DIAGNOSTICS, CONTROL AND EXTERNAL BEAM OPTIMIZATION BY COMPUTER AT THE KARLSRUHE CYCLOTRON

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Summary

A variety of new procedures and programs have been added to the existing diagnostic system[1] to include new diagnostic and control hardware and to improve existing software. The CAMAC branch has been completely reorganized using a star-like arrangement. For control purposes an extendable FORTRAN multitasking system has been implemented. Actually it allows the continuous surveillance and static control of a variety of parameters for the external beam guiding system. Dynamic control of some beam properties like beam profiles is in the test phase. First results of the optimization of the external beam are available showing that it is necessary to use similar optimization strategies in on-line optimization as in the case of theoretical simulations.

Introduction

The motivations for a computerized diagnostic and control system for the Karlsruhe Isochronous Cyclotron can be summarized by the following topics:

- increasing requirements for beam quality parameters by users such as good emittance, accurate knowledge of the absolute energy, small or large phase width, extremely high suppression rates for the various beam pulsing systems, an enlarged beam diameter for the internal beam isotope production, higher intensities of the external beam, etc.

- as the different user demands cannot be met by equal parameter settings, there are often changes in machine adjustment due to a frequently varying time schedule. A great part of routine work can be taken over by the on-line computer.

Therefore in 1975 a computer diagnostic system with a Nova 2/10 computer was established. Since then the program system CICERO[1] has been continuously extended to improve existing diagnostic procedures and to add new features and possibilities. It is now intensively used by the operators and experimentalists for machine adjustment and control. This can be seen from the accounting of the real time of the first half of 1978. For 45% of this period the various diagnostic and control procedures were active, for 35% the system was ready for use and 20% were left for program development, service and system maintenance.

Hardware Configuration

The increasing demand to use the system for machine diagnostic and control likewise reduced the availability for program development. Therefore a standby-system is being built up to facilitate program development and increase system security. The computer system (Fig. 1) consists of a Nova 2/10 and a Nova 3/12 with 48k of memory each, two dual disks, three consoles, two CAMAC branch controllers, a computer-computer-link and one link to a big IBM 370/158-168. A star-like arrangement of the parallel CAMAC branch connects the 6 crates in the control room, the experimental area and the cyclotron vault. This special arrangement of the CAMAC branch has minimal length and therefore minimal execution times. Each of the two branch controllers is extended by an additional connector, a control line and a hardware scanner, thus enabling both controllers inter-leaved access to the same CAMAC branch. The interrupt precessing software is able to distinguish between known and unknown interrupts. The consoles offer teletype input/output, TV-display with alphanumeric and graphic

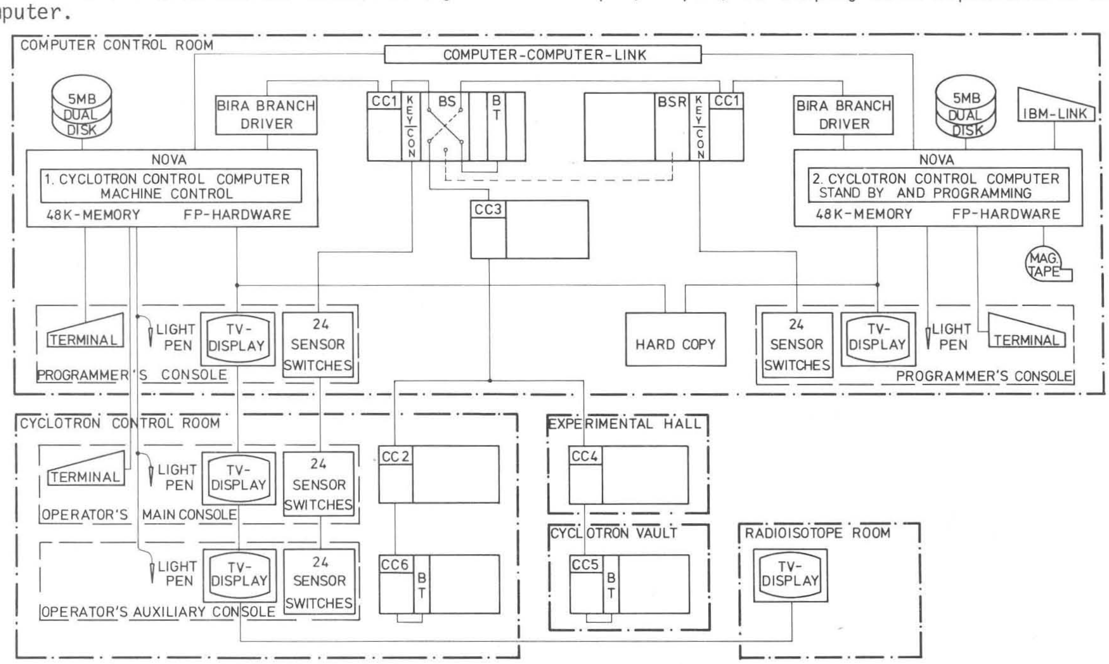

Fig. 1: New cyclotron control computer configuration showing the direct and CAMAC coupling of the dual computer system, the programming and operating consoles.

