

## INTEGRATION OF COMPUTE-BOUND TASKS IN THE SIN CONTROL SYSTEM

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### Abstract

At the Swiss Institute for Nuclear Research the development of a new class of control computer programs has started. These programs deal mostly with beam diagnostic measurements and with the corresponding display and interpretation based on mathematical models. This paper explains why different parts of a task are assigned to different hardware elements. It comments on the mathematical methods applied for fitting and deconvolution and on the graphical output facilities. Four programs which are already in use for the control of SIN Injector II are presented in some detail. These examples handle the following measurements: the radial differential probe, the radially moving phase probe, the phase selecting collimator at injection and the simultaneous measurement of radial and time structure of the beam at extraction.

### The Accelerator to be Controlled

Since 1974 the accelerator facility of SIN produces proton beams of 600 MeV. The Injector II, a four Sector ring cyclotron for 72 MeV protons [1] has been added with the final goal to reach beam intensities above 1 mA. Injector II came into operation in 1984. Some control computer programs for beam diagnostics have been used for the commissioning of the new accelerator, some others have been developed since. The new concept, which assigns most of the calculation to a MicroVAX II included in the control system, will be gradually applied to the beam diagnostic programs. An application of similar principles for the beam diagnostics of the 600 MeV ring cyclotron is planned.

### The SIN Control System

During the commissioning of Injector II and in the few years before, the scope of the SIN control system had to be widened by a large amount. It was not only the new two-stage accelerator and the corresponding beamlines that caused more load, but also at the same time the task of accessing active and of reading passive elements was assigned to the control computer. This big step towards computerisation had to be achieved without causing a major disruption in the working of the control system. It is obvious, that several measures had to be taken in order to avoid a complete overload of the control computer. The most important of these was the splitting of the control system into three parts, Injector I, Injector II and 590 MeV ring cyclotron, each served by its own PDP 11 computer.

In order to provide a steady operation of the control computers a fourth PDP 11 is dedicated to program development and upgrading. A standard Ethernet/DECnet bus acts as datalink between the system parts and provides the facility of data exchange and code installation. Another means to diminish the load on the control computer was the improvement of the software for the data transfer from and to CAMAC devices. Some special tasks could be moved out of the control computer and were installed in auxiliary crate controllers (ACC), little computers directly located in the CAMAC-crate.

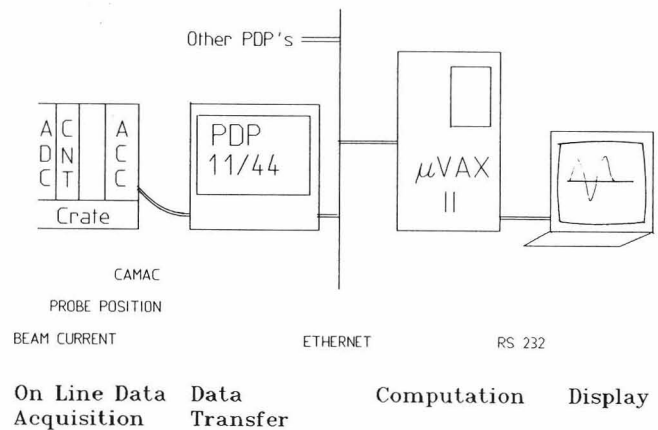


Fig. 1: Data flow for beam diagnostic measurements including subsequent evaluation in a mainframe computer.

In spite of all these measures the load on the PDP's remained high. In this situation the jobs running continuously, providing the contact between the operator and the accelerator, had to be given priority. From the typical beam diagnostics programs two main parts were moved to other processors, leaving only a small part of the whole task in the main control computer. This remaining part comprises program start, masterfile access and data transfer. The real-time job of collecting the data continuously from the probe was realized in an ACC. At the other end, the evaluation of the measured data and the graphic display was programmed on the central VAX computer of SIN. Later a MicroVAX II was attached to the control system allowing for a more direct connection between the three partial tasks of beam diagnostics (see fig. 1).

### The Beam Diagnostics Programs

The special control computer programs being developed for beam diagnostics of Injector II have several features in common:

- Tasks are splitted into two or three parts, which run on different processors.
- Large amounts of data have to be handled and processed.
- The results are presented to the operator both graphically and as numbers.
- Each program must run in two modes, one with fixed parameters for the use by operators the other with a high flexibility for special experiments.

