PANEL SESSION : "COMPUTER-CONTROL FOR CYCLOTRONS"

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SCHUTTE

I have handed over to the panelists a few sheets with a number of statements, asking them to comment on the several items. They contain arguments pro and contra closed loop control, as well as some ideas on control strategies and methods of automatic control. I now should like to present the same statements to the audience.

A survey table on automatic control projects at several laboratories is attached to them (see table I). Later, I will turn over to the panelists to comment on the several statements.

Let me start with the contra's to closed loop control.

CONTRA

1. macro view
   At the contemporary state of technology, all systems can be stabilized up to a sufficiently high degree in order to produce a macro-reproducible and stable beam for experiments during a long period. By "macro" is indicated that the beam representation in the 6-dimensional phase space x, p_x, z, p_z, ϕ, E, can be considered as homogeneous and taken as the total beam representation.
2. complexity
   The total system complexity increases heavily.
3. support
   There should be adequate financial and manpower support.

PRO

1. micro view
   Especially when single turn extraction, a small emittance, or well-defined beam properties are required, a micro-reproducible and stable beam may be desired. In this case, only a small part of the 6-dimensional phase space representation is used; the phase space has to be considered to have a discrete distribution. Then, small variations (10^{-5} - 10^{-6}) in the mean magnetic induction, in the shape of the magnetic field, or in the frequency of the accelerating voltage may have a large effect on beam quality and beam current. Many parameters can, in this way, exercise unwanted influences.
2. incorrect settings
   Even small deviations of settings may imply non-reproducible beam properties. This is especially of importance at matching locations, e.g., at the entrance of the beam transport system. Erronenous settings are easily detected and rapidly corrected.
3. disturbances
   Disturbances in values of beam properties such as beam current, RF phase angle and energy spectrum are easily detected and rapidly corrected.
4. correction time
   The latter two corrections mentioned normally have to be carried out by the operator. Generally, during this time the beam will not be available for the experiment. With a closed loop control, the corrections can be performed smoothly during operation, which implies no loss of time.
5. setting time
   Generally, an energy scan implies sequentially new setting procedures. In the case of well-known beam properties and a closed loop control the setting procedures are predictably, simply and smoothly performed.
6. beam properties
   Beam properties can be measured quickly, reliably, reproducibly and accurately. Furthermore, a large variety of beam property measurements is possible.
7. necessity
   In the case of matching the beam from an injector cyclotron into a ring cyclotron and/or at complex cyclotrons with a large number of correction coils (e.g. TRIUMF, S.I.N., Indiana), an automatic control is inevitable.

Control Strategies

1. Static - control to prescribed value

a) matrix inversion
   If only small variations are taken into account, the cyclotron parameter vector and the beam property vector are related by a linear variation matrix. If the number of cyclotron parameters equals the number of beam properties, by means of the inverse variation matrix, we are able to

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calculate the necessary corrections of the cyclotron parameter vector to obtain all desired variations in the beam property vector.

b) least squares
If the number of cyclotron parameters is smaller than that of beam properties, a least squares method can be applied to find a value of the cyclotron parameter vector which yields a beam property vector as close as possible to the desired one. An analogue representation can be given by choosing an appropriate set of orthonormal base vectors in such a way that increasing order implies decreasing correlation coefficients (e.g. Chebishev polynomials).

c) least squares and conditions
If, in addition, some elements in the beam property vector have a mandatory value, these constraints can be added by using undetermined Lagrange multipliers.

d) optimisation
If elements of the beam property vector have to be controlled to an optimum value instead of a prescribed value, the problem can be reduced to the control of the parameter deriative of the beam properties vector to prescribed values. This implies the parameter derivatives are determined periodically for properties which vary (slowly) with time. For this purpose, small variations of short duration can be introduced on the settings of the elements involved in the cyclotron parameter vector. The responses in the beam property vector correlated with the disturbances yield the values of the parameter derivatives to be set to a prescribed value.

2. Dynamic
Iterative processes and the use of correlation technique with large time constants are time consuming. Although not always necessary, this time can be reduced in several ways:

a) time-dependent correction
Application, during a short period of time, of a larger correction than necessarily has to be carried out, after which the calculated corrected setting is applied.

b) prediction/correction method
Prediction of the corrected value, comparison with the desired value, and, before the correction has passed the total system, thus before the next iteration may start, application of a new correction.