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facilities, light-pen and a sensor board with 24 individual switches. This provides great flexibility and simplification for program choice and operation. A hard-copy unit makes a copy of the TV-picture within a few seconds. The magnetic tape is used by the first machine mainly for system maintenance purposes.

Software Systems

The use of the programming language BASIC for most of the diagnostic and control procedures has been proved an excellent choice for the following reasons. Program development in interpretive languages like BASIC is much faster than in any other compiler language. This point is important, because for the control of most hardware there exists no unique ' priori' algorithm. Therefore the programmer can use the interpreter, with immediate console commands, to find out the best way for hardware control. This method is also very useful when searching for hardware and/or software malfunction. The limits of an interpreter system like BASIC are execution speed, the restriction to single tasking and the impossibility for modular design of programs.

These difficulties can be overcome by using FORTRAN IV with real-time extensions[3]. As FORTRAN is a pure compiler language, it doesn't provide similar test- and debug-facilities like BASIC. Therefore FORTRAN is more suited to be used for procedures with known and secure algorithms, requiring a minimum of operator intervention. If these criteria are valid, the use of FORTRAN leads to an ideal extension of an interpretive system.

BASIC Diagnostic and Control System

The diagnostics and control system written in the programming language BASIC comprises a variety of individual procedures for beam diagnostics and machine adjustment. These programs are independent of each other, controlling only that part of hardware that is necessary to do the job. Upon request they can be loaded and executed. Much emphasis is laid on operator guidance through the system. The most important programs are the status programs, phase measurements and quality of pulsing systems, measurement of the absolute energy, iodine quality control, emittance measurement, the external beam control program and the adjusting of the correction coils. In the following a brief description of the particular programs is given. In some cases this concerns additions and improvements to procedures already described earlier.[1]

The status program for the external beam has been extended by a static control routine. This procedure can operate in two modes, the 'automatic adjustment' (T) and the 'automatic setpoint-tuning' (U). The T-mode performs parameter settings by the exact reproduction of nominal parameter values within a few seconds. The U-mode only guarantees constant parameter settings within small correction limits. Whereas the T-mode is intended to 'switch' between completely different parameter settings, the U-mode is used to compensate small long time drifts, e.g., due to temperature instabilities of the power supplies. The static control routine is based on a closed loop operation using home-made BCD-output modules[2] for the digital control of the power supplies and a separate CAMAC controlled integrating digital voltmeter (SOLATRON LM 1604) for the measurement of the output current via high precision inductive shunts. The regulation itself is done iteratively by software, with attention to the relatively large time constant of power supply variation for quadrupole and bending magnets.

The emittance measurement described in Ref. 1 has been extended to include a complete evaluation section for the fit of the respective phase space ellipses. An example of a complete emittance measurement in horizontal and vertical directions can be seen on Fig. 2. Since there are some noise problems in the existing wire scanners of the emittance measurement system, this unit will now be replaced by new ones. The new wire scanners (Fig. 3) with stepper motor control solve this problem and enable also the measurement of the emittance at currents down to 0.05 μA. For fast data acquisition the signals of the eight wires can be digitized in parallel.

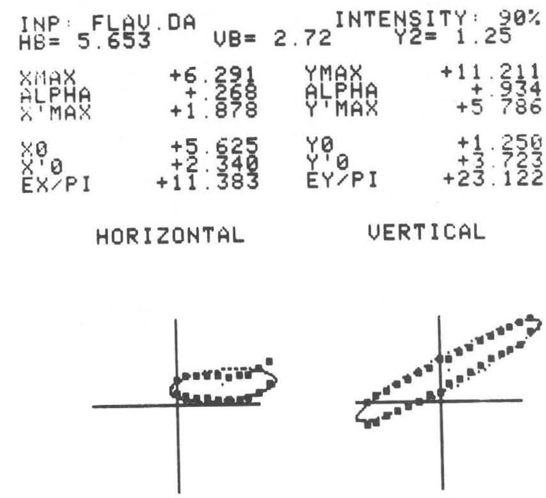

Fig. 2: Typical result of a horizontal and vertical emittance measurement for the 52 MeV deuteron beam.

