AN EXPERT SYSTEM FOR LOCAL COMPENSATION OF FIELD DEFECTS IN A CIRCULAR ACCELERATOR.

D. BRANDT, F. VARLOT * and A. VERDIER,
LEP Division, CERN, Geneva, Switzerland
* Université de Paris VI, 75005 Paris, France.

Abstract. A first version of an expert system for local closed orbit correction has been achieved. It has been developed for application to large machines such as LEP. It is based on the fitting method used in such a way that it is possible to find every local compensation of field defects within the measurements accuracy. This system relies on the optics model of the machine and provides a means of testing it as well as the measurement calibration, through the analysis of a known betatron oscillation.

INTRODUCTION

A method to detect and estimate the field defects in an alternating gradient circular machine has recently been proposed1. It was successfully tested on a small machine in which it detected the correct location of the most important horizontal field defect2. In this process, the orbit fits used in the analysis were computed with the CERN IBM machine, but the interpretation was done by the analyst. As this is time consuming, it was decided to develop a first version of an expert system to do it, i.e. to simulate the reasoning of the analyst. The most important issue of this attempt was not the expert system itself, which has a modest performance, but the analysis performed to get it working.

THE METHOD1

It is based on the possibility of modelling very accurately an A.G. circular machine provided that its components have been properly designed and measured. We can then fit an orbit measurement with a betatron oscillation with a least square fit method. The r.m.s. difference between the computed fit and the measured values should be of the order of the r.m.s. reading error if the fit is relevant and will be much larger if there is either a wrong measurement or an orbit discontinuity (i.e. a kick resulting from a defect) in the measurement range.
In what follows we will call $F_{n,j}$ the quantity:

$$F_{n,j} = \left[ \frac{1}{n-2} \sum_{i=j}^{i=n+j} \left( \frac{Y_{ci} - Y_{mi}}{\sigma} \right)^2 \right]^{1/2}$$

where $n$ is the number of measurements used to make the fit and $j$ the index for the position of the monitor where the fit starts; $\sigma$ is the rms error reading, $Y_{mi}$ are the measured positions and $Y_{ci}$ the fit-computed ones.

Practically, it is worth computing the $F_{n,j}$'s for fits starting at each monitor (i.e., $j$ ranging between 1 and the maximum monitor number) and for $n$ varying between 3 and 7 if the fits are made with two adjustable quantities which is the case treated here.

Once a field defect is detected between two monitors, its exact location and its value are determined from the discontinuity between upstream and downstream fits.

In order to find all possible defects, we then introduce $\bar{F}_n = <F_{n,j}>_j$ and we examine the evolution of $\bar{F}_n$ when $n$ is increased. If this value converges toward a constant, we claim that all defects and wrong measurements have been found. Furthermore, this constant value should be exactly unity if $\sigma$ has been correctly set, which provides a confirmation of the conjecture. Up to now this convergence could always be achieved for machines as different as EPA 1, 2, LEAR and the SPS.

**PROCEDURES USED IN THE EXPERT SYSTEM**

**Detecting wrong measurements**

It is obvious that the clearest signature of a wrong measurement at monitor $j$ is the existence of $n$ "large" $F_{n,j}$ values for $j \in [j-n+1, j]$ (whereas an orbit discontinuity would lead $n-1$ high values). However, applying systematically this criterion might lead to rejecting (or suspecting) too many measurements.

After several trials, it appeared that the most reasonable signature of a wrong measurement at monitor $j+3$ is:

$$\frac{F_{4j}(j+3) - F_{4j}(j+4)}{F_{4j}(j+3)} > 0.5$$

where $(j+3)$ indicates that the fit is computed with the measurements $j$, $j+1$, $j+2$, $j+3$ and $(j+4)$ means that it is computed with the measurements $j$, $j+1$, $j+2$, $j+4$. 
Detecting orbit discontinuities
They are detected with so called "obvious signatures" which are defined as:
n-1 large $F_{n,j}$ (i.e. $> \sqrt{2} \bar{F}_n$) surrounded by two small values (i.e. $< \bar{F}_n$).

Combined defects
If the tests described in the last two sections do not succeed, then two other searches are launched:
1) Find $j$ for which $F_{4j} - F_{3j}/F_{3j} > 0.5$ and $F_{4j} > \bar{F}_4$. This leads to the registration of two hypothesis:
   a) wrong measurements at $j+3$,
   b) orbit discontinuity between $j+2$ and $j+3$.
2) Find large $F_{3j}$ (i.e. $F_{3j} > \sqrt{2} \bar{F}_3$), which leads to the registration of five hypothesis:
   wrong measurement at either $j$, $j+1$ or $j+2$ and discontinuities between $j$ and $j+1$ or $j+1$ and $j+2$.

Computation of discontinuities
When the system suspects a discontinuity between measurements $j$ and $j+k$ ($k \geq 1$, there might have been wrong measurements eliminated between $j$ and $j+k$), each machine element in this area is systematically tested. To this end each element is given a kick such that if its effect is added to the extrapolation of the upstream fit, then the sum will reproduce at best the downstream measurements.

The choice is then left to the operator to accept or not the best kick found by the system, since our experience demonstrated that it was rather complicated to treat this choice automatically.

Each time a discontinuity is accepted, its effect is then subtracted from the orbit measurements.

PRACTICAL OPERATION

The system is composed of four procedure loops. Each loop is "centered" on a given search test. The general organigram is shown in the figure.

- The first loop is centered on a trivial test for suspecting the wrong measurements, namely those which have a reading larger than twice the rms closed orbit distortions. The choice is left to the operator either to directly discard them, or to test them as wrong measurements by means of the test for monitors proposed above.
- The second one is centered on the search for obvious signatures (see above).
- The third and fourth ones are centered on the more detailed hypothesis described in the previous section.

Note that the number of generated hypothesis increases when going through the procedure. All the hypotheses are stored in a "base of facts" which can be inspected at any time. It is updated according to the results of the tests.

The automatic chaining of the procedure is done with a main program written in PROLOG language. The numerical calculations (whose results can be inspected at any time by the operator) are performed by subroutines written in TURBO-PASCAL language.

When operating this system, it may happen that it enters in an endless loop because the operator is not convinced of the relevance of a discontinuity calculation: he must then stop the program. The discontinuities already accepted are stored in a file and used again, if desired, when the system is restarted.

Obviously the present system is far from being optimal and it should therefore only be considered as a first version of an expert system for this kind of analysis: these relative imperfections are the consequences of the short time (4 man month) dedicated to its development.

As far as the treatment of a large machine is concerned (like the SPS or LEP) the result is rather disappointing, since the old-fashioned approach (manual treatment on the IBM) is almost as fast as the new procedure. This is because the strategy has been developed for a small machine and the problems associated with a larger one have been somehow underestimated.

CONCLUSION

Developing a first version of an expert system for applying the fitting method to the search of field defects in an A.G. circular machine was quite an interesting work for us. It certainly led to a substantial improvement of the criterion's used for the detection of both field defects and wrong measurements.

Although the first applications on small machines like EPA and LEAR were very successful, it appeared pretty soon that the program would have to be modified for dealing with larger machines like the SPS and LEP (mainly a question of CPU time). We feel that the criterion's used so far should remain unaffected, but a huge effort on the strategy to be applied for treating a large machine in many steps instead of a single one still remains to be done.
REFERENCES


2. H. Kugler et al., Closed orbit distortions and their corrections in the 600 MeV electron-positron accumulator at LEP., 1st EPAC (Rome, June 1988).
Default accepted

Upstream loop

No convergence

Search test

Wrong measurement

Discontinuity signature

Discontinuity not accepted by operator

Test measurement

Wrong measurement

Discontinuity signature

Discontinuity computation

Discontinuity accepted by operator

Computation of the $F_{n,j}$

Discontinuity signature

Convergence test

Yes

STOP?

Print results

No

Downstream loop

No convergence

Wrong measurement