Methods of Automatic Control

The manual control of an isochronous cyclotron is mainly a procedure of, successively, setting, optimising (controlling), monitoring and logging. Some of all of these tasks can be taken over by an on-line digital computer:

i) setting, logging and monitoring
The most obvious way of coupling a computer to a cyclotron is taking over the setting of the various parameters. This, however, only yields a beam with prescribed properties if all systems involved are stabilized and reproducible to a very high degree. The settings may be programmed and possibly carried out by the computer. The same computer can also be used to record all settings (logging) and to monitor a number of crucial parameters, such as the RF voltage, vacuum, water leaks, safety system, etc.

ii) continuous measurement of beam properties without interception
For a cyclotron with slightly less accurately stabilized systems than in the case mentioned above, at many locations in the cyclotron and the beam transport system, the beam properties may be measured continuously and without (obtrusive) interception of the beam. The observed data can then be fed into the computer and compared with required values. The computer calculates the corrections of all parameter settings and automatically performs the adjustments. For this mode of operation, a well-developed beam diagnostic system is necessary in addition to a thorough knowledge of the relations between cyclotron parameters and beam properties.

iii) semi-continuous measurement of beam properties with interception
A hybrid system may have rather well-stabilized parameters combined with devices to measure beam properties using intercepting techniques. From these experimental results and from orbit-dynamics, computer programs, the corrected cyclotron settings may be calculated numerically.

The cases ii) and iii) may be combined with an automatic setting, logging and monitoring system.

Survey of Automatic Control Projects

In table I, the data obtained from the institutes dealing with some type of automatic control are listed. The numbering is from Howard's list of AVF and FM cyclotrons (these proceedings) where more references can be found. At nine laboratories, the first approach is being elaborated (c.f. section 3). At Michigan State University, the automatic setting is combined with the last method mentioned iii), whereas at Eindhoven University of Technology, the second possibility, control by measuring beam properties without (obtrusive) interception of the beam and a closed loop to cyclotron parameters, has been worked out. This is performed in such a way that a computer-aided setting procedure can be easily added.

However, this is a point of money. As can be concluded from table I, almost all institutes with automatic control projects have decided to use the CAMAC data handling system in various degrees of implementation.

GURD

You listed in your discussion of closed loop control a number of items both pro and contra and, if we just count them up, the score is very heavily in favour of the pro's. I think, perhaps, it might be better if you take the approach that we saw a couple of days ago from South Africa and use weighting factors. My own opinion is that, if we did the South African trick, we would discover that the contra's would outweigh the pro's, certainly for the very elaborate systems that are suggested in the latter part of your talk. In particular, the contra's dealing with the complexity of the system require a complete knowledge of both the beam property vector, as you describe it, and its relation to cyclotron parameters. In most of the new machines, no such attempt is being made because I do not think that the relationships are sufficiently well known. The third contra that you have mentioned concerned support and I am sure that you will agree that in that area, such a system requires a great deal of financial and personnel support and a long programming effort. This involves a great deal of cost and most of the new facilities are not prepared to invest as much as I think would be required in order to go that route. Certainly, the evidence of the papers that have been presented to the Poster Session on controls indicate that the new facilities are taking a very conservative approach towards closed loop control in almost all cases - there are one or two exceptions.

The four approaches that you suggest all involve fairly complex mathemathical correlations, going from the beam properties back to the cyclotron parameter, but one can take a far more conservative approach: namely, to deal with individual parameters. Having set up, manually, a cyclotron situation that is acceptable for operation, one can then observe that the individual parameters of the cyclotron stay within a predetermined limit and let the computer control system keep the parameters where they belong by making minor adjustments. I would also suggest that an alarm be made announcing that a correction has been made to the operation personnel. One other feature which is not really closed loop but which, nevertheless, most of the new facilities are attempting and have done (it is the first step towards the implementation of closed loop),is automatic setting procedures to nominal values or to values from previous experimental runs. I think that the poster session indicates that most of the few facilities are attempting to do this and that it is a very easy task to accomplish. It is very time saving, but it still leaves the responsibility in the hands of the operator to close the loop.