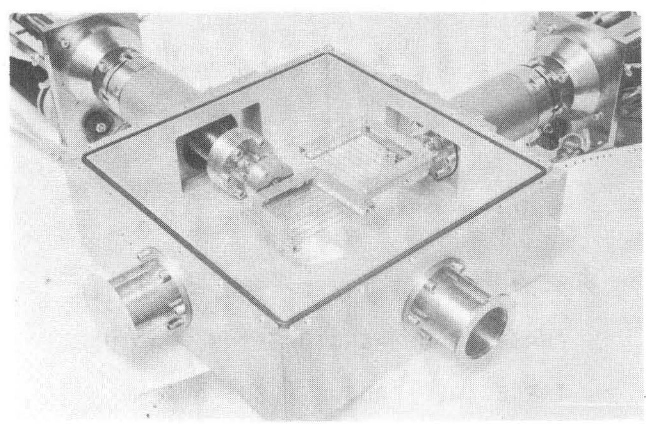

Fig. 3: New wire scanners for the emittance measuring system. Both wire systems for horizontal and vertical directions can be moved separately actuated by stepper motors.

This scanner has been built by NTG[3] according to our specifications with a complete CAMAC compatible I/O-control.

Various programs for scanning the intensity distribution of the external beam have been developed using the slits and the wire system of the emittance measurement unit and several rotating wire systems (Fig. 4) according to the system developed by Hortig.[5] Intensity distributions taken by the latter system can be seen in Fig. 7. Due to graphite/rhodium contacts for the rotating wire, currents down to 0.5 μA can be measured without noise problems. Measurement of a horizontal and vertical intensity distribution inclusive of the evaluation of the maximum and the FWHM takes about 2-3 seconds. In order to achieve distributions independent of the current fluctuations, the differential current measured by the wire is related to the total current measured by an inductive pick-up probe[6]. This is done by dividing the wire signal by the pick-up signal before it is digitized by the ADC.

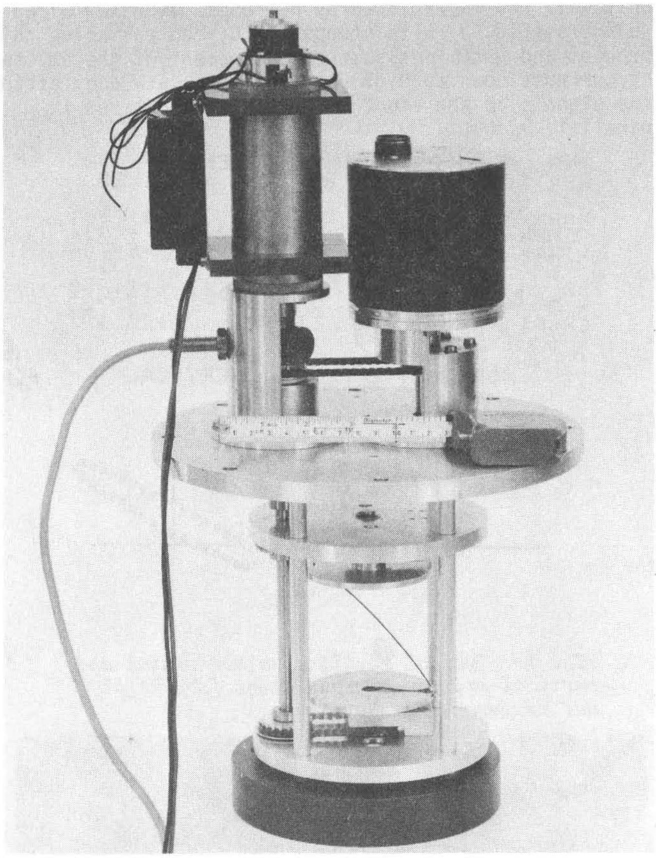

Fig. 4: Fast rotating wire system for the measurement of the intensity distribution of the external beam.

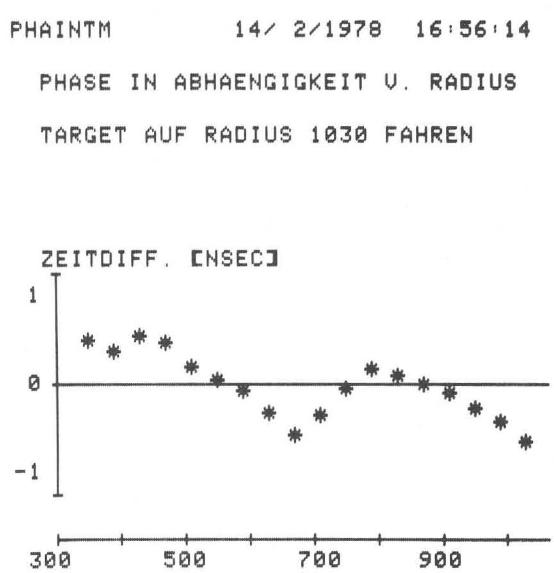

Fig. 5: Typical result of the measurement of the phase position as function of the radius with the 52 MeV deuteron beam.