The first example of such a program was the radial differential probe which is presented below. Its success gave us the motivation to apply the same principles to other tasks as well. One of the important requirements of beam diagnostic evaluation is the creation of a compact result which sums up the essential information contained in the large amount of measured data. Various filtering methods are applied to many cases in order to improve noisy measurements. The use of mathematical models and of fitting methods can yield a small number of relevant parameter values. A well designed graphic display of complex data easily provides an insight into the essential structures.

The consequent assignment of different partial tasks to that type of processor which is well suited for it, helps to fulfill the requirements and at the same time allows to provide a rather short time delay between the measurement and the output of the results. A quite efficient optimization of the used filtering methods and mathematical models is achieved by using modular code which allows an easy exchange of the modules. Among the used subroutine libraries we would like to point out SIN's GRAPHX-package [2]. Which has been proven to be a convenient plotting system for all kind of graphics.

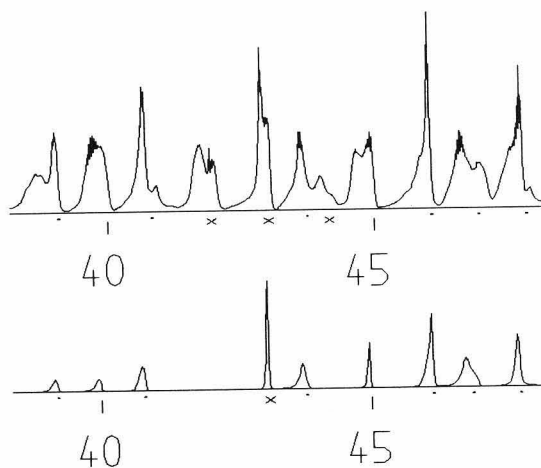


Fig. 2: A scan of an extremely badly centered and matched beam shows how the turn identification works. Turn positions that cannot clearly be correlated to a turn number for all fingers simultaneously, are marked with a cross and will not be considered in the subsequent evaluation. Turn numbering occurs with respect to a calculated reference table.

### The Radial Differential Probe

The program which evaluates the measurements with the radial differential probe contains many ideas taken from a similar program constructed some years ago [3] for the 590 MeV ring cyclotron. The evaluation starts with a digital filtering of the measured data. Local minima in the measured current as a function of radius indicate where the separation between successive turns could be. The next step checks whether the value of a local minimum is low enough and makes sure that there is really a peak between two adjacent minima. For Injector II the outer edge of a peak is taken as turn location rather than the center of gravity of a peak. This is done because of the high phase width accepted in the center of Injector II. Because of the special probe head [4], which has two inclined wires and a vertical one, it is essential to assign a proper turn number to each peak found in any of the three traces. Figure 2 shows the result of the algorithm: all peaks which cannot be assigned a turn number unambiguously are discarded for further processing.

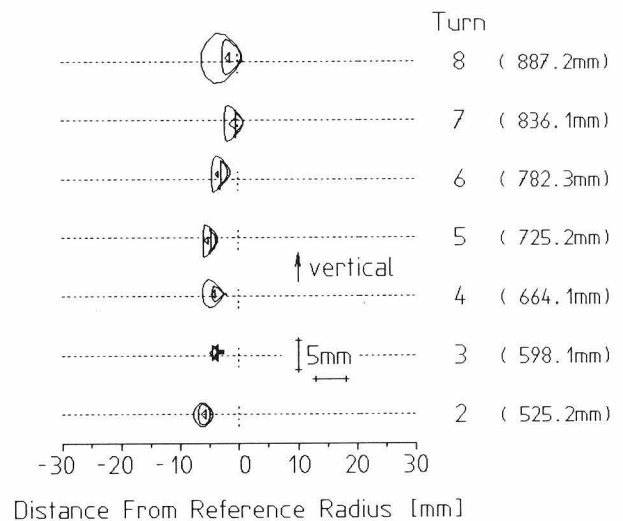


Fig. 3: Beam cross section of turns 2 - 8 as reconstructed tomographically from a three finger beam probe.

The signal of the three-wire probe contains information on the horizontal and on the vertical position and width of each turn. The method which allows such a reconstruction of beam properties in the vertical direction from a purely radial scan is a simplified version of tomography (see fig. 3). As a summary of the measurement, the program finds the betatron amplitude and phase in horizontal and vertical direction, information that can be used for automatic centering.

### Fine tuning of phase in SIN Injector II

Isochronism in Injector II is achieved by correcting the magnetic field of the sector magnets by means of 11 trim coils. The effect of every coil has been measured and the results stored on a reference file. The phase deviation of the accelerated beam is measured by a moveable phase probe.

