Automatic and expert systems for orbit analysis

André VERDIER,Jean-Cédric CHAPPELIER(VSNA)
CERN CH1211 Geneva 23

Abstract

In alternating gradient machines, the analysis of closed orbit or trajectory measurements in terms of betatron oscillations is useful to detect field defects. This has been used for long to help realignment.

In a large machine like LEP it is not practical to launch a survey check without making sure of the existence of the defects. In order to improve the reliability of their detection, it is extremely useful to have a fast system which makes it possible to cross-check several measurements.

For treating a large quantity of information in an empirical way, the use of an expert-system was proposed. In fact the numerical content of accelerator orbit measurements as well as the good knowledge of the modeling of such a machine makes such a system useless. The experience gained on the analysis of closed orbit measurements done at CERN shows that a simple algorithmic process is more efficient to analyze closed orbit measurements.

I. Historical introduction

The search for field defects by fitting closed orbit measurements with betatron oscillations has been used for a long time [1]. The principle is that, in a part of a machine without any field error, the closed orbit is merely a betatron oscillation. As the modeling of these oscillations is well known, it is easy to determine whether a given closed orbit measurement behaves like a betatron oscillation or not by means of the very common technique of the least-squares fits. If the fit residue is large with respect to the expected r.m.s error of the measurements, a defect has been detected.

What is useful for a circular machine is to detect field defects and especially to distinguish them from orbit measurement errors. This last point is very important as it avoids a displacement of personals towards a place without any interest. For this analysis many tests have to be done. As we wanted to make an automatic system to perform those tests for LEP, a first feasibility study was done on the accumulation ring EPA at CERN [2]. It made it possible to determine exactly the location of the main dipole error in this machine.

At this time a Fortran program was written to compute the fits. The test of measurement relevance was done by looking for special patterns on the printout constituted of tables of residues associated with fit done with four to eight or more measurements downstream each Beam Position Monitor (BPM). Then removing the effect of detected field defects and disabling bad measurements was done by editing the input of the Fortran program. Thus the feasibility of the method was shown but the procedure was very much time consuming. Therefore it was decided to launch a further study to make a faster system.

It was felt that the patterns observed by printing tables of fit residues [3, 7] were symbolic quantities and that many rules were applied systematically in the course of the analysis. As we thought that we could do a more efficient analysis by increasing the number of rules, the approach of expert-system was attempted [4]. About half a man-year was spent on this. We obtained a system which was able to analyze the EPA orbit in some minutes whilst it took about some hours to do it with the Fortran program. However when we tried to apply this system to a larger machine like SPS (LEP was not built yet), we observed that it was no longer faster than the old procedure based on the Fortran program : it took some days to do the analysis. This was due to weaknesses in the organization of the system and also to the fact that we were not able to find efficient rules nor to identify a large number of typical patterns in the residue tables.

When LEP was in operation, we decided to launch again the study with a new mind. Drawing lessons from the past, the expert-system approach was dropped. In what follows, we show why this approach was not the right thing to do.

II. What expert-systems are and are not

A general definition of what is an expert-system could be "a system for representing large quantities of knowledge" [5]. More precisely an expert-system is "a computer program that has a lot of knowledge in a specific field and is able to reach human-expert results in that field" [6]. But this definition does not take into account the methodological aspect of expert-systems, which consists of putting apart the knowledge of a specific field on one side (men-

0-7803-1203-1/93$03.00 © 1993 IEEE

tioned as "facts" and "rules" on figure 1) and the 'reasoning' mechanisms on the other side ("inference engine" on figure 1).