For the experiments with the neutron time of flight spectrometer, the continuous monitoring of the phase width and phase position by program has been proved of great advantage. Therefore a control link to the data acquisition computer has been realized via CAMAC, giving the acquisition program the information when the phase width and phase position is going out of predefined bounds. The same hardware permits the measurement of the phase width and phase position as a function of the radius too (Fig. 5). The positioning of the target, however, is done manually by the operator at the moment. A CAMAC controlled target input machine will be available at the end of this year. It will then be possible to measure the phase as function of the radius with approximately 20 target positions in less than one minute.

FORTRAN Multitasking System

Once the adjustment of the cyclotron and external beam guiding system has been performed, it seems to be sufficient for many users to load a special monitoring and control procedure to supervise the rest of the beam time. Generally this procedure will be user dependent due to the great variety of user demands on the beam quality. Since all diagnostic tools available have their appropriate programs in BASIC, it will be evident that a user-dependent monitoring procedure normally can be composed by the suitable BASIC programs.

Contrary to pure diagnostics, monitoring and control must be able to process in parallel, i.e., multitask, and needs less interaction with the operator. Since the BASIC used has no multitasking facilities, the BASIC diagnostic programs must be partly rewritten in FORTRAN to form the user-dependent monitoring procedures. The modular design and the higher execution speed of the same algorithms are the main advantages of using FORTRAN. Compared to a fully new FORTRAN program development, the disadvantage of rewriting parts of a known BASIC program is overcompensated by the saving in programming- and testing-time.

The FORTRAN multitasking system for monitoring and control actually contains the following facilities:

1. Choice of the parameters to be monitored. This is done in groups as in the BASIC status programs. It is divided between parameters for injection, cyclotron and external beam guiding system. The monitoring is performed by comparison with nominal parameter sets. The mechanism for loading and saving nominal parameters sets is the same as in the corresponding BASIC status programs with a fully compatible data structure.

2. Choice of the parameters to be controlled by a simple static control routine. This control routine represents the FORTRAN equivalent of the U-mode available in the BASIC program status external beam. As in BASIC this is, at the moment, only possible for the parameter settings of lenses, bending elements and trim coils.

3. Choice of monitoring the beam quality parameters like the horizontal and vertical intensity distribution. The intensity distributions for this purpose are taken by rotating wire systems (Fig. 4) which perform nondestructive measurements for most cases.

4. The execution of the different procedures is performed periodically. The time between successive executions of the same program can be selected at the start of the system for each program separately. A detailed monitoring protocol can be printed out continuously on the main console or directed to some intermediate

files on disk or magnetic tape. The action taken by the individual monitoring tasks in case of unexpected disagreement with nominal values is to call for operator intervention.

External Beam Optimization

The experience with the static control procedures for the external beam guiding system shows that the parameter settings of the lenses and bending elements is exactly reproducible. Normally also the measurable beam quality parameters like intensity distributions from beam scanners can be reproduced. In this case the static control routines are sufficient. If, however, the beam quality parameters cannot be reproduced with the appropriate known parameter settings of lenses and bending elements, the whole system has to be optimized again. A variety of users and also some diagnostics programs within the CICERO system require a reproducible, well adjusted beam to perform the proper experiment or measurement. Therefore automatic optimization procedures are being developed to shorten the adjustment time between the different experiments.

One pilot example of such a diagnostic program represents the measurement of the absolute energy (ENER) of the cyclotron beam. The principle of the measurement is based on the time which the beam needs to reach two separate targets (Fig. 6).

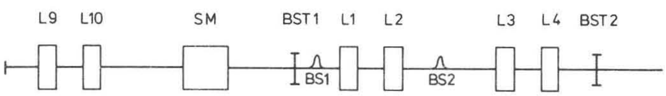

Fig. 6: Schematic view of the arrangement of switching magnet SM and quadrupole lenses L9, L10, L1, L2, L3, L4, the two beam scanners BS1, BS2 and the beam-stops BST1 and BST2 in the external beam handling system.