The measured phase deviation and the actual currents of the coils are fed to the program, which then calculates the trimcoil currents needed to get the minimum phase deviation. The least squares method used in this calculation optimizes the residual phase deviation, the total current in the trimcoils and the difference between the current settings of adjacent coils. The Singular Value Decomposition which solves the corresponding system of linear equations has the advantage that it does not crash in the presence of idle parameters in the fit.

The program plots the measured phase deviation and the residual phase expected after trimcoil correction (see fig. 4). The proposed coil currents are displayed in a line under the plot. The setting of these values is done manually by the operator.

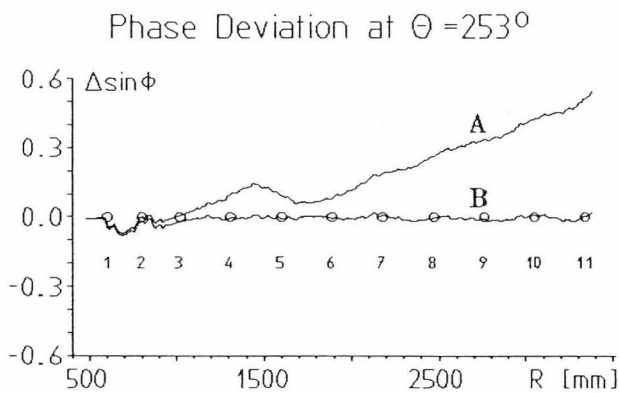


Fig. 4: The measured phase deviation 'A' can be reduced to 'B' by setting the trim coil currents proposed by the fitting routine.

### The Phase Selecting Collimator

In SIN Injector II selection of beam intensity is performed by a high power collimator placed after the first half orbit. It changes the phase width of the beam accepted, hence the fraction of the injected beam which is accelerated. This collimator can be used as a high power beam scanning probe: beam intensity deposited on the collimator as well as the fraction of the incoming beam that reaches the beam dump on turn 4 are recorded as a function of the position of the collimator. An example of such a transmission function is plotted in figure 5. In order to resolve the beam profile which corresponds to such a transmission function, a Fredholm integral equation of the first kind must be solved. These integral equations are well-known examples of ill posed problems. Following a hint from B. Schorr [5] an algorithm which could successfully solve this problem has been written. A slightly simpler method which still yields some information on the beam width at this collimator is a nonlinear parametric fit for the desired value.

The example presented in the figures 5 and 6 shows good agreement between the beam profile as obtained by the deconvolution method and from parameter fitting. Note, that the method of convergent weights used for the solution of the integral equation (which is equivalent to a deconvolution) is fine enough to reveal the different slopes on the left and right side of the peak.

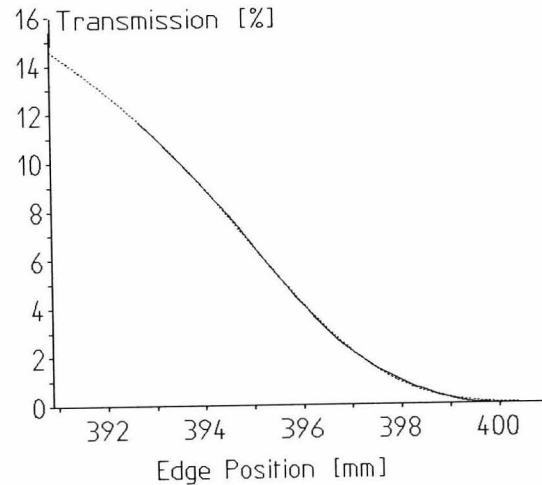


Fig. 5: Fraction of injected beam passing the phase selecting collimator in the center of the cyclotron, plotted as a function of the collimator position. The dotted line refers to a mathematical model of this transmission curve. This model serves as the basis for a parametric fit, which yields estimates for the position, width and intensity of the incoming beam.

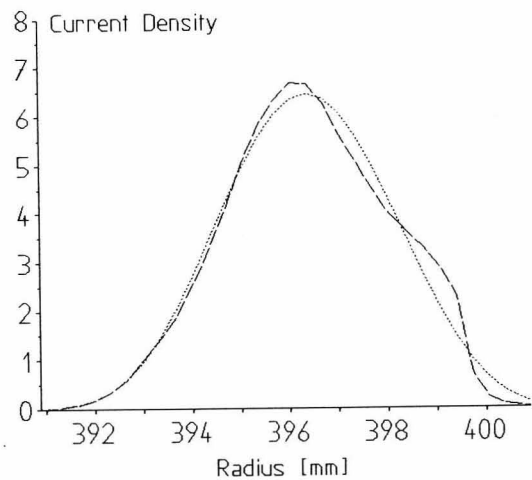


Fig. 6: Reconstructed beam profiles at the phase selecting collimator. The dashed line refers to a full reconstruction via a deconvolution algorithm, whereas the dotted line corresponds to a fit with a mathematical model.