There is one other matter which is really a very different topic from those that you discussed, and is still very controversial. Based upon the poster session papers, we see that there are varying approaches: namely, the approach towards the console design and to, what in the jargon we call, human interface. W. Joho suggested to me at lunch a couple of days ago that the first decision one has to make in designing a control console is whether one wants to sit or to stand when operating the cyclotron. Yesterday afternoon we saw a control room at S. I. N. where a decision was clearly made that the operators must stand and walk around. This is one approach: a large console, a large number of knobs and the operator's stand. On the other hand, we have in the poster sessions the opposite approach from Indiana: the small console with only a very few knobs. In this case, the operator remains seated. At TRIUMF we have chosen some kind of a compromise: somewhere between a standing and a sitting position. I think some of the operators would say that an attitude of prayer - on their knees - is best. We have an intermediate size console and a number of knobs, and I think you can manage to get at them in a seated position if your seat has wheels. This was controversial a few years ago, but now, after having had some operating experience on some of the machines with the different philosophies of console design, I think that we should comment on how they have worked out in practice.

There is one other item which you did mention in passing, and that is the problem of data logging. In discussions with people around the posters here today, I find different approaches concerning data logging. I know that at TRIUMF, when our approach to data logging was being discussed, there were those who felt that we should log all 1 000 parameters that were in the system at least once a second and there were those who thought that, perhaps on Wednesday morning, one might record the RF-frequency. Somewhere in between is the compromise and I think that we might discuss this to a certain extent: the type of data logging, the medium of data logging and the use to which the data is ultimately put in the light of our experience today.

SCHUTTE

I have just one comment to make on the weighting factor. I have indeed a list of eight pro's and three contra's, but that does not mean, for instance, that the weighting from the third point, manpower and financial support, cannot override the eight pro's.

BESSE

I was invited to give the statement of my personal views on computer control. Since the time is limited to discuss this item (probably for some healthy reason), I want to make two short remarks. The first point I would like to mention is the general definition of computer control.

What is computer control? I think most of the people use this definition very frequently and even dealers of small cars, like VW, try to sell the car using the name "computer diagnosis".

However, computer control, at least for the accelerator control, is such an important part in the general philosophy of a control system that we are not able to skip this problem. I think everyone working in the control room should really be faced with the problem of what computer control means.

Generally speaking, computer control means replacement of a traditional control system which was only vaguely centralized. (Control being centralized does not only mean equipment but also responsibility). The old system was some kind of single device, privately transmitted, point to point connection with dedicated knobs and meters. Therefore, there were advantages since it was easy to buy, easy to understand and easy to repair for everyone. Now we want to go to computer control, which is more centralized in design and centralized in responsibility some way,using shared lines between devices and having less private lines, knobs and meters, but, on the other hand, more pushbuttons, keyboards and displays. Now we have, of course, many advantages but you have really to make use of them in order to be happy with the system. However, at the same time, the system indicates some kind of disadvantages. For example, fewer people are able to understand, to repair and to maintain the system. Therefore, a serious system design is necessary. For this reason, computer control does not mean, for me personally at least, that you buy a big computer or several less expensive ones and just have it moved into the control room by workers, set up a staff of programmers and ask your colleagues what sort of problems they wish to have solved by computer.

I now want to skip this problem and comment on another one mentioned by D. Gurd before. This is the human interface. I think that we should choose the computerized way. Therefore, you may decide to use some human interface devices which are perfect in cooperation with the computer but always imperfect in cooperation with the human being. I now should like to point out that some people have to sit down in advance and think about how to operate the computerized system, which delivers unbeliveably high logical power. It is fine to make use of it but, generally, you will obtain a limited number (one, two, perhaps three) of human interfaces to the computer. This is, of course, enough to deal with logical strategies like multiparameter calculations, setup of the magnets of a complete beamline, etc., but very little to support every twiddling in the control room. Do not forget that probably several accelerator engineers and physicists want to deal simultaneously with all the devices by not using the computer power you want to give them. Therefore, we furnished the control room with some, let me say, old fashioned devices being able to just deal with one, of course digitized, parameter at a time. They are easy to operate so that everybody can do it without any particular introduction, as there are just knobs. In addition, we have, of course, all the local adjustment possibilities for the engineers, i.e., they do not have to sit at the intelligent console during the shut-down time just to perform simple tests. If you now make use of the correct system design you will be able to support all manipulation the traditional control has ever supported. Additionally, you will state that those human accesses will keep the accelerator people happy without considerably increasing the total expenses.