An explicit description of the details has already been given[7]. Normally if the program ENER has to be executed, the operator has to adjust the beam manually prior to the proper measurement. As is seen from Fig. 6, good transmission between target BST1 and BST2 can be achieved by adjusting a flat waist at location BS2 with the help of lens L9 and L10. The restriction to two parameters also reduces the complexity of the problem. This problem, however, can be solved by an iterative procedure to optimize the horizontal and vertical beam profiles and positions at the location of the beam scanner BS2.

An iterative program using least squares technique has been developed in BASIC to achieve automatic adjustment of the external beam for this problem. Necessary for starting the optimization program is the existence of a measurable optimizing function, CHIQU. CHIQU can be obtained as the sum of the squares of the differences between nominal and actual beam profiles and beam positions. At the starting point of iteration the horizontal and vertical beam intensity distributions must not be too far from the optimum. Otherwise a computer controlled variation of the lenses would result in a discontinuous optimizing function CHIQU, because the beam transmission can vary greatly. Test results of an optimizing run can be seen on Fig. 7. As can be seen from 7a to 7d, the main effect of the optimization is reached after 4 iterations. The gain between iteration 4 and 6 is minimal. Also 10 further iterations do not minimize CHIQU any more which means that the optimum is reached. The different parameter adjustments between the 4th and 16th iterations show that there is a relatively wide "parameter-band" reaching CHIQU-values near the optimum. It may also be seen by the parameter change (L9, L10) between the 4th and 6th iteration that the iteration procedure directly approaches the optimum. This has been solved by using the method of conjugated directions of Powell[8].

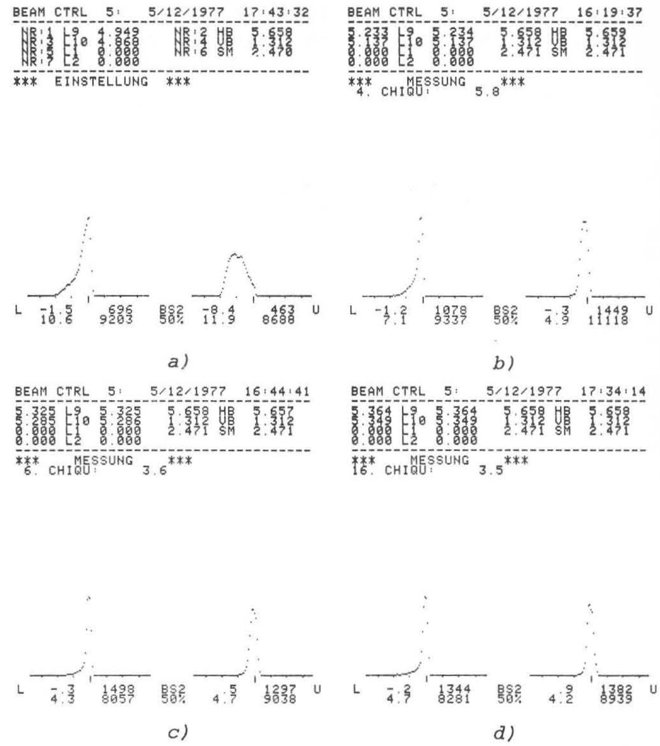

Fig. 7: On-line optimization of the 52 MeV external deuteron beam. Beam quality is measured by the beam scanner BS2, parameter variation is performed with the quadrupoles L9 and L10. In a) to d) the beam profiles are represented by the following scheme:

HORIZONTAL			*VERTICAL*	
POSITION	*INTENSITY*	*BS2*	*POSITION*	*INTENSITY*
FWHM	*INTEGRAL*	*50%*	*FWHM*	*INTEGRAL*

a) showing the beam profiles at start of optimization
b) state after 4 iterations
c) state after 6 iterations
d) state after 16 iterations

Future Developments

The incorporation of new and more diagnostic and control hardware into the computer control system (like the target input machine, automatic beam stops and slits in the external beam guiding system, a variety of further status parameters in the external injection line and the NMR-control of several magnets) can be done easily via the CAMAC system. However on the software side it involves the problem that even if FORTRAN multitasking is used, certain programs cannot run simultaneously. The recent development in micro-computers for CAMAC enables decentralization of the whole system. Since these developments offered by a variety of CAMAC manufacturers are able to be programmed in high level languages like BASIC or FORTRAN, the software effort to use them can be held within foreseen limits. Thus an increased computing power can be achieved with a number of small and cheap micro-computers in CAMAC. The fact that parallel processing is done in hardware rather than in software also reduces much of the software system overhead so often found in today's mini-computers.

Acknowledgement

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