CARSO - A Program For Automated First Turn Steering

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Abstract

CARSO is a program package which contains several new software tools to be used during first turn steering of a storage ring, or during the steering through a beam transfer line. CARSO includes routines which check the effects of magnetic components on the beam, check the measurements of the beam position monitors and simultaneously steer the beam through the ring to perform one full turn. The programs are written in ANSI extended standard FORTRAN 77 and comprise 6000 lines of source code, 87 subroutines and about 1000 different variables. The concepts used within CARSO are presented.

I. INTRODUCTION

The conventional approach to first turn steering is first to adjust manually some steering elements so that the beam reaches the last beam position monitor, and then to apply numerical orbit correction procedures to reduce the r.m.s of the orbit displacements measured at the beam position monitors [1,2]. During the manual phase the machine physicists often have to make some checks and reason about possible malfunctions of the equipment such as incorrect beam position measurements, quadrupole polarity errors, ineffective steerers, etc.

CARSO automizes the first phase and combines it effectively with the second. CARSO performs routine equipment checks systematically, notifies the operator when some possible errors have been found and tries to correct for some of them at their source. For the ones it can not correct, CARSO provides a fine adjustment of the beam towards the beam axis in a semiempirical way.

CARSO combines for the first time two concepts which itself are rather new for machine physics software. First, it actively uses the beam itself as a measuring device to test the components of the ring (a possibly similar approach is described in [3]). Before steering, first the relevant components are checked by sweeping the beam. Only if they behave as expected, they are used to adjust the beam towards the beam axis. The second concept is that rather than comparing the model of the storage ring with the measured beam positions globally, CARSO checks each monitor and the elements surrounding it separately (the same philosophy is applied in [4]). Thus it is able to localize gross errors rather precisely.

CARSO is capable of steering the beam successfully in spite of certain types of component malfunctioning, because it can recognize a few classes of error patterns and correct its model of the ring accordingly. CARSO still provides many interactive input/output messages and prompts, in order to give the human operator complete control over its performance. In this respect, CARSO can be viewed as an "apprentice" doing the simple and obvious routine tasks, reducing the load of the operator, who can thus concentrate on global reasoning.

CARSO uses machine theory as well as some heuristic experience of a skilled operator to evaluate the checks. If a problem is encountered that can not be solved by using this knowledge, CARSO informs the operator and waits for his/her intervention. Sometimes CARSO may "overlook" a severe error, but from its output the operator is nevertheless able to detect the error or to get at least some hints about the problem.

II. THE STRUCTURE OF CARSO

A. The Guidelines

The guidelines for the development of CARSO were:
- compare the predictions of the theoretical optics, which is represented by the model, with the measured beam position ;
- in case of a mismatch between the two, correct either directly the source of the error, correct the model, or at least minimize the effect of the error on the beam trajectory;
- make as little as possible assumptions, that can not be verified by a measurement - i.e. use the model only for comparison and not for calculations;
- avoid pure quantitative checks if qualitative ones can give reasonable answers, because there might be too many unexpected errors, degrading the numeric precision below acceptable levels;
- ensure that no action taken by CARSO sets the hardware beyond its limits;
- adjust algorithms to include heuristic rules of a human operator.

B. The Approach Chosen

For the purpose of first turn steering, when the beam traverses each element only once, a storage ring can be viewed as a simple beam transfer line. In a transfer line the basic approach is to adjust the elements so that the beam travels from one monitor to the next and so on, until the last monitor is reached. If the beam does not reach a monitor, it is obvious

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that the error must be with an element that is located upstream of the monitor, most probably between the last reached and the first missed monitor.

It is therefore natural to divide the beam line in groups of elements between two adjacent monitors. CARSO steers the beam from one group to the next and stops when the last monitor is reached.

One such group is named a 'monitor group'. The whole structure of CARSO is built to first check one group and then to fine adjust the beam so that the BPM readings of the two monitors forming the group boundaries are close to zero. CARSO assumes that all upstream groups are without errors, because they have already been checked. Also the upstream monitor of the group is assumed to be O.K., since it has been checked when it was the downstream monitor of the previous group.