CUSACK (from the Audience)

Do you think that a computer system could improve a poor cyclotron by using closed loop?

BESSE

I would like to say, in short terms, that if you have a very bad cyclotron with big instabilities due to some thermal problems or something of that kind, it would improve by using all this information and feeding it back through the computer. This means that, for example, if you have hundreds of power supplies, the cost of each of them could be lowered if you define the stability just for two hours. I am quite sure that every computer available on the market today could pick up the information every half hour, and make adjustements so that you are within certain limits. I do not think that you could improve a cyclotron by means of some very fast dynamic loops wired over the computer.

CUSACK

Just one supplementary question: Do you think that, if a computer (with open or closed loop system) is implemented, it is worthwhile to incorporate it into the original design of the cyclotron concerned?

BESSE

Yes.

GURD

I have an equally short answer to R. Cusak's first question. It is "no".

SCHUTTE

I would like to state that, if you have a very bad cyclotron, i.e., according to my opinion, a cyclotron with bad beam properties, it cannot be improved by computer control. If this were the case, then my cyclotron manufacturers would be very grateful.

COLLINS (from the Audience)

Could I ask each of you to make a brief comment on the degree of support that you would consider necessary at your respective institutions, in order to implement a good closed loop system?

v. HEUSDEN

You need a lot of time for measuring the relations between beam properties and cyclotron parameters: In our case it was about 30 % of the beam time in the past. If you once know those relations, the rest depends on the electronic system you use. If you take CAMAC, for example, then the coupling between the computer and the cyclotron is no problem.

SCHUTTE

I think the question does not only refer to time but also to manpower and finances.

v. HEUSDEN

Concerning manpower I cannot give a good figure: we use a lot of students and I do not know how to account for their contribution. In general, we have four students per year working on this subject in our laboratory.

Many things are made in internal workshops of our University where you will never see a bill, therefore. Also, for mechanical and home-made electronic parts, it is very difficult to make cost estimates.

SCHUTTE

I think I can answer that for the Cyclotron Laboratory at the Technical University of Eindhoven. It is about 50 kSw. Fr. per year, not counting the cyclotron time, wages and support from the University's workshops.

v. HEUSDEN

One comment: The costs also depend on what type of control you desire. Our case is a typical research setup and that means that you do not need to make the things too nice. If you plan the control system to be used by the operators for normal daily control of the cyclotron, O.K., you need a lot of money. But that was not our case. Let me pass now this question to S. Lewis.

LEWIS

The question covers a lot of ground. If you are talking about one or two interesting feedback loops, beam phase and something like one or two trim coils, it might be a modest effort. If you are taking a more long term view and eventually you would like to close lots of complex loops, then you are talking about a long term interface situation with standards and cabling and generalized software. It is pretty clear that this then involves several hundred thousand dollars and something between, say, 10 to 20 man/years of engineering plus software. It depends just on what you want. I think it also depends, to go back to the general remarks, on whether you are talking about a mature cyclotron to which you would simply like to add a few nice features, or whether you are talking about a brand new facility in which the decision is made to have full computer control at the start.

BESSE

In our case, we try to balance out the costs between computer control and some kind of traditional control. It was quite easy to go to computer control, because we have to deal with a console of parameters on a high level of accuracy. I think 400 or 500 parameters are actually connected to the computer system. Therefore, at least for hardware and system software, the cost is somehow in balance.

It is a different question, of course, if you want to use the installed computer power optimally for the accelerator over many years. In that case, you need (to improve beam quality or stability) very highly qualified programmers, mostly well qualified accelerator physicists. Therefore, you have really to decide step by step, which kind of soft-wired actions give you an optimal benefit compared to manually controlled actions.

GURD

The last men down the road can contribute little, but I agree with the estimates given by S. Lewis. At TRIUMF, we have inadequate computing power to do the mathematics that are required, so there would be an additional expense for computing power.

