORBCOMP was implemented.

Until (and if) the MAD-program will provide the TWISS-file in direct-access format as described in sec-4.1 and in Appendix-1, another auxiliary program, WRDIRF was implemented. This program simply takes a sequential TWISS-file and converts it to a direct-access file.

9.1 OPERCM

The program displays the present content of the OPERATOR-file on two screen pages as shown on Figs. 2. Then, the following operations are offered:

MODIFY: After specifying the line# (as shown on the left side of the screen) to be modified, the cursor jumps to the right position to accept the new value.

ADD, DELETE: These operations are relevant on the 2-nd screen-page only, where a list of corrector-names and kicks are displayed for the CALC option. One can extend or shrink the list by specifying the line-# and item-#. The number of correctors to be used (ITER) automatically gets updated by these operations.

NEXT: To go from page-1 to page-2

PREVIOUS: To go from page-2 to page-1

EXIT The new values are getting written onto the OPERATOR-file.

The create and modify options do not differ; the OPERATOR-file can be empty before running the program.

In the present version, the input OPERATOR-file is overwritten.

9.2 INFOSC

This program displays information (including warnings and error messages — see Appendix-2) from the RESULTS-file onto the operator-screen. The before & after correction orbits are not displayed since it will be graphically done (besides taking up most of the operator-screen).

There is no screen scrolling, all the information remains on the screen until further operator action. A few sample screens are shown on Figs. 3.
9.3 ORBCOMP

This program calculates the difference orbit (both horizontally and vertically) as
\[ \Delta \vec{V} = \vec{V}_{\text{compare}} - \vec{V}_{\text{reference}} \]

where \( \vec{V} \) stands for \( X \) or \( Y \). The difference orbit is then displayed on the operator screen and also written on the difference-orbit-file. A sample screen is shown of Fig.4.

10. PROGRAM MAINTENANCE AND EXECUTION.

The loading and execution of all PRDEV-programs and program-sequences are "prepackaged" into perform-macro’s, which in turn are grouped into two libraries. A perform-macro is flexible enough to accept parameters (e.g. file names) either as entered from a PRDEV terminal or as shipped over from a CC.

The PERF-LIB-500:MCRO library contains all macros, needed to load any of the ND-500 programs and to execute any of those, which are noninteractive. The two interactive programs (OPERCM and INFOSC) presently cannot be executed from a macro due to the nonavailability of any system-command to switch between terminal and macro input.

The PERF-LIB-100:MCRO library contains all macros, needed to compile, load and execute INFOSC and OPERCM on the ND-100 and the total execution sequence of the ORBCOR-system on the PRDEV (i.e. OPERCM - ORBCOR - INFOSC).

The following is a list of content of the two libraries with the instruction on how to use them.

to execute ORBCOMP:
@PERF P-L-5 ORBCOMP-GO <ref orbit> <comp orbit> <diff orbit> to load
and/or execute ORBCOR:
@PERF P-L-5 ORBCOR-LOAD
@PERF P-L-5 ORBCOR-GO <orbit to correct> <TWISS-file-pointer>
@PERF P-L-5 ORBCOR-LG <orbit to correct> <TWISS-file-pointer> to load
any program with cursor-control (on the ND-500):
@PERF P-L-5 VLOAD <program> to load and/or execute WRDIRF
@PERF P-L-5 WRDIRF-LOAD
@PERF P-L-5 WRDIRF-GO <seq-TWISS-file> <direct-access-TWISS-file>
@PERF P-L-5 WRDIRF-LG <seq-TWISS-file> <direct-access-TWISS-file>

to compile, load, execute a program (e.g. OPERCM or INFOSC) with cursor control (on the ND-100):
@PERF P-L-1 VTM-CLG <program>
@PERF P-L-1 VTM-LD <program>
@PERF P-L-1 VTM-GO <program>
@PERF P-L-1 VTM-LG <program>
to execute the ORBCOR-sequence (3 programs):
@PERF P-L-1 ORBCOR-GO <orbit to correct> <TWISS-file-pointer>
APPENDIX-1

