CERN 74-1
Laboratory I
Track Chambers Division

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

COMPUTER-AIDED CONTROL
OF SEPARATED BUBBLE CHAMBER BEAMS

P. Lazeyras, I. Lehraus, R. Matthewson
and W. Tejessy

CERN, Geneva, Switzerland

G E N E V A

1974

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1. INTRODUCTION

Tuning high-energy separated beams is very often a tedious, repetitive and lengthy procedure. The amount of time lost on tuning leads to a considerable reduction of the number of bubble chamber pictures which were originally planned to be taken for a particular experiment at a given beam momentum. Typically, about 1 day of tuning was needed every one or two weeks of bubble chamber run.

That was the main reason why an on-line control system was incorporated into the already existing manual controls for the separated beams serving the 2m CERN hydrogen/deuterium bubble chamber. The new system was gradually built in over a period of about 1 ½ years without interruption of the bubble chamber program.

For this reason and from the purely economical point of view it was considered necessary to preserve the existing manual controls of different beam elements and modify them as little as possible in order to allow for computer access. Obviously, better results could be achieved if a completely new system was built without taking into account a given stage of historical development of the existing hardware. Nevertheless, the reliability of our system featuring fully redundant parallel manual and computer access is very satisfactory. In case of a breakdown of the computer, the system still remains fully operational via manual controls.

The design of the on-line structure on the software side was determined firstly by the strongly repetitive nature of the beam tuning which consists of a long series of largely predefined steps. Secondly, various considerations deemed it necessary to use part of the computer already installed for the 2m bubble chamber monitoring and control. This led to constraints in the hardware and software development.

Although beam tuning steps are well defined, experiences over many years have shown that the complexity of the beam lines is such

that it would be unrealistic to hope for a completely automatic tuning program with no operator guidance, e.g. one which would on command "8.25 GeV/c K^+ " produce the requested beam fully tuned. Continual operator decisions are therefore a necessity, while the choice remains as to the number of sequential steps, which the computer chains together before demanding these decisions. Due to the constraints coming from the computer configuration it was decided to restrict chaining and to build the system up around a series of independent well-defined user routines, each separately called for by the operator at his discretion during tuning, and to leave large parts of the chaining of logical segments to a later stage of development.

Since operator intervention is required, the choice of using a higher level computer language with full interactive dialog via teletypewriter versus a machine language approach (MACRO) with reduced teletype requesting facilities and a comprehensive request panel (thumb switches, function buttons, request button) had to be taken. The former allows for faster program changes once the system is implemented, the latter uses less core, is much faster in operation and less prone to operator errors. We have decided upon the latter and experience has shown that, for repetitive procedures with little necessity for program changes, this method of entry of commands and parameters is very efficient. Obviously, it is also more readily combined into a shared computer system as described above.

The design of this system was preceded by an alarm-monitoring and logging program sequence without on-line control running off the same computer. Work on this system was started in 1968; it was used in operation from the middle of 1969 [1,2]. The design of the actual version of this on-line system was started in second half of 1969 and finished by mid-1970. All hardware equipment was produced and all necessary programs were developed by members of the CERN Track Chamber Division Beam Group and installed during the first half of 1972. The whole system was fully operational by mid-1972

together with the final version of multiwire proportional chambers developed especially for fast ejection beam spill. It has worked well since that time, almost without interruption.

2. GENERAL LAYOUT

The fast ejection septum installed in the straight section 58 of the PS (Fig. 1) can extract 1 to 5 10 ns long bunches of particles, 105 ns apart. The ejection can be repeated after about 150 ms to serve the second expansion of the 2m bubble chamber during the same PS cycle. The external proton beam line e6 transports the ejected protons onto an external target of the high energy radio-frequency (RF) separated U5 beam, which works in the momentum range of about 4 to 20 GeV/c. When the U5 target is removed, the external proton beam can be focused onto the target of the medium energy (about 2 to 5 GeV/c) electrostatically separated beam m6. Finally, further downstream along the e6 proton beam line there is the target for the low energy (from some 0.8 to 2 GeV/c) electrostatically separated short k8 beam. All three beam lines, situated in the East Experimental Hall, converge into a common part (obviously only one beam at a time is running) before entering the 2m bubble chamber building. At one corner of this building there is an extension in which the 2m bubble chamber control room is situated. This control room contains also the PDP-9 computer used for on-line connection of both bubble chamber and beam controls. At the advanced stage of the beam on-line project (beginning of 1972) the computer configuration was based on 24k of (18 bit word) core memory and 3 DEctapes running under a background/foreground monitor.