SCHUTTE

Thank you. I would like to postpone the discussion for a while and go on with the general comments by the remaining panelists.

LEWIS

I really think there are many types of benefits to be gained from computer control, and I think you do not have to take any one as a sole justification for taking this approach. I think there are many areas where the combination of the computer and the operator is really the best way to go and I think you have to exploit each one for its best feature. It is clear that operators, human beings, are good at certain types of integral problems.

Where there are many parameters, not all of which are completely understood, still, a person can make a judgment and come up with right solutions a reasonable number of times. So you want to use the operator as that kind of feedback element: mainly in that type of situation where you are talking about beam development and other kinds of unknown questions. The computer is very good for handling the drudgery. It also has a certain speed advantage in well defined situations. So that is where you want to use the computer.

If possible the computer should also help the operator doing his job. This means that you put the maximum amount of information at the operator's disposal in a way that he can interpret it without computer jargon making it less informative at the end. I agree with D. Gurd very strongly that you have to take a fairly conservative view and I think there is nothing wrong in doing the obvious things which are also useful. One of the obvious things is, of course, the logging and monitoring. I think it is clearly valuable to have good data on what you have already done. They help you to find out whether you have done things correctly or not. At Indiana, we have considered setting, monitoring and logging as being very important. We have also taken the sit-down approach to the console, but we have not abandoned the idea that knobs and meters are good things for persons to interface with.

So to me, the reasonable approach, if you decide from the beginning to go with computer control, is to do certainly no worse than you could have done with a conventional console. What you do achieve is the attachment of the computer to all of the things on which you eventually need to do the more sophisticated kind of feedback. I think a very difficult road to follow is to go half way at first and then decide later on, you wish you had done a somewhat better job. Then you have disruption and duplicate costs.

For instance, one area where you can save a lot is the cabling costs. With the centralized data-bus, if you are careful about it, that is a significant amount of money, which might pay at least for the cost of the computer. It is really the same order of magnitude. There are other areas where you can begin with the computer which are not, shall we say, controversial or critical. One is the area of start-up, where the computer can use some very simple equations which describe the generalized beam dynamics, or do table interpolations. Essentially, it pre-sets the cyclotron and then it is up to the operator to introduce the beam in a controlled way and make the final adjustments. The other area where the computer can be very useful is for a shut-down. You can pre-plan the strategies for shut-downs under normal or emergency situations. That is probably a place where the computer is in better shape than the operator.

A lot can also be gained from just having simple types of open loop control where the operator has the knobs and the meters. For example, super-knobs (one single knob controlling a linear combination of parameters) are not very complicated but very useful. One can do a lot of tricks with just simple software which would be rather expensive in hardware. Magnet cycling strategies, automatic probe scans and so on - nothing very difficult to do, but all of immense value to an operator who is faced with a beam that will not accelerate or disappears in a beamline.

I think, eventually, you will begin with local strategies, i. e., very simple feed-back loops. At Indiana, I hope we will get into a kind of global feedback which contains a lot of arithmetic. Again, I agree with D. Gurd that any present computing power does not imply an immediate rush towards the inversion of 20 x 20 matrices. But if it appears fruitful, one can add computing power for that purpose.

<u>v. HEUSDEN</u>

As many of you will know, at Eindhoven we have a different situation, since we are working on the research of the feedback control loops themselves. Therefore, I firstly would like to have a look at three types of feedback loops, upon which work is also done at other laboratories. Secondly, I will comment on the use of a computer control system as a diagnostic tool, e. g., to study the extraction mechanism.

At first, I would like to review the RF-phase control loops. As far as I know, there are three laboratories working on this subject. The first one is at Dubna, the second one at Michigan State University and the third one is Eindhoven University of Technology. These three control loops are all real closed-loop systems. In Dubna, the control system samples the complete signal induced on inductive pick-up probes (Anosov et al., these proceedings). From the shape of the induced signal, the RF-phase can be determined by the computer. In Michigan State University, the control loop is carried out without a computer. They have one capacitive phase probe in the beam line outside the cyclotron and they use a sort of phase-locking technique (Marchand, these proceedings), described by Peter Miller two days ago. This system, in fact, controls the RF-phase continuously. The last example is the way we are doing it. We are measuring the RF-phases with capacitive probes at 13 radii and we have 10 pairs of concentric correction coils at our disposal to control the RF-phase. It is clear that you need criteria to decide how many phase probes and how many correction coils you really need. The criteria can be found using Chebyshev polynomials as orthonormal base (v. Heusden et al., these proceedings). Furthermore, it is also a matter of saving costs.

The second group of control loops I would like to discuss is the optimisation of the extraction efficiency. As far as I know, only at the Eindhoven laboratory does this type of control loop exist.

It is perhaps interesting to remark that this control loop shows that, though the relations between beam properties and cyclotron parameters are really awful, it is possible to build a reliable control loop (v. Heusden et al., these proceedings). If you have an optimisation problem, you do not deal with prescribed values for the beam properties, but you know that in the optimum the first derivatives with respect to the different parameters are zero. Therefore, we are measuring these derivatives continuously in the way already mentioned by F. Schutte. The derivatives are zero in the optima of the extraction efficiency. Unfortunately, there are many optima.

We have shown that even in a very bad situation, the extraction efficiency can be optimised. The main point I want to illustrate is that, though it seems sometimes to be very difficult, it is possible to build very reliable computer controlled systems using beam properties as input data.

SCHUTTE

Would anyone like to comment on these statements?

SCHROEDER (from the Audience)

I have the impression that, for existing machines, the situation might be a little bit different. In the first place, I think that adding a computerized control system like, e. g., the one of Indiana, would be extremely costly and hardly useful. In the second place, I think that for the smaller machines, like ours at Groningen, computerized setting would hardly save any time. The third point is that for smaller machines, maybe the more useful things a computer control system or a computerized system could do is helping in beam diagnostics because the computing power available makes it possible, not only to do the job for the operator, but also to interpre the results in a meaningful way.

GURD

I would like to comment on the last point first. I agree that for small or large cyclotrons, one of the most important tasks the computer can do is to help with the diagnostics and do the analysis and things of that nature. In such a way it can speed up the improvement of the facility.

I think that it is difficult to accept the usefulness of adding a computerized control system to a small machine. I believe that there is a fairly close relationship between the cost of the control system and the cost of the machine itself and I think that, probably even for a small machine, the computer has a good effect because of the help you get with the diagnostics. The benefit from computer control might not be so obvious for small cyclotrons; on the other hand, one should not overestimate the costs, since the fixed costs for the computerized system are not so high. So, even for a small cyclotron, it is probably worthwhile to implement computer control because of the help you can obtain with diagnostics and other applications.

BESSE

I also think that for very small and well-known machines, there is no reason to start now to computerize all the parameters just to have the possibility of automatic setup or logging. It is another case if you want to do (with the help of the computer) something you have not been able to do before. As a very rough estimate, I would consider the size of our injector, with approximately 80 parameters, as a lower limit where it is worthwhile to implement computer control on a running machine. For new projects, I would set this boundary line further down to the size of a machine having 40 to 50 parameters.

LEWIS

I think it is pretty clear to everyone that, if you have a very small research facility and a very well understood cyclotron, you really do not need computer control. There is one exception where you want computer control and that is the situation where you want the small cyclotron to be operated by untrained operators instead of highly motivated accelerator research physicists. One example would be the medical field. You would like to send these machines out, each one may be a little bit specialized in a particular kind of therapy, and you would like to publish a small instruction booklet, no more complex than what you get to operate a Xerox machine. In addition you want safety and reliability. But we are mostly interested in research facilities and I agree that there is probably a minimum size below which the capital costs of the computer appears a bit too large.

There are many qualitative judgements involved, depending very much on how you allocate the costs. The cost of a large classical control room with the 500 knobs and 1 000 meters it would take to run a cyclotron of the size we are familiar with, added to the cabling costs, would come very close to the capital cost of the computer equipment and the interface. So, then you are in the grey area of allocating the manpower costs - how many hours do your technicians spend running cables? - how many hours do your programmers spend writing programs? What it boils down to is the spin off. When you have finished doing the conventional system, there is not much more to be gained. When you have finished the computer system, you have actually increased the possibilities.