Layout of the input/output-files

OPERATOR-file

<table>
<thead>
<tr>
<th>REC</th>
<th>Flag</th>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>free-form</td>
<td>IXY, IOFLG, ISEND, P(actual), P(implement)</td>
<td>[Gev/c]</td>
</tr>
<tr>
<td>2</td>
<td>A4,2X,A4</td>
<td>ring designation (IRING), operation: GLBL/LOCL/CALC/HELP</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>free-form</td>
<td>IRESET, ITER (IRESET is used only for GLBL)</td>
<td>(ITER is used for GLBL and CALC)</td>
</tr>
<tr>
<td>4</td>
<td>A8,2F6.1</td>
<td>BPMNAME, XYO, XYPO [mm] (used only for LOCL)</td>
<td></td>
</tr>
<tr>
<td>5:9</td>
<td>8(A8,1X)</td>
<td>corrector names for CALC (max. NCOR=40)</td>
<td></td>
</tr>
<tr>
<td>6:11</td>
<td>free-form</td>
<td>kicks for CALC [mrad] (max. NCOR=40)</td>
<td></td>
</tr>
</tbody>
</table>

CORRECTOR-file

1 identical record for each corrector (H or V) in the ring:

<table>
<thead>
<tr>
<th>CORNAME</th>
<th>PSNAME</th>
<th>NGCOR</th>
<th>CURMX</th>
<th>CURPR</th>
<th>CALIB</th>
</tr>
</thead>
<tbody>
<tr>
<td>A8</td>
<td>2X</td>
<td>A16</td>
<td>I2</td>
<td>F14.8</td>
<td>F14.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

where CORNAME is the corrector name
PSNAME is the power-supply name
NGCOR is the disable/enable-flag (=0/enable, =1/disable)
CURMX is the maximum current [Amp]
CURPR is the present value of the current [Amp]
CALIB is the conversion-factor in [T*m/Amp]

CORSTR-file

1 identical record for each power supply which has to be changed:

<table>
<thead>
<tr>
<th>PSNAME</th>
<th>[Amp]</th>
<th>A16</th>
<th>E12.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ORBIT-file

1 identical record for each monitor in the ring:

<table>
<thead>
<tr>
<th>XO</th>
<th>YO</th>
<th>NGPUE</th>
<th>MONNAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>F9.4</td>
<td>1X</td>
<td>F9.4</td>
<td>1X</td>
</tr>
<tr>
<td>1X</td>
<td>I2</td>
<td>1X</td>
<td>A8</td>
</tr>
</tbody>
</table>

where XO, YO are the measured orbits [mm]
NGPUE is the disable/enable-flag (=0/enabled, =1/H-disabled, =2/V-disabled, =3/H&V-disabled)
MONNAME is the monitor name
TWISS-file

Standard MAD output-file. The items used by ORBCOR are shown here only.

REC #1
( NS ISP NELM
( 5A8 I8 A8 I8

REC #2
( A80

5 records
(KEYWORD NAME TYPE
( A8 A8 A4 F12.6 3F16.9
for
( 5F16.9
each
( BETAX PHIX DISPX
( F16.9 F16.9 F16.9 F16.9 F16.9
in
( BETAY PHIX DISPY
( F16.9 F16.9 F16.9 F16.9 F16.9
the
ring
( 5F16.9

REC #(last-2)
(DELP GAMT CIRC
(F16.9 F16.9 F16.9 2F16.9

REC #(last-1)
( QX QPX
(F16.9 F16.9 F16.9 2F16.9

REC #last
( QY QPY
(F16.9 F16.9 F16.9 2F16.9

Plus (NELM/4) additional records for the Directory Table, where each record contains 3 pointers to 4 elements:

(KEYWORD,NAME,TYPE)-1,2,3,4
A8 A8 A4

where
NS
is the number of superperiods on the TWISS-file (has to be 1, i.e. the whole ring has to be described, since ORBCOR can not propagate the machine functions)

ISP
symmetry-flag (not used)
NELM
# of elements on the TWISS-file
KEYWORD
element type: DRIFT, RBEND, QUAD, etc.
NAME
element name
TYPE
user specified element type: HCOR, VCOR, PUE, etc.
BETA,PHI,DISP
machine functions at the end of the elements
DELP
AP/γ
GAMT
transition-γ
Q,QP
tune and chromaticity
## APPENDIX-2