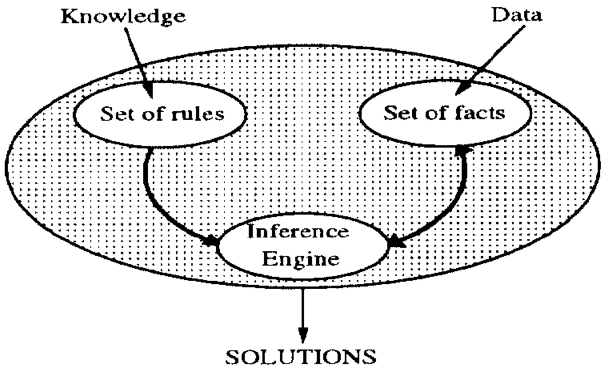

Figure 1: Expert-system architecture

The main applications of such systems are : symbolic knowledge manipulation, 'reasoning' in a fuzzy and incomplete domain, natural communication with humans [5]. More generally, any problem for which no algorithmic solution [1] is known, i.e. problems which need heuristics[2] belong to expert-systems (and more generally Artificial Intelligence) domain [5][6]. All those domains have two common characteristics :

- the informations used are symbolic,
- some choices have to be made, choices without certainty between many possibilities.

The expert-system field is even more precisely defined in [6] with the list of the seven kinds of problems which can be treated by such systems : "static" and "dynamic" diagnostic, task ordering and resource assignment, intelligent filtering, computer-aided design, conceptualization and computer-assisted instruction.

III. Analyzing a closed-orbit measurement

It appears, from the above considerations, that the "expert-system" approach is not appropriate for analyzing closed-orbit measurements for several reasons :

- what previously gave us the idea of expert-system was these patterns we called "signatures" [2]. For instance, we consider fits done over four successive measurements and we list the residues of these fits done at each BPM. A single bad measurement results in a sequence of 4 large residues (signature of a bad measurement) whereas a single field defect results in a sequence of only 3 large residues (signature of a field defect). However when the situation becomes more complicated than those simple cases (mixing of bad measurements and field defect) these signatures disappear. This is precisely the case where a computer program is needed. On the other hand the number of symbols ("signatures") and rules used is very limited : except for the above simple signatures, it was never possible to determine other more complicated patterns to deal with any complicated case. This small number of patterns and empirical rules is a good indication for trying algorithmic processes. It shows that this problem does not need the power of expert-systems : building such a system is really time consuming (in our first try : half a human-year was not enough to obtain an operational system) and is justified only for big amount of rules.
- we know a precise mathematical model for betatron oscillations and closed orbit distortions. There is no symbol in that problem the expression of which cannot be fully calculated. It is more a computable input-output relation than a "reasoning tree" : it is a "low-level" problem. Furthermore the symbolization reduces information, but in this case without simplifying the problem. Symbolization is only useful when the reduction of information is sensible and induces simplifications without which no solution can be found.
- we wanted a fast treatment, whereas expert-systems are more often very slow to conclude, as it was the case in our first trial.

We then developed an algorithmic program which solves most of the situations [7]. It can certainly be improved by including solutions to more situations in which the human-expert empirical rules are still very simple. But one should keep in mind that in such a system there will always be a point at which the program should ask "what to do" or "how to continue" to the human-expert. This point has to be well defined, considering an equilibrium between programming cost (time and money) and convenience of use. In our case, where we have to process about 500 measurements, the number of cases left to the operator decision is of the order of one tenth. This number is small enough to let the analysis be completed within one hour.

IV. Conclusion

The numerical content of accelerator orbit measurements as well as the good knowledge of the modelling

[1] set of well defined operations which can be run in a finite time on a computer.
[2] rules with which one can find a solution without reliable theoretical background.

of such a machine makes expert-systems useless for orbit analysis. The experience gained on the analysis of closed orbit measurements we have done shows that a simple algorithmic process is more efficient to analyse closed orbit measurements. We built up an automatic procedure which is able to find the field defect of LEP in less than one hour, which is a considerable improvement compared with the methods previously used. Notice that with this algorithmic approach all possible solutions at one step can be tested in a short time, showing, if still necessary, that the expert-system approach was for sure not appropriate. As mentioned in [6] : "*The expert-system approach is not justified for all kinds of problems. For example, in cases where all possible solutions can be exhaustively tested in a reasonable time (...) there is no need searching for another method*".

ACKNOWLEDGMENTS

We would like to thanks D. Brandt and J.-P. Koutchouk for the help of their useful discussions.

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