An automatic finder of field defects in a large A.G. machine

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Abstract

A series of program modules has been written in C, which can perform various tasks to analyze closed orbit measurements. They have been grouped into a software package which can be used by an operator to find field defects from orbit measurements. The basic algorithms used are well known and simple, based on fitting betatron oscillations. The effort has been put in the execution speed and ease of use.

New algorithms have been introduced to detect wrong measurements and check the relevance of the kick calculation, which are a decisive step towards automatization. It is presently possible to localize all relevant dipole field defects in a machine as large as LEP within less than one hour, including the check of the orbit readings.

I. THE PRINCIPLES

The essential part of the orbit treatment is the so-called fitting method. In a defect-free region, the on-momentum orbit measurements are expected to follow a betatron oscillation like :

$$y_i = a \cdot \sqrt{\beta_i}\,\cos(\mu_i) + b \cdot \sqrt{\beta_i}\,\sin(\mu_i) + c + \eta_i$$

where y_i stands for the i^{th} measurement of the orbit, β_i and μ_i for the corresponding TWISS parameters and η_i for a realization of a null-mean additive noise. Given this definition of η_i, we must put in the equation the average of the noise which is c. This parameter can be interpreted also as an offset of the measurements.

The values of a, b and c, are computed by means of the least-squares method. In fact what is interesting is not the values of a, b or c themselves, but how relevant is the fit, i.e. whether the measurements follow a betatron oscillation or not. To answer this question, we compute the residual $F_{n,j}$ of the fit :

$$F_{n,j} = \sqrt{\frac{1}{n-3}\sum_{i=j}^{j+n-1}(\tilde{y}_i - y_i)^2}$$

where $\tilde{y}_i$ is the estimation of y_i on the interval $[j,\ j+n-1]$. In practice the fitting width n varies between 4 (the minimum width since we fit 3 parameters) and a given maximum fitting width we will call M. j denotes the position of the current measurement. The sums are here expressed from j to $j+n-1$ for sake of clarity. In practice we do not take into account the measurements considered as bad, so that the sums are done over n "good" measurements starting from position j (which can go further than $j+n-1$ if bad measurements are in between). The bad measurements are merely skipped.

Since $F_{n,j}$ is obviously related with the r.m.s. of η, we decided to normalize it in order to deal with numbers of the order of unity :

$$F_{n,j} = \sqrt{\frac{1}{n-3}\sum_{i=j}^{j+n-1}\left(\frac{\tilde{y}_i - y_i}{\sigma}\right)^2}$$

with σ the r.m.s. of η. So a large value of $F_{n,j}$ indicates a bad fit, i.e. a defect inside the fitting range, whereas a value around unity indicates a good fit, i.e. a piece of closed orbit behaving like a betatron oscillation.

Thus if there is a defect between $i-1$ and i, all the values $F_{n,i-n+1}, \cdots, F_{n,i}$ will be large. If the $F_{n,j}$ values are displayed in array tables, n being the column index and j the line index, we observe typical patterns associated with defects. To a single measurement wrong at position j correspond n large values of $F_{n,j}$ at positions $j-n, j-n+1, ..., j$. To a discontinuity in the orbit between positions $j-1$ and j, correspond n-1 large values of $F_{n,j}$ at positions $j-n, j-n+1, ..., j-1$. As it is easy to recognize such patterns in a residue table, they were called "signature" in previous studies [2]. A common feature of the two examples above is the appearance of large values of $F_{n,j-n}$ following small values of $F_{n-1,j-n+1}$. This looks like a stair in the table and can be easily detected. This is what is used to locate defects.

II. NEW ALGORITHMS

A. Defect searching

The defect detection in A.G. machines was previously done by looking at the above defined signatures. But it appeared, after many orbit treatments, that simple signatures are not frequent and that it is much more efficient to look for "stairslike pattern" to find the defects. There-

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fore this was the criterion chosen to be implemented in the automatic system. The algorithm to find a defect is the following : We compute the fit residues for the current measurement –let us say j– for different width : $F_{4,j}, \ldots, F_{M,j}$, where M stands for the maximum fitting width. If $F_{4,j}$ is "large" (with respect to a given threshold experimentally set to 1.1), the algorithm begins to search for a stair, i.e. it looks if $F_{5,p(j)} > F_{4,p(j)}$ where $p(j)$ is the previous measurement strictly before j which is not disabled (usually $j-1$). The algorithm carries on until it reaches the maximum fitting width M : for a current width n it tests whether $F_{n,p^{n-4}(j)} > F_{n-1,p^{n-4}(j)}$. If it as been the case for all n from 4 to M, then a defect is detected between measurement $j+3$ (excluded) and $j+4$ (included).

When such a defect has been detected, a penalty parameter is computed to in order to evaluate its importance. Since a defect between pick-up $i-1$ (excluded) and pick-up i (included) affects $N-1$ fits earlier (i.e. from measurement $i-N+1$ to measurement $i-1$ at least), N being the fitting-width, we decided to introduce :

$$f(i) = \sqrt{\frac{1}{(M-1)\cdot(M-3)} \sum_{n=4}^{M} \sum_{k=i-M+1}^{i-1} {F_{n,k}}^2} \qquad (1)$$

The smaller (or at least the closer to 1) this number is the better all the concerned fits are and then the less important is the detected defect.

B. *Relevance of an action performed on orbit measurements*

In order to test the relevance of actions made on orbit measurements (like deletion of one measurement, addition of a field defect or their opposite), we introduce a measure of its efficiency as follows :

$$efficiency = 100 \cdot \frac{f(i) - \tilde{f}(i)}{f(i)} \qquad (in\ \%)$$

where $\tilde{f}$ denote the value of f, defined in (1), after the action has been performed. So if this action is relevant, the fits will be better after it and therefore $\tilde{f}$ will be smaller than f and the above efficiency will be positive. If the action performed is not relevant the efficiency will be around 0 or even worse : negative.

C. *The automatic system*

With the detection and evaluation of defects and with the measure of the efficiency of a performed action, we now have the tools to built up an automatic treatment of orbit measurements. The algorithm we developed is described by figure 1. At first the expected noise r.m.s. is adjusted in order to deal with fit residues around 1. To this end the

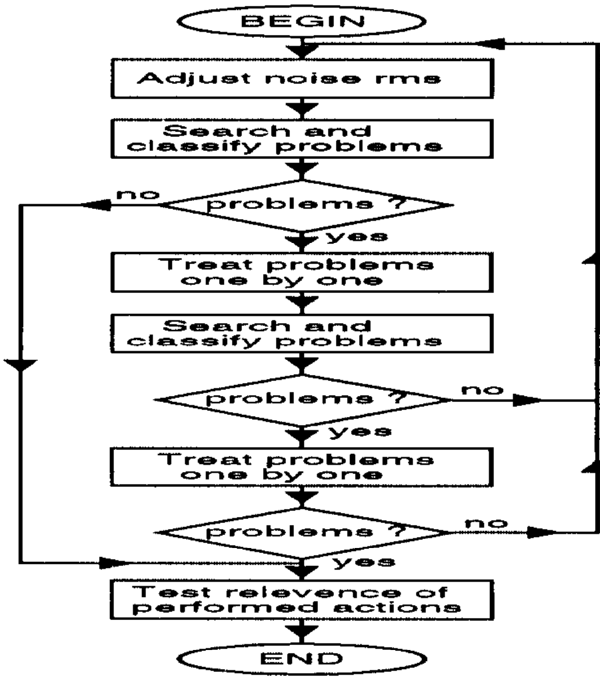

Figure 1: Automatic orbit treatment algorithm

fit residues are computed for the whole machine and for all fitting width from 4 to M. Since those residues must be around 1 if no defect occurs and if the noise r.m.s. is the one expected, this r.m.s. is set to a value such that the mean of all residues is 1.

Then a search for defects is done all around the machine, as explained in subsection A., and the defects are classified according to their penalty parameter in order to deal we most important ones first. Treating minor defects before major ones can bring severe errors and misunderstandings of the actual defects. Defects with a penalty less than a given threshold (which can be adjust by the user) are neglected in order not to treat to many defects at the same time.

Then for each defect detected, we analyze it as follows :

a - first test the suspected measurement by removing it and looking at the efficiency of the removal. If this efficiency is greater than 7.5%, the measurement is labeled as faulty.

b - if the measurement is not found faulty, then search for a field defect, i.e. a kick, between i and $i-1$ (for a defect occurring in i). The kick calculation is done by minimizing the error between the downstream measurements and the upstream measurements extrapolated with the effect of the kick.

c - if no field defect is found between i and $i-1$ test both adjacent measurements of i : $i-1$ and $i+1$ as in a)

d - if no bad measurement if found within those neighbors, search for a field defect between $i-1$ and $i+1$

e - if nothing found, look for a field defect between $i-2$ and i

f - if nothing found, search for field defect between $i-2$ and $i+1$

g - if there is still nothing found, give up here and let the problem unsolved. It will either be solvable afterwards or solved by the human user.

As described in the organigram (fig. 1) either the automatic system is run as a loop if all the detected defects have been treated, or the treatment is tried once again because the change of the situation can have made solvable problems which were not before. If after this second trial there are still remaining problems, the relevance of all the performed actions is checked by looking at the efficiency of their opposite. For example, if a measurement has been disabled, it is enabled and the efficiency of this action is tested. If the efficiency is negative the measurement is kept disabled otherwise it is enabled. The same treatment is applied to the field defects found. Then the process is stopped and the hand is given back to the user. If no problem remains after the second trial, the automatic process is run as a loop.

III. Results

The automatic system was used at the end of 1992 to help the search of defects in coordination with the survey. Almost all large misalignments were found, the detailed report can be found in [3].

However the LEP machine was too much misaligned and this effort did not pay. In particular an important defect consisting of a common misalignment of seven quadrupoles was missed because it did not appear on the measurements done with a 90° optics. The pattern of the misalignment is shown on figure 2. In fact this defect was identified with the 60° optics. It was simply not considered relevant because it disappeared on the 90° optics. This experience was useful as it leads us to the right procedure, i.e. choosing the lowest possible phase advance per cell for the closed orbit analysis with the fitting method.

IV. Conclusion

An automatic system to find field defects in a large A.G. machine is available. It allows to locate defects in an orbit made of about 500 measurements in about one hour.

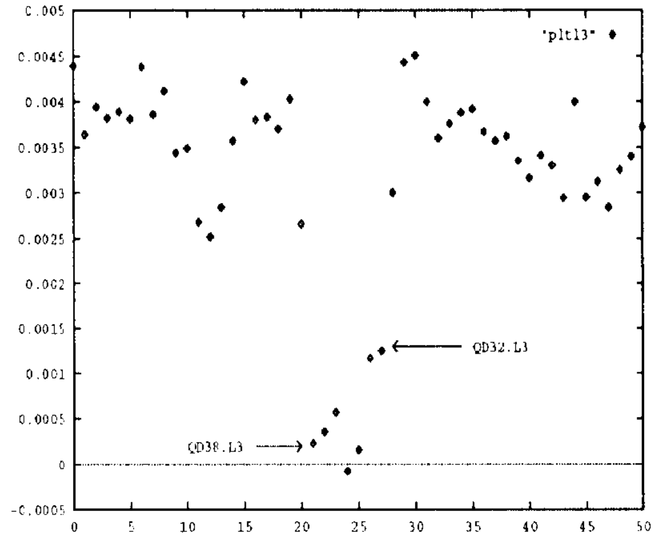

Figure 2: Misalignment missed by the fitting method. This misalignment makes a series of π-bumps if the phase advance per cell is 90°, which is the case for the named quadrupoles.

Using in the analysis of orbits for helping the LEP realignment in 1993, made it possible to identify problems related with its use. A positive outcome of this exercise was that the sampling of the orbit in term of betatron phase advance is critical. With one BPM at each D quadrupole, as in LEP, it is necessary to use an optics with a phase advance per cell below 60° in order not to miss defects.

V. References

[1] **G. GUIGNARD**
The closed orbit measurement as a diagnostic tool for localization and correction of misalignments in the ISR, 11^{TH} International Conference on High Energy Accelerators , held at CERN, July 1980. Also CERN ISR-BOM/80-21.

[2] **D. BRANDT, A. VERDIER**
Exhaustive search of field defect compensation and reading errors in A.G. machines, First EPAC in Rome, June 1988. Also CERN/LEP-TH/88-25.

[3] **J.C. Chappelier and A. Verdier**
Bare orbit analysis before the 92/93 shutdown. SL-MD Note 73 (January 27, 1993).