v. HEUSDEN

I would like to comment on another aspect. It is a fact that, in small machines, we do not need to make big data logging and such interesting things. But there is another question: if you put slits in the center of your cyclotron or if you have the slits of the analyzing system, then the stability of the beam depends heavily on the stability of your cyclotron. Again, if you do not have a slit and have an achromatic transport to your target for isotope production, then you do not need any computer control. But if you use really small parts of your beam, then you depend on extremely high stability and, in that case, it is very nice to have computer control. It does not stabilize fluctuations in a time scale of seconds, but small drifts remaining from traditional stabilizing circuits with a time constant of one minute or longer. There is one more comment on the use of the computer control as a diagnostic tool. If you have phase shifts, then you have strange effects in your external beam and if you have computer control, then you can study those effects to optimize the external beams for the experimentalists.

BLOSSER (from the Audience)

I would like to comment on the question regarding the benefits of installing computer control in an existing cyclotron. I, of course, agree about the benefits which have been mentioned: setup, logging, trouble shooting, etc. I think, however, that the major benefit will be in making energy variability easy. We all have nominally variable energy machines; yet in the published literature almost all excitation function experiments come from tandem laboratories. We have exceeded the tandems on precision - when computer control systems really work I think we will also be able to outdo them on energy variability and I think that will be perhaps the most important benefit from computer control

ERDMAN

We are fortunate to have with us the dean of cyclotron operators and the dean of cyclotron builders in J. R. Richardson, who has started off with knobs and has finished with computers. It would be nice to have him give a final comment to this discussion.

RICHARDSON

Since the 1972 conference, the computer controls group and I have undergone a process of mutual brainwashing so that, on the one hand, I am very favourably impressed with the flexibility of computer control and, on the other hand, the control group is very conservative in closing loops.

As an example of flexibility, I would like to mention the adjustment of three of our 54 trim-coils in a predetermined way with a single control. Another example is my recent request to D. Gurd to give us the display of a single parameter formed by dividing the intensity of the cyclotron beam by its axial width. This flexibility has been very important for us.

Table I. Automatic control projects

no. (ref. 2)	2	5	14	19	21	31	36		43	46	51	65
institute	UCL	TRIUMF	VICKSI	JULIC	KFK	EUT	SIN		UnInd	MSU	ORIC	U120
computer	PDP8/E	4 Super-NOVA	PDP11/40	PDP11/40	NOVA2/10	PDP9	IBM 1800	PDP 8/S	Sigma2	PDP11/15	MComp III/S	M 6000
word length/bit	12	16	16	16	16	18	16	12	16	16	16	16
memory/k	12	32	80	24	32	24	32	4	20	8	24	8
cycle time/s	1.0	0.8	1.0	1.0	1.0	1.0	2.0	1.2	1.0	1.0	0.8	2.5
magtape	2 DEC	-	-	-	2 cass.	5 DEC	1 step.		1 XDS	1 TM11	+	
disc	-	2 NOVA	3 RK05	2 RP04	2 NOVA	-	3 IBM		1 XDS	-	1 Diablo	
display	VT05	2 Tek611 1 refr.	2 Tek611 + TV	-	TV hm	1 Comptek 300	5 Tek611 +TV hm		3 CCI	1 Tek611	+	
plotter	-	1 chart rec.	1 Versa-tec.	-	-	Calc565	hard copy		Calc565	-		
data handling							ROAD(hm)		XDS+hm	interf. microcomp (f PDP11/45)		
CAMAC	+	+	+	+	+	+			(+) data acq.	+	+	-
crate	1	35	35	≈2	5	1				≈3	2	
system	Nucl. Ent.	Elliot	KSC/DEC serial	Borer	SAIP / Siemens/ KSC	Borer + hm					hm	
control type	(i)	(i)	(i)	(i)	(i)	(ii)	(i)		(i)	(iii)	(i)	(i)
monitoring	+	+	f	pf	+	-	+		+	f	+	+
setting	f	+	f	pf	(+)	f	+		+	f	+	+
measuring beam prop.	-	+	f	-	+	+	+		+	f	-	+
correcting cycl.param.	f	+	-	pf	f	+	+		-	f	-	+
closed loop control	f	-	-	pf	-	+	f		f	f	-	+

p = in past
f = in future
hm = home made

\+ = performed
\- = no plans