### Error Handling

<table>
<thead>
<tr>
<th>ERROR CONDITION</th>
<th>ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITER &gt; NCTOT</td>
<td>ITER = NCTOT</td>
</tr>
<tr>
<td># of correctors to be used</td>
<td></td>
</tr>
<tr>
<td>total # of enabled correctors</td>
<td></td>
</tr>
<tr>
<td><strong>BMPNME</strong> as specified on the OPERATOR-file was not found on the TWISS-file</td>
<td>write ERROR-message-1 on PRINT- and RESULTS-file then STOP</td>
</tr>
<tr>
<td><strong>MONNME</strong> as specified on the ORBIT-file was not found on the TWISS-file</td>
<td>Write WARNING-message-1,2 on Print- and WARNING-m-1 on RESULTS-file then disable monitor</td>
</tr>
<tr>
<td>an element on the TWISS-file specified as TYPE='PUE' was not found on the ORBIT-file</td>
<td>Write WARNING-message-3 on PRINT- and RESULTS-file then disable monitor</td>
</tr>
<tr>
<td><strong>CORNME</strong> as specified on the CORRECTOR-file was not found on the TWISS-file</td>
<td>write WARNING-message-4 on PRINT- and RESULTS-file then disable the corrector</td>
</tr>
<tr>
<td>any NAME used in the CALC-mode as specified on the OPERATOR-file was not found on the TWISS-file</td>
<td>write ERROR-message-2 on PRINT- and RESULTS-file then STOP</td>
</tr>
</tbody>
</table>

ERROR-message-1: Element-<BMPNME> not found on TWISS-file
ERROR-message-2: <NAME> is not a corrector

WARNING-message-1: <N> correctors not on TWISS-file (not found: <name-of-first-not-found>)
WARNING-message-2: PUE-<name from ORBIT-file> not found on TWISS-file
WARNING-message-3: More PUE on TWISS- then on ORBIT-file
WARNING-message-4: Corrector-<name from CORR-file> not found on TWISS-file
APPENDIX-3

Calculations performed in the GLBL/LOCL/CALC options.

1. GLBL

In the followings \( x \) stands for either \( x \) or \( y \) (hor. or vert. displacements).
Let \( x_{\text{meas}} \) [mm] be the measured orbit displacement at the \( m \)-th monitor (\( m=1,N_{m} \)).
Let \( \theta_{j}^{0} \) [mrad] be the strength of the \( j \)-th corrector before the correction.

The displacement at the \( m \)-th monitor due to the \( \theta_{j}^{0} \) kicks (\( j=1,N_{c} \)):

\[
x_{m}^{\text{corr}} = \sum_{j} A_{mj} \theta_{j}^{0}
\]

where \( A_{mj} \) is the "response" matrix:

\[
A_{mj} = \frac{\sqrt{\beta_{m} \beta_{j}}}{2 \sin(\pi \nu)} \cos(\pi \nu - |\Delta \phi_{jm}|)
\]

Let \( x_{m}^{\text{syn}} \) denote the synchrotron part (horizontal only) of the \( m \)-th displacement:

\[
x_{m}^{\text{syn}} = \eta_{m} \frac{dP}{p}
\]

The \( dP/P \) relative momentum error can be calculated in the following way:
using the \( x = \eta^{*}(dP/P) \) relation, the momentum error which results in the
\( x_{m} \) displacements at locations with \( \eta_{m} \) dispersion can be calculated as

\[
dP/P = \sum (\eta_{m} x_{m}) / \sum (\eta_{m})^{2}
\]

The \( dL \) path length change due to the \( dP/P \) momentum error is

\[
dL = L \times \alpha \times (dP/P)
\]

There is also a \( dL = \sum \eta_{j} \Delta \theta_{j} \) path length change when the corrector strengths
change by \( \Delta \theta_{j} \) mrad. The \( dP/P \) corresponding to this orbit change is

\[
dP/P = \sum \eta_{j} \Delta \theta_{j} / (L \times \alpha_{p})
\]