### Radial and Time Structure Measurement

Proton scattering from a thin carbon wire can be used to measure beam intensity as a function of time. The geometrical layout of the probe is sketched in fig. 7. It measures the average intensity of the beam bunch in the radius-phase plane. One measurement sample contains the development of the intensity of the passing beam bunches at a fixed radius. This method, developed by Th. Stammach, recently has been adapted to the needs of SIN Injector II [6].

The evaluation code offers several ways of presenting the measured data, such as projections in radial and azimuthal direction, contour lines of equal intensity or three dimensional plots of the beam bunch. The contour plot has turned out to be a powerful instrument to examine the overall setting of the main cyclotron parameters: A slanted axis of the bunch is caused by an error of the relative phase between main and flattop cavities, an incorrect RF-amplitude of the flattop cavity causes the bunch to take up a "banana" shape.

**Twin Beam:** Radial and Time Structure measurement allows a high precision measurement of isochronism. As a well known fact in cyclotrons, beam bunches deform towards a hoop as seen in the radius-phase plane. If the outermost particles of the bunch are cut away by a phase collimator, two "sockets" remain and form the so called Twin Beam. In an exactly isochronized field the sockets will be of the same size. Figure 8 shows a contour plot of a twin bunch.

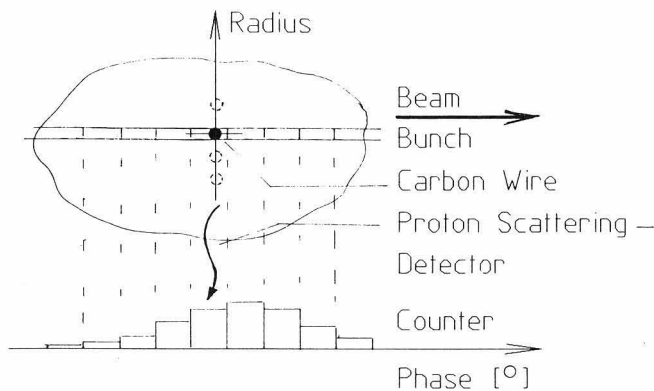


Fig. 7: Sketch of the Radial and Time Structure Measurement. The number of scattered protons is collected in the channel of the corresponding phase at a fixed radius over a measuring time of about 10 seconds. This yields the intensity distribution of the averaged beam bunch.

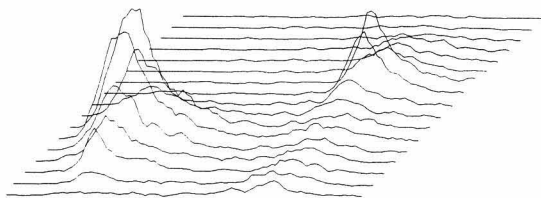


Fig. 8: Three dimensional representation of the measured data samples and corresponding contour plot. 13 samples at different radii are collected.

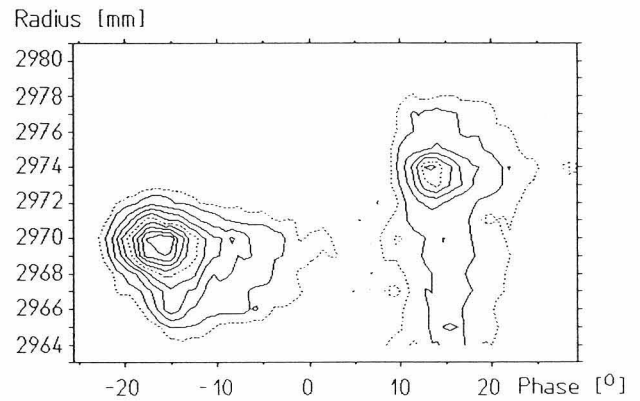


Fig. 9: Example of Radial and Time Structure plot of a Twin Beam. The difference in the size of the bunch parts is caused by a small deviation from isochronism on the first four revolutions between injection and the phase collimator.

### Acknowledgements

The authors would like to record their debt to the colleagues who have participated at this work. The ACC-part of these tasks has mainly been programmed by T. Blumer and H. Keller. Many questions related to data transfer and to the synchronisation of the different processes have been solved by A. Mezger. Miss Sigrun Andradottir, a summer student, has evaluated the deconvolution algorithm for the phase selecting collimator.

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