The assumption that all the elements upstream from the monitor group are errorless is essential. It allows CARSO to use all upstream steerers and monitors to localize a possible error within the monitor group. To be precise, CARSO assumes only that the upstream dipole and quadrupole strengths are correct. It is not affected by transverse positioning errors, because it performs difference measurements. Even if the steerer that is used for the difference measurement is not correct, CARSO will spot it in most of the cases, because it checks the monitor group by measuring the beam position in the two monitors. The actual steerer strengths do not enter into the calculations.

If some elements between the steerer and the upstream monitor of the monitor group are incorrect, and they have been overlooked during checks of upstream groups, CARSO might assume a steerer error or an error in the monitor group. CARSO does not have the complexity to spot such effects. Therefore CARSO provides sufficiently rich output messages, which allow the operator to decide, whether there was really an error in the monitor group that was under investigation. CARSO changes its model of the ring to comply to its measurements only if the operator confirms the suggested change.

Even if the operator's decision is wrong, CARSO will soon recover from erroneous assumptions, because once the faulty elements are upstream of the steerer which is used to check a monitor group, they do not influence the measurements any more.

The only limitation on the performance of CARSO comes from the measuring precision of the beam position monitors. CARSO uses the measured beam position at upstream monitors to extrapolate it (by means of the model) to the downstream monitor of the monitor group and to compare it with the measured beam position. If the measuring errors are too large, they screen all other errors that come from a mismatch of the real lattice with the model. The limiting measuring precision depends on the lattice chosen and on the monitor spacing.

C. The Errors Looked For

As the beam position measurement during first turn steering is never very accurate, CARSO looks only for large element errors, such as:
- large beam energy errors or dipole field errors, respectively;
- quadrupole polarity errors;
- BPM button electrodes cabling errors;
- "hot" or dead button electrodes or whole monitors, respectively;
- lumped steerer cabling errors (wrong polarity or exchanged planes);
- incorrect steerer current/strength relations.

By comparing the predictions from the model with the measurements, CARSO is also able to detect larger deviations from the nominal element strengths and BPM imperfections, but it is not able to localize them uniquely, unless there is only one element between two monitors. This is left to the human operator who has much more ability for global reasoning than any software.

D. The Actions Taken

If CARSO encounters problems, it either corrects the errors at the source or tries to overcome the effects of the errors. CARSO can perform the following actions:
- recalculate the beam position from BPM button signals, if buttons are miscabled;
- reassign steerer polarity and plane, if the steerer's power supply connections are wrong;
- change the sign of a quadrupole strength in the model, if the quadrupole has a wrong polarity - CARSO is then able to continue and still complete the first turn, although the operator would usually stop the processing in such a case;
- measure the transfer matrix of a whole group of consecutive elements and place this matrix into the model for continuation of CARSO, if the error can not be localized to one single element;
- look at downstream monitors, if the monitor shows no beam;
- perform a systematic two dimensional blind scan using one or several steerers simultaneously, if the beam is lost or does not reach the next monitor;
- adjust the beam position to zero at two consecutive monitors with one or two steerers, in both planes, if the beam position reading is outside the tolerance given by the BPM resolution;
- scan the current of the dipole around the nominal value, if the monitors which are downstream show no beam even after a blind scan;
- switch off a quadrupole and measure its current/strength relation.

The last two actions are seldom performed because it usually takes a lot of time to change the power supply currents of dipoles and quadrupoles by large amounts.

If CARSO encounters steerer and monitor errors that it can not correct, it simply discards the steerer or monitor, respectively, and does not use them any more during its run.

E. The Flowchart of CARSO

For each monitor, CARSO performs the following algorithm:
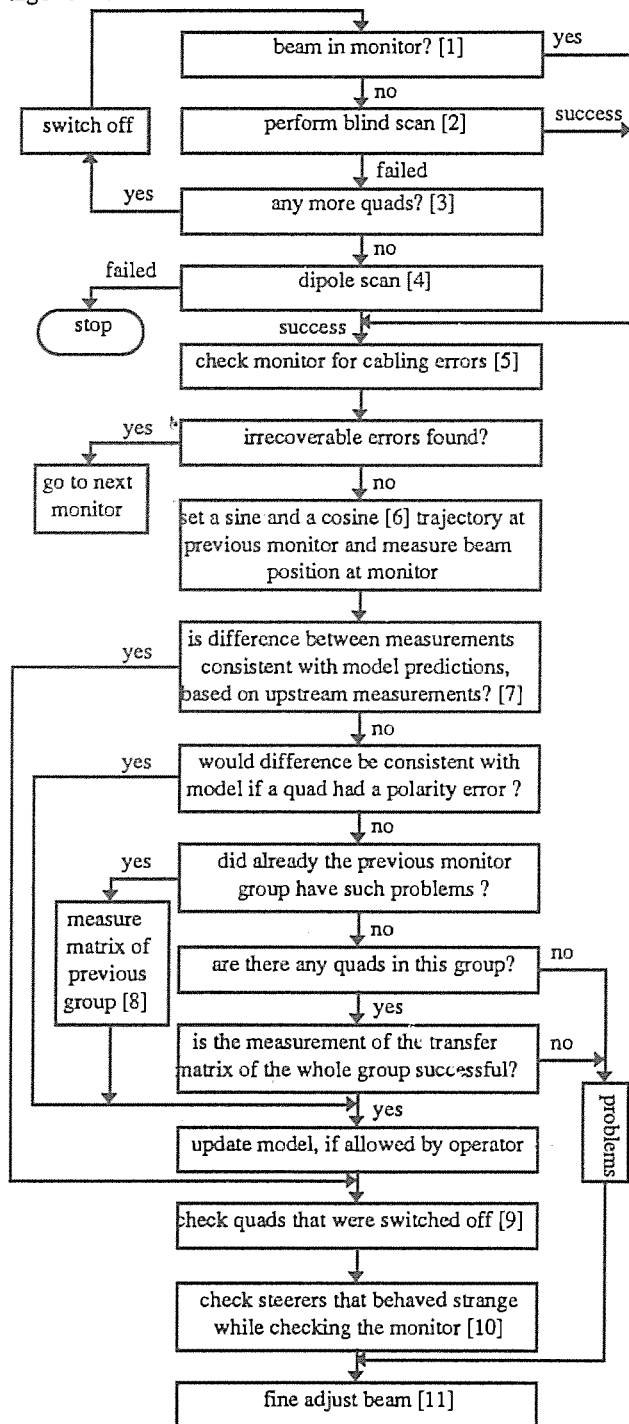
The notes mean:

[1] If there is no beam in the monitor, downstream monitors are also inspected. If one of them gives a positive signal, then the monitor group is extended up to this monitor and all the monitors in between are marked to be dead.

[2] The blind scan is first done with the most effective steerer, then with the next effective steerer and so on, until it succeeds to get a signal from any downstream monitor. If it does not succeed with single steerers, it uses several in parallel.

[3] CARSO takes into account that quadrupoles that are powered in series with upstream quadrupoles can not be switched off.

[4] Only one dipole in the group is scanned, since usually the dipoles are powered in series. Also the energy error is either spotted already in the first dipole, or never.

[5] The monitor is checked by sweeping the beam across all its four quadrants. Up to three steerers are used, to rule out possible steerer errors. Therefore also wrong steerers are detected in this routine.

[6] A sine trajectory means that the beam position at the monitor is zero and its slope is maximal. A cosine trajectory has zero slope and a large displacement from the beam axis. First, a cosine trajectory in x and a sine trajectory in z are established, then a sine trajectory in x and a cosine trajectory in z. If either one of these can not be set due to limited steerer strengths, only a simple difference measurement is performed.

[7] The beam position in the second upstream monitors must be measured to determine the slope of the beam in the first upstream monitor. Here the model of the ring between the two monitors must be used. CARSO assumes that it is correct, because it has been checked in the previous monitor group. From the determined position and slope at the upstream monitor, the expected beam position at the checked monitor is obtained by matrix multiplication.

[8] If the previous group was already wrong, then the check is meaningless, because the slope of the beam at the upstream monitor of the monitor group can not be determined correctly (see [7]). However, if the current monitor group is correct, then at least the transfer matrix of the whole previous group can be measured and stored, so that the error does not influence calculations of transfer matrices of elements that are further upstream. If there is a steerer within this previous group, it is marked to be locked, set to zero and not used anymore.

[9] The current in the quadrupole is increased stepwise and for each step the quadrupole strength k is measured in both planes and compared to the expected one.

[10] The steerers that could not move the beam significantly or looked as if their cables are misconnected, are checked numerically by comparing their measured M_{12} transfer matrix element with the one calculated from the model.

[11] The beam is adjusted such that the measured position at the upstream and at the downstream monitor of the

monitor group is minimal, i.e. below the measuring imprecision of the monitors. This is achieved in both planes separately with one or two steerers. CARSO provides two options - either the use of measured M_{12} transfer matrix elements for the steerers or the use of the ones from the model.

III. THE CURRENT IMPLEMENTATION AND ITS LIMITATIONS

CARSO is written in ANSI extended standard FORTRAN 77 and has been successfully compiled and run under VAX/VMS and HP-UNIX operating systems. It has been tested and studied with a linear simulation of the storage ring ELETTRA [5], which simulates transverse magnetic element and BPM positioning errors, dipole quadrupole and steerer strength errors, quadrupole and steerer polarity errors, and BPM button electrodes cabling errors.

The model which is used by CARSO is a linear thick lense model using transport matrices, without skew elements. Fringing fields and nonlinear fields are not taken into account, neither is the finite beam size nor the BPM nonlinear response. However, the BPM nonlinear response which is due to the field distortion of the vacuum chamber wall, can in principle be corrected for by the BPM software.

Besides the procedures to check and steer one monitor group, as described in the previous chapter, CARSO also includes an initialization and an epilogue. The initialization performs the following:

- initalizes the CARSO variables and defines output screens;
- reads the data describing the model of the ring from a file;
- calculates the transfer matrices of each element;
- defines a list of effective steerers for each monitor;
- measures the launch (injection) coordinates (x,x',z,z').

The launch coordinates can be measured only if there are at least two monitors between the injection point and the first bending magnet and if the quadrupoles in between are switched off. This is feasible for ELETTRA [6], but may not be so for other rings, in which case the launch conditions must be supplied by the operator.

The epilogue just displays some statistics about the beam position in each monitor, the r.m.s. of the measured orbit and the maximum steerer strengths.

CARSO was built with the electron storage ring ELETTRA in mind. Although CARSO is a general program, which can take any lattice from an input file, some details are nevertheless specific for a ring like ELETTRA.

It is obvious that - since CARSO runs automatically - nondestructive beam position monitors must be used. Fluorescent screens could be adopted only if they were moved into the beam pipe automatically and providing the beam position could be read out by software.

The check of the BPM button electrodes cabling errors works only for BPMs with four button electrodes, where the buttons are placed around the centres of the respective quadrants. If the buttons are placed on the x and z axes, the

subroutine which checks the BPMs must be changed or skipped.

The next site specific algorithm is due to lumped steerer magnets. The current implementation of CARSO supports only combined horizontal/vertical steerer magnets. CARSO generally treats the two planes separately but for two cases: the blind scan and the monitor check are done with both planes of one steerer. Hence the most effective steerer is defined to be effective in both planes. For rings with single plane steerer magnets, the data structure also will have to be changed.

A minor change in the initialization of CARSO will have to be made if pure dipole magnets or sector magnets are in the lattice. ELETTRA has only hard edge dipoles with a nonzero index. However in this case only the subroutine defining the transfer matrix of a dipole must be slightly changed as well as the input statements to distinguish between different types of bending magnets.

IV. CONCLUSIONS

CARSO replaces successfully the machine operator for routine tasks during first turn steering, once the hardware is stable and reproducibly controlled by the control system. However, it requires a reasonable beam position monitor spacing and measuring precision and full computer control over the equipment.

It is planned to use CARSO during the commissioning of ELETTRA and also after longer periodical shut downs. Being tailored to the specific ELETTRA components, CARSO can also be used for first turn steering of other storage rings with little changes to the software.

V. ACKNOWLEDGEMENTS

VI. REFERENCES

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