Since \( dL \) must not change with the changing of the corrector strength, the
momentum error is calculated as:

\[
\frac{dP}{p} = \frac{\sum \eta_{m} x_{m}^{\text{meas}}}{\sum \eta_{m}^{2}} + \left[ \sum \eta_{j} \frac{\theta_{j}^{0}}{p \alpha_{L}} \right]
\]
2.1 Calculation of orbit displacement and slope

The $x_o$ displacement and $x'_o$ slope of the orbit at any location (with betatron phase $\phi_o$) in the ring can be calculated from the $x_1$ and $x_2$ displacements, measured by two monitors located at $\phi_1$ and $\phi_2$ (see Fig. A) and from the $M_{10}, M_{12}, M_{02}$ transport matrices by using the following equations:

\[
\begin{pmatrix}
(x) \\
(x')_o
\end{pmatrix} = M_{01} \begin{pmatrix}
(x) \\
(x')_1
\end{pmatrix}
\]

\[
\begin{pmatrix}
(x) \\
(x')_2
\end{pmatrix} = M_{02} \begin{pmatrix}
(x) \\
(x')_o
\end{pmatrix} = M_{02} \begin{pmatrix}
(x) \\
(x')_1
\end{pmatrix} = M_{12} \begin{pmatrix}
(x) \\
(x')_1
\end{pmatrix}
\]

The solution of Eqs (5) can be written as:

\[
\begin{pmatrix}
(x) \\
(x')_o
\end{pmatrix} = \frac{1}{\sin(\phi_2 - \phi_1)} \begin{pmatrix}
\sqrt{\beta_{1}/\beta_1} \sin(\phi_2 - \phi_o) & \sqrt{\beta_{2}/\beta_2} \sin(\phi_2 - \phi_o) \\
-\frac{1}{\sqrt{\beta_{1}}} [\cos(\phi_2 - \phi_o) + a_o \sin(\phi_2 - \phi_o)] & \frac{1}{\sqrt{\beta_{1}}} [\cos(\phi_o - \phi_1) \sin(\phi_o - \phi_1)]
\end{pmatrix} \begin{pmatrix}
x_1 \\
x_2
\end{pmatrix}
\]

(6)

2.2 Calculation of new corrector strengths

The four correctors, used to change the $[x,x']_o$ displacement and slope to the desired $[x,x']_d$ values, are located at $\phi_1, \phi_2, \phi_3, \phi_4$ (see Fig. B). Let $\Delta x, \Delta x'$ be the change in displacement and slope. The $B_j, j=1, 4$ new corrector strengths have to satisfy the following requirements:

\[
\begin{align*}
\Delta x_o &= x_d - x_o \\
\Delta x'_o &= x'_d - x'_o \\
\Delta x_1 &= 0 \\
\Delta x'_1 &= 0
\end{align*}
\]

\[(7a) \quad (7b) \quad (7c) \quad (7d)\]
Using eq. (1) and its derivative at $\phi_0$:

$$x'_0 = -\frac{a_0}{B_0} \sum_j \frac{\sqrt{B_0 \beta_j}}{2 \sin(\pi \nu)} \theta_j \cos(\pi \nu - |\Delta \phi_0|) + \frac{1}{B_0} \sum_j \sqrt{\frac{B_0 \beta_j}{2 \sin(\pi \nu)}} \theta_j \sin(\pi \nu - |\Delta \phi_0|) =$$

$$= -\frac{a_0}{B_0} x_0 + \frac{1}{B_0} \sum_j \sqrt{\frac{B_0 \beta_j}{2 \sin(\pi \nu)}} \theta_j \sin(\pi \nu - |\Delta \phi_0|) = -\frac{a_0}{B_0} x_0 + \frac{1}{B_0} \sum_j C_{0j} \theta_j,$$

The (7a-b) requirements can be rewritten as:

$$\Delta x_0 = \sum_j A_{0j} \theta_j$$

$$B_0 \Delta x'_0 + a_0 \Delta x_0 = \sum_j C_{0j} \theta_j.$$

Thus the $\theta_j$ solutions can be obtained from

$$\begin{pmatrix}
0 \\
0 \\
x_D - x_0 \\
B_0 (x_D - x'_0) + a_0 (x_D - x_0)
\end{pmatrix} = (D)
\begin{pmatrix}
\sqrt{B_1} \theta_1 \\
\sqrt{B_2} \theta_2 \\
\sqrt{B_3} \theta_3 \\
\sqrt{B_4} \theta_4
\end{pmatrix}$$

where

$$(D) = \sqrt{\frac{B_1}{2 \sin(\pi \nu)}} 
\begin{pmatrix}
1 & \cos(\phi_2 - \phi_1) & \cos(\phi_3 - \phi_1) & \cos(\phi_4 - \phi_1) \\
0 & \sin(\phi_2 - \phi_1) & \sin(\phi_3 - \phi_1) & \sin(\phi_4 - \phi_1) \\
\cos(\pi \nu - \phi_0 - \phi_1) & \cos(\pi \nu - \phi_0 - \phi_2) & \cos(\pi \nu - \phi_0 - \phi_3) & \cos(\pi \nu - \phi_0 - \phi_1) \\
\sin(\pi \nu - \phi_0 - \phi_1) & \sin(\pi \nu - \phi_0 - \phi_2) & \sin(\pi \nu - \phi_0 - \phi_3) & \sin(\pi \nu - \phi_0 - \phi_1)
\end{pmatrix}.$$

3. CALC

The $\Delta^*$ change in the orbit displacements (observed at the monitors) due to a $\Delta \phi$ corrector change is calculated from Eq. (1).
Fig. 2a

Screen page #1 of OPERCM

LINE-1; Name of correctors used for CALC:
F87  F91  F97

LINE-2; Corresponding kicks in [mrad]:
.20000  -.15000  .25000

Fig. 2b

Screen page #2 of OPERCM
### Fig. 3a
Screen-page of INFOSC for the GLBL-option

<table>
<thead>
<tr>
<th>NAME</th>
<th>BEFORE</th>
<th>AFTER</th>
<th>NAME</th>
<th>BEFORE</th>
<th>AFTER</th>
<th>NAME</th>
<th>BEFORE</th>
<th>AFTER</th>
</tr>
</thead>
<tbody>
<tr>
<td>F39</td>
<td>0.006</td>
<td>0.176</td>
<td>F95</td>
<td>0.009</td>
<td>0.367</td>
<td>F21</td>
<td>-0.008</td>
<td>0.408</td>
</tr>
<tr>
<td>F65</td>
<td>-0.013</td>
<td>0.356</td>
<td>F99</td>
<td>0.010</td>
<td>0.140</td>
<td>F31</td>
<td>-0.004</td>
<td>0.119</td>
</tr>
<tr>
<td>F63</td>
<td>0.007</td>
<td>0.400</td>
<td>F67</td>
<td>-0.006</td>
<td>0.408</td>
<td>F37</td>
<td>-0.001</td>
<td>0.069</td>
</tr>
<tr>
<td>F57</td>
<td>0.000</td>
<td>-0.196</td>
<td>F11</td>
<td>0.014</td>
<td>-0.334</td>
<td>F71</td>
<td>0.001</td>
<td>0.093</td>
</tr>
<tr>
<td>F91</td>
<td>-0.010</td>
<td>0.350</td>
<td>F23</td>
<td>0.001</td>
<td>0.395</td>
<td>F75</td>
<td>-0.011</td>
<td>0.408</td>
</tr>
<tr>
<td>F15</td>
<td>0.001</td>
<td>0.313</td>
<td>F51</td>
<td>0.002</td>
<td>0.408</td>
<td>F73</td>
<td>-0.007</td>
<td>0.374</td>
</tr>
<tr>
<td>F97</td>
<td>0.014</td>
<td>0.408</td>
<td>F47</td>
<td>-0.007</td>
<td>0.408</td>
<td>F65</td>
<td>0.004</td>
<td>0.041</td>
</tr>
<tr>
<td>F29</td>
<td>0.004</td>
<td>-0.196</td>
<td>F45</td>
<td>-0.004</td>
<td>0.180</td>
<td>F19</td>
<td>0.004</td>
<td>0.205</td>
</tr>
<tr>
<td>F69</td>
<td>0.006</td>
<td>0.408</td>
<td>F49</td>
<td>-0.004</td>
<td>0.408</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F79</td>
<td>0.003</td>
<td>0.021</td>
<td>F77</td>
<td>0.007</td>
<td>-0.338</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F87</td>
<td>-0.007</td>
<td>0.222</td>
<td>F03</td>
<td>-0.014</td>
<td>-0.174</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Enter any number to continue.

### Fig. 3b
Screen-page of INFOSC for the LOCL-option (with warning-messages)

* Additional messages on the PRINT-file
  ** WARNING: g65 not on TWISS-file
  ** WARNING: f69 not on TWISS-file

** Additional messages on the PRINT-file
  ** WARNING: f69 not on TWISS-file
  ** WARNING: f51 not on TWISS-file
  ** WARNING: f67 not on TWISS-file
Fig. 3c
Screen-page of INFOSC for the CALC-option

Fig. 3d
Screen-page of INFOSC for the CALC-option (with error-message)

Fig. 4
Screen-page of ORBCOMP
Fig. 5  
PRINT-file for the GLBL-option

as read from the OPERATOR-file

as read from the ORBIT-file

from 1-st record of TWISS-file

combined information on "matched" PUE's (extracted from the ORBIT & TWISS-files)

combined information on "matched" corr's (extracted from the CORRECTOR & TWISS-files)

as read from the TWISS-file

--- after matching PUE names from TWISS-file

--- after matching corr names from TWISS-file

no redefined and eliminated corr's;
all corr's are on different power-s
Fig. 6
PRINT-file for the LOCL-option

as read from the OPERATOR-file

as read from the ORBIT-file

from 1-st record of TWISS-file

combined information on "matched" PUE's (extracted from the ORBIT & TWISS-files)

combined information on "matched" corr's (extracted from the CORRECTOR & TWISS-files)

as read from the TWISS-file
Fig. 6 (continued)
PRINT file for the LOCL option

after matching PUE names from TWISS-f
after matching corr name from TWISS-f
no redefined and eliminated corr's;
all corr's are on different power-s
present x and x' as calculated

correctors, chosen by the program

MONITOR DELETE FLAGS:

CORRECTOR DELETE FLAGS:

ELIMINATED CORRECTORS

REDEFINED CORRECTORS

FROM MONITORS 8.6 AND 8.7, THE ORBIT AT THE POSITION OF LOCAL CORRECTION:
DISPLACEMENT = -1.920 mm
SLOPE = -0.0024 mm

THE 4 CORRECTORS CHosen FOR ORBIT CORRECTION:

<table>
<thead>
<tr>
<th>SEQ#</th>
<th>NAME</th>
<th>STRENGTH BEFORE CORR.</th>
<th>POWER</th>
<th>STRENGTH AFTER CORR.</th>
<th>POWER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DVT38</td>
<td>-0.018</td>
<td>P1</td>
<td>-0.0547</td>
<td>P1</td>
</tr>
<tr>
<td>2</td>
<td>DVT44</td>
<td>-0.012</td>
<td>P1</td>
<td>-0.0814</td>
<td>P1</td>
</tr>
<tr>
<td>4</td>
<td>DVT54</td>
<td>-0.012</td>
<td>P1</td>
<td>-0.0118</td>
<td>P1</td>
</tr>
<tr>
<td>5</td>
<td>DVT64</td>
<td>-0.0001</td>
<td>P1</td>
<td>-0.0722</td>
<td>P1</td>
</tr>
</tbody>
</table>

READINGS ON THE 40 POSITION MONITORS:

<table>
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** TIME REPORT AT LOCL END **
TIME=24:15:49 HP
CPU = 110
as read from the OPERATOR-file

from 1-st record of TWISS-file

combined information on matched PUE's (extracted from the
ORBIT & TWISS-files)

combined information on "matched" corr's
(extracted from the
CORRECTOR & TWISS-files)

ATTENTION:
4 correctors on the same power supply

as read from the TWISS-file

after matching PUE names from TWISS-file

after matching corr names from TWISS-file

the 4 corr's on 1 power-supply were substituted by 1 equivalent corr, the other 3 were disabled