The beam control room is situated at the opposite corner of the bubble chamber building at a distance of approximately 50 m (about 70 m of cable length). All controls and indications for magnetic elements collimators, separators, detectors, etc. are concentrated there.

At the beginning of 1972 a ~ 400 m long parallel data link was installed as a component of our on-line system between the beam control

room and the East Generator Building and connected there to a Siemens 301 computer (16k, 24 bits words of core memory), which has direct control of all the generators feeding the East Experimental Area.

The beam on-line system was designed to take into account the above mentioned constraints. In the following sections, the characteristic and operational features of all beam components and their controls are explained in more detail, especially for the complex U5 beam.

3. RADIO-FREQUENCY SEPARATED HIGH ENERGY BEAM

3.1 Beam optics [3]

The magnetic elements are either horizontal or vertical 1 or 2 m bending magnets (M) or 1 or 2 m quadrupoles (Q). The characteristics of those standard elements are to be found in [4].

Fig. 2 shows the general layout of the U5 beam. The external proton beam strikes the target at essentially zero degrees producing secondary particles which are collected with maximum acceptance of ± 7.5 mR and ± 4.6 mR in the horizontal and vertical planes respectively. This is defined by horizontal collimator C1 and by vertical collimator C2, followed by an FDF (focusing-defocusing-focusing) triplet Q1, Q2, Q3, Q4, which gives a horizontal image of the target at the momentum slit (collimator C4). A set of two 2 m bending magnets M1 have a dispersion necessary for a momentum bite of about ± 0.25 %.

Collimator C3 defines the vertical divergence of the beam and is imaged at the beam stopper. The field lens Q5 images the deflection center of M1 to the deflection center of M2 (identical to M1) with the magnification of -1 in order to compensate for the dispersion. Behind Q5 the beam is parallel in the vertical plane. The horizontal acceptance is defined by C5. The FD doublet Q6, Q7 gives the vertical and horizontal image of the target (focus) at the center of the first RF separator cavity and with Q5 and the intercavity optics it images C3 onto the beam stopper. W.CH.1 and 2 are 64 channel multiwire

proportional chambers with 1 mm effective resolution. They are fixed at each end of the RF cavity in special boxes under vacuum. Remote control allows for rotation of those chambers by 90° for vertical or horizontal scanning of the beam profiles. When the tuning of this part of the beam is finished, the chambers are pneumatically pushed out from the beam line (even a very small amount of scattering introduced at this point into the beam could spoil the separation of unwanted particles). Q8a,b, Q9 form a symmetrical triplet focusing the center of RF1 at the center of the second cavity RF2 with vertical transfer matrix $\begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix}$. Q10a,b, Q11a,b is a DFDF quadruplet, focusing the center of RF2 at the center of RF3 again with the transfer matrix $\begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix}$. W.CH.3,4,5,6 are identical to W.CH.1,2. W.CH.7 is fixed for a scan in the vertical plane (it is mounted in the gap in the vacuum beam pipe) and serves for adjustment of the correct intercavity RF phase. BS is a beam stopper which blocks the unwanted particles. C6 helps in cleaning the beam from μ -mesons. Q12, Q13 allow for focusing the beam in both planes between C7 and C8. W.CH.8, situated there, can be rotated by 90° for a scan in vertical and horizontal planes. C7 and C8 redefine the target for the last stage of the beam. The bending magnet M3 (two 2 m magnets) and horizontal collimator C9 permit a momentum analysis and clean the beam from background coming mostly from the beam stopper. Vertical bending magnets M4 (1 m) and M5 (1 m) are used for adjustment of the vertical position of the beam in the bubble chamber. Q14 and Q15 focus C7 at C9 in the horizontal plane and give an almost parallel beam in the vertical plane inside the bubble chamber. BC1 is a counter used for tuning, flux monitoring and for the bubble chamber flash triggering.

The total length of the U5 beam from the target to the center of the bubble chamber is 181.6 m, of which some 148 m are inside vacuum beam pipe.

The separation of unwanted particles is achieved in the following way: Let us assume two-cavity separation over 50m intercavity distance, rejection of one kind of unwanted particles only. A momentum analysed

beam containing wanted and unwanted (majority) particles undergoes a sinusoidally time-varying deflection in the first RF cavity. The intercavity beam optical system images this deflection with unity magnification but of opposite sign into the second RF cavity. At discrete values of beam momentum the difference of time-of-flight between wanted and unwanted particles will be just equal to the period of the RF field (e.g. about 0.3 ns over 50 m at 10 GeV/c between K and π , the RF frequency being 2855 MHz). The relative phase between the two RF cavities can now be adjusted such that the deflection in the second cavity will just cancel the first one for the unwanted particles. A central beam stopper with appropriate thickness placed behind the second cavity will stop all unwanted particles and obviously also a certain fraction of wanted particles which were not deflected sufficiently to pass either side of the beam stopper.

3.2 Collimators

The requirements for precision and for reproducibility of position of the collimator's jaws are $\geq \pm 0.1$ mm. The jaws are either 50 cm or 1 m long, machined from brass or from iron (magnetic collimators used in the final cleaning stage of the beam). Fig. 3 shows a cross section of a magnetic collimator. Both jaws are mounted inside a vacuum-tight box on precision ball bearings "SPHERAX". Each jaw is moved independently by its own 2800 r.p.m. 3 x 380 V ac electric motor via 400:1 reduction gear and precision screw of 2.5 mm pitch. This rather slow speed of movement of about 0.3 mm/s is necessary to assure correct position without overshoot (electromagnetic brakes at the motors). The jaws can be either opened or closed symmetrically with respect to the axis of the beam or set for a slit of a given width and moved across the beam. The magnetizing coils create a closed field within each jaw. The polarities are opposite and chosen such as to deflect scattered particles out from the beam. This arrangement brings some complications in the design of the controls, because the jaws must be prevented from touching (they will remain held together by the remanent field) and when opening relatively small gaps, the excitation current must be first switched off. From this point of view variable

speed of movement (fast for long displacement, slow for final positioning) was considered as an unnecessary complication.

Fig. 4 shows a 1 m magnetic collimator on its support and the manual control box used prior to the introduction of the on-line system. Also shown are the selection box (explanation later) and the power supply for magnetizing coils.

The encoders for the position measurements must be rugged and very reliable, because the access to some collimators is very difficult (radiation shielding). The collimators placed close to the external target must work in rather high level of radiation, therefore sensitive electronic components and some plastic materials can not be used there. It is preferred to encode the positions in absolute (not incremental) code to avoid troubles with recalibration of zero position after each power failure. So, as long ago as 1965, the Beam Group developed a 3 decade shaft encoder consisting of metallic coding discs, in which the sensors were miniature microswitches. Fig. 5 shows a later 4-decade model with capacity of 10 000 positions in 1 000 revolutions of the input shaft. The encoders are coupled to the precision screw moving mechanism so as to give 10 positions for each 1 mm of displacement of the collimator jaws. The backlash in the system is safely below the allowed errors of ± 0.1 mm. Three-decade encoders with capacity corresponding to ± 49.9 mm of movement with respect to the beam axis are generally sufficient for the high-energy beams.

Fig. 6 shows the non ambiguous decadic code used for the encoders.

Encoder position	Coding discs				BCD			
	d	c	b	a	d	c	b	a
0	0	0	0	0	0	0	0	0
1	0	0	0	1	0	0	0	1
2	0	0	1	1	0	0	1	0
3	0	1	1	1	0	0	1	1
4	0	1	0	1	0	1	0	0
5	1	1	0	1	0	1	0	1
6	1	1	1	1	0	1	1	0
7	1	0	1	1	0	1	1	1
8	1	0	0	1	1	0	0	0
9	1	0	0	0	1	0	0	1

The code on the discs a,b,c is symmetric around positions 4 and 5, which allows coding either from 0 to 999 or from 0 to ± 499 (our application). The sign is determined by the most significant disc d. Both coding examples are shown on Fig. 6 and the reason for the existence of double zero position (positive and negative) is clearly visible. The influence of backlash in the 10:1 reduction gears inserted between the individual decadic stages of the encoder is eliminated by mounting double rows of sensors on the tens and hundreds, spaced in a V-scan configuration by $\pm 1/4$ of the appropriate discs positions. The lead-lag switching of corresponding row of sensors is done by small reed relays, controlled by the first decade disc.

Fig. 6 also shows the electronic circuit used for a conversion of each decade of the described code into BCD, which is necessary for comparators in preselection and for indications. The transcoding is obviously done in the control room once for all collimators. The distributed multiplexing system for 9 collimators used in the U5 beam is shown on Fig. 7. There are two bus cables running from the control unit situated in the beam control room to the last collimator and then in a daisy chain to the very first one. One set of wires brings all position indications, limits and touch flags etc. into the control room. The other set of wires contains the movement commands for the motors and the selections. Local selection boxes placed near the collimators in the beam line allow for connection of a chosen collimator onto the bus cable. There are no local memory elements at each collimator and there is only one set of comparators in the control room unit (to compare if the actual position is still not equal to the desired one), so clearly only one collimator could be moved and its position indicated at a given moment. From Fig. 7 it is to some extent already clear what were the necessary modifications of the manual control units needed for on-line connection later on.

Fig. 8 shows some more details of the inner logical structure of the collimator system. The element selected in the beam line sends

to the control room its actual position which is converted into BCD code and compared with desired preselected value. When the "MOVE" instruction is issued, the motors start to move one or both jaws in the appropriate direction until the comparators signal EQUAL or when some limit was reached. The correct sequence of operation is: select element - preselect value - compare/determine sense of movement - move. The connection of a chosen element to the input/output bus cables is done by relays in the selection boxes placed in the beam line. There must be a delay of about 10-20 ms between the selection and the MOVE command to eliminate influence of reaction time and contact bouncing.

3.3 Beam stopper

The beam stopper should block all unwanted particles deflected back onto the beam axis by the last RF cavity. It consists essentially of 10 brass plates of different thickness, mounted on a rotating shaft (Fig. 9). The plate of desired thickness is put in the beam axis. The assembly can be moved by ± 49.9 mm in the vertical direction to be centered at the unwanted particles peak. The beam stopper can be removed from the beam line by another movement in the horizontal plane. The desired precision and reproducibility of position is the same as for the collimators, i.e. $\geq \pm 0.1$ mm. The encoders for position measurements are the same as used for the collimators as is the basic structure of the control. Certain complications arise from the need of accurate locking-in of the required plate thickness (= angular position). Due to the different weights of the plates the rotating system is not properly balanced; for that reason the speed of all movements is kept rather slow.

3.4 RF separators

The structure of the RF separators control system containing servoloops for stabilization of phase and power etc., was described in detail elsewhere [5]. What is interesting from the point of view of on-line control and what is accessible to the beam operators is, essentially, the possibility to change the relative phase between any two cavities as well as the amount (within certain limits) of

RF-power entering each cavity. Appropriate indications are provided for these entities, as well as for error conditions. There is also a possibility to switch any one of the three cavities "out" of synchronism with the beam (= no deflection). To allow for asynchronous reading by computer, all phase and power values are separately latched, since the signals enter the beam control room in serial form.

Special lamps indicate the status of the fast vacuum valves at each end of each cavity which automatically close if the vacuum in the beam pipe is not good enough and there is a danger of spoiling the 10^{-8} Torr vacuum inside the cavities. In case of occasional breakdown of the cavity, the normal working conditions are automatically restored. During the breakdown interval a veto for the bubble chamber flash trigger is issued.

3.5 Scintillation detectors and target monitor

As already mentioned in the preceding paragraphs, there is only one scintillation counter in the beam. It is used as a total flux counter for tuning and monitoring and it gives the flash trigger for the bubble chamber [6].

Due to an extremely short beam spill time it is impossible to use any coincidence counting technique (for scintillation detectors as well as for MWPC) and the number of particles is determined via pulse height analysis [7]. In order to reduce large statistical fluctuations of the ionization losses in the low intensity beam near the bubble chamber, the smallest value from 4 identical scintillation counters is used to determine the number of particles entering the bubble chamber window.

The ratio of counts/number of particles is determined by the H.T. setting on the photomultipliers and is best verified by the number of tracks observed on the film test strip just before the run.

For beam tuning with high flux there is an interest to keep the peak intensity for a given flux in the center of the dynamic range of the ADC for all detectors. It is therefore foreseen to add the high tension as an additional parameter into the on-line system and automatically regulate it.

The quality of the adjustment of the extracted proton beam with respect to the secondary target is measured in principle by integrating the charge deposited in the target by the external proton beam. This information is sent from the PS control room to the beam users in the form of a pulse train which can be scaled separately for 1st and 2nd bubble chamber expansion. It is used as an (unfortunately rather poor) intensity monitor for the secondary beam leaving the target.

3.6 Wire chambers

The introduction of multiwire proportional chambers saves considerable time in beam tuning and monitoring, as compared with previously used step-by-step scanning using a scintillation finger counter [7,8]. As a typical example of wire chamber application, the following describes the method used to find a directly inaccessible focus inside an RF cavity (Fig. 10). A collimator placed near the target selected an appropriate pencil ray of + 3 mR and two beam profiles were measured on two wire chambers placed symmetrically at each end of the cavity. The procedure was then repeated with a symmetrical - 3mR pencil ray and two more profiles were determined. Fig. 10 shows how the actual focus position was located. The focus was then moved to the desired position in the cavity center by changing the current in the appropriate quadrupole.

The "standard" multiwire proportional chambers cannot be used under fast ejection conditions. There might be as much as 10^4 particles per wire during 10 ns spill time and the only way how to use those chambers is to work in the truly proportional mode and perform the pulse-height analysis of signals from each wire [8]. Extreme care must be taken during the fabrication of the chambers to keep very small all mechanical tolerances in parallelism, wire stretching etc.,

in order to achieve practically identical response from all wires. The gas amplification factor must be kept well below space charge saturation limit ("magic gas" is excluded). It was found that for reliable proportional operation of the wire chambers using 20 μ diameter signal wires (gold-plated tungsten) the minimum wire spacing is 2 mm. Two identical wire chambers were therefore stacked together and displaced by 1 mm so as to give 1 mm apparent channel width. 64 channels were sufficient for our purpose, but a larger (about $10 \times 10 \text{ cm}^2$) chamber was necessary to achieve acceptable uniformity in the middle part (end effects). Fig. 11 shows the essential construction details. The H.T. planes were formed by 100 μ diameter gold-plated molybdenum wires, stretched with 1 mm spacing perpendicular to the signal wires. The interelectrode spacing is 8.0 mm. No guard strips were used but the discharge path was increased by a recess machined out from the Vetronite frames. The frames were glued together by Araldite resin and closed by 125 μ thick Mylar windows. Four times sixteen amplifiers were mounted directly on the chambers. The gas used, a pre-mixed argon + 5% propane, was allowed to flow slowly through at atmospheric pressure.

Fig. 12 shows a complete chamber with 4 amplifier cards and 64 output coaxial miniature cables, mounted on a support which may be rotated by 90° to work either in horizontal or vertical plane. Precision axial and radial bearings eliminate almost entirely any backlash, the rotation is done by a pneumatic piston. Using fast ejection there is no possibility to count particles by coincidence techniques by employing two chambers with crossed wires. Anyhow, the tuning is always done separately in horizontal and vertical planes.

For mounting the chambers at the RF cavities, additional conditions must be fulfilled. Namely, the chambers should operate inside the vacuum beam pipe and should be removed from the beam after tuning. Otherwise, even the rather thin Mylar windows will spoil considerably the separation. An outline of the adopted solution to this problem is shown in Fig. 13. The chamber and its rotating support

are fixed inside a vacuum-tight box having two thin Mylar windows on the beam axis. The inner box can be moved up and down (in the beam/out of the beam), sliding on precision bearings by another pneumatic piston mounted on the outer box. The assembly is enclosed in this outer, vacuum-tight, box to which the flanges of the beam vacuum pipe are fixed. The inner box communicates with the atmosphere through a "chimney" closed by vacuum bellows. This chimney serves also for passing the cables, compressed air and gas for the chamber. Such a system must obviously be very reliable since the chambers are inaccessible during the beam operation.

At present, 8 chambers are used in the U5 beam, the first six of them inside the described vacuum boxes. The system is organized as shown on Fig. 14. Each chamber is connected to the 64 coaxial cable bus and to the indication and control bus cables via selection boxes. For each chamber there is a H.T. power supply, controls for which are situated in the beam control room. From there it is possible to select the desired chamber and move it (horizontal/vertical; in/out) as desired. The analogue signals are fed into a set of 64 parallel analogue-to-digital convertors in the control room. This configuration has been found to be the least expensive and most suitable for this application. The digital pulse train from these ADC's are counted in 64 4-decade BCD scalers and the measured beam profiles displayed on a scope or read by the on-line computer.

The detailed circuit diagram of the analogue electronics is shown on Fig. 15. Each signal wire of each chamber has its own two stage amplifier with voltage gain close to unity. The negative pulse from the wire is integrated at the high input impedance and transmitted along the 200 m 50 Ω coaxial cables to the control room. The selection of any one of the chambers is simply done by applying the supply voltage to the appropriate set of 64 amplifiers, leaving the other amplifiers switched off. The signal breakthrough from unexcited amplifiers is negligible.

The ADC's work on the ramp comparison principle. The master control unit is triggered by a fast ejection pre-pulse which starts a train of 10 MHz clock pulses (max 256) to all 64 scalers. At the same time the ramp generator starts feeding all 64 comparators. When the wire signal is equal to the ramp voltage on any one of the comparators the clock pulses to this channel are stopped. After the 256th pulse the ramp generator is reset and a new cycle begins. The numbers stored in the scalers are proportional to the ionization loss in the chamber. The convertor system has a dynamic range of $256:1 \pm 1$ L.S.B. The non-linearity is typically $\pm 1\%$, the conversion time is $25.6 \mu\text{s}$. Fig. 16 shows (left) a NIM module containing comparators for a group of 8 channels and (right) the master DAC unit. In the foreground there are cards with 16 signal amplifiers.

Clearly, a certain equalization of signal outputs from the individual wires is necessary. Otherwise, the measured profiles will be considerably distorted with respect to the real beam profiles, the differences from wire to wire being typically $\pm 20\%$ before the equalization.

The equalization procedure was as follows: Each chamber was mounted on a precision X/Y movable support, one Fe^{55} collimated source was fixed above and another one below the chamber so as to be able to work on both halves simultaneously. The support was then moved in 1 mm steps in order to irradiate one signal wire after the other. The 5.9 keV peak of the Fe^{55} spectrum was registered on a pulse height analyser and necessary corrections were made by varying the gain of the chamber amplifiers. In a few successive approximations all outputs were easily equalized to within tolerable limits of less than $\pm 5\%$.

Fig. 17 shows a typical set of characteristics of these chambers with 2 mm spacing using argon + 5% propane gas filling, and the described ADC. The digital output is plotted against the H.T. setting with particle flux as a parameter. The chamber and the analogue

electronics handles a dynamic range from 1 (1 particle = 1 output count) to 256 particles per wire per burst at 1800 ÷ 1900 V, and from 256 (256 particles = 1 output count) up to about 5×10^4 particles per wire per burst at 1000 V (limit of proportionality). The ADC saturation limit of 256 counts corresponds to 1 V output level, the maximum proportional gas amplification factor being roughly 5×10^4 . The breakdown limit is safely at least 500 V above the low flux operational point. A typical ionization loss distribution for 2 mm wire spacing and 16 mm thick chamber has more than 100% FWHM for a single relativistic particle. For one to one relation between number of particles and output counts there will be a considerable loss of single particle events in low flux parts of the beam, falling below the electronics threshold. Under those conditions it is preferable to increase the H.T. so as to have two, three or even four counts per particle. From Fig. 15 it is also quite clear, that it might be rather difficult to distinguish between one or two particles due to the overlap of the ionization distributions.

Fig. 18 shows a few beam profiles as measured by the chambers and displayed on Tektronix 611 storage display scope, using a wired-in histogram plotting routine. There are 64 channels (bins), each of them representing 1mm in space. Channel 32 (labelled by a more densely dotted line) is aligned on the beam axis. On Fig. 18a there is a typical profile of the focused beam in some particular spot. The steps in each channel represent the increments counted per many successive bursts. Fig. 18b shows a vertical profile of RF deflected particles taken in front of the beam stopper. Fig. 18c is a superposition of deflected and undeflected particle profiles. Fig. 18d shows an example of a display of a few different profiles (horizontal or vertical) with different scale factors.

Finally, Fig. 18e and f show an interesting effect of a profile distortion due to an inherent feature of the MWPC principle of operation. There is a rather sharp profile centered on a few wires only. The big negative signal on these wires induces a signal of opposite polarity of about 20% its amplitude onto the adjacent wires.

Since this signal subtracts from the true signal on adjacent wires, the resultant signal can fall to zero or even reverse polarity, producing zero counts in one or several channels whereas normally there would certainly be some. It results in a measured profile narrower than the true one, with the possibility of discontinuity in the tails. There is unfortunately no cure for this effect which means that these chambers cannot be used, for instance, for the separation curve in electrostatically separated beams where the small wanted particle peak will be completely covered by artificial bumps created by the huge unwanted particles peak on the side. Some profiles presented on Fig. 18 show also a small systematic difference between odd and even channels, due to the already mentioned difficulties in the equalization procedure of the two halves of each chamber.

4. BEAM CONTROL MULTIPLEX

It follows from the preceding paragraphs that the principal constraints for determination of the structure of the on-line beam control system were :

- the necessity to incorporate already existing manual controls into the on-line system, instead of developing an entirely new set of controls;
- the shared use of a small computer heavily charged with bubble chamber control work with its inherent dangers of mutual interferences;
- the need of full reliability of operation (fault-proof data links etc., working in heavy noise environment);
- maximum redundancy in the system (manual access always possible in case of computer breakdown);
- large allowances for future extensions.

By contrast, speed is not a problem in our case because counting rates are integrated over each burst and the over 2 second repetition

rate of the accelerator is our time limiting factor. So data links can be slow, and elements can be moved sequentially, no simultaneous access being needed.

Fig. 19 shows the general block diagram of the complete system. All the input and output multiplexing was concentrated in a new central control box and only slightly modified old manual controls were connected to it, where existing. Passive filters or relays were added into cable terminals where noise problems were foreseen.

All connections are made in parallel form between the central control box and the scalers, as well as the local control boxes for collimators, beam stopper, RF separators and wire chambers. The digital electronics of the wire chamber system was actually built into the beam multiplex, together with histogram plotting display hardware. Additional code conversion and comparators were provided for devices using the above described position encoders.

4.1 Data link to the PDP-9 computer

The connection to the PDP-9 computer is done via 18-bit parallel data links (one for input, another for output). For a given distance of about 70 m of cable length it is still a reasonable solution, which allows for easy "echo" method of transmission verification without critical timing problems.

Fig. 20 shows the bloc diagram of the data link structure. Separate parallel links of 18 bit twisted pairs with differential line receivers and drivers were used for input and output. Reliability of operation rather than transmission speed was considered important. Ordinary parity checks are not quite efficient under heavy electrical background conditions, because the probability that the parity bit will suffer from the same background is rather high. Transmission verification by sending the data back to the computer was used instead. One 18-bit word is first put into the accumulator, sent accross to the multiplex and strobed

there into a principal buffer register. The strobing is done by issuing an appropriate Input/Output Transfer (IOT) instruction, which produces a CHECK IOT pulse.

To be sure that the strobe was indeed this particular instruction and not a noise pulse and that the instruction was not lost during the transmission, the following measures were taken: The instruction is sent via twisted pairs in a 6 bit code with 5 bits changing status with respect to the quiescent state. Simultaneously, a flag is set and the decoded pulse is sent back in true and complementary form via 2 twisted pairs to reset this flag. The re-setting of the flag is checked by the computer before continuation. The correct instruction CHECK sets a flip-flop which in turn opens appropriate multiplex gates and sends the complement of the original word back to the computer for verification. Only if everything was found to be in order, is the first word shifted into one of the "working" registers by a further IOT instruction.

The six combinations of the redundant code used for transmission of the instructions are

<u>Quiescent state</u>	<u>000 111</u>
CHECK	011 000
OUTPUT	101 000
RELEASE	110 000
CLEAR FLAGS	111 001
(Spare)	111 010
(Spare)	111 100

The OUTPUT IOT instruction is used for strobing bits 6 to 17 of the verified content of the principal buffer register into one out of six "working" registers (Fig. 21). The bits 0, 1 and 2 of the principal register are decoded and used as register address for OUTPUT instruction distribution.

The first 12 bit register contains in bits 6 to 9 binary coded actions, namely:

- MOVE 1	- CHANGE POLARITY
- MOVE 2	- COUNT
- MOVE (1+2)	- STOP COUNTING
- TURN HORIZONTAL	- RESET SCALERS
- TURN VERTICAL	- SELECT AND READ
- IN THE BEAM	- (Spare)
- OUT OF THE BEAM	- (Spare)
	- (Spare)

Up to fifteen different actions are possible for each multiplexed device.

The next 4 bits of the first register contain the selection address for up to 12 possible devices which could be incorporated in the on-line system; (COLLIMATORS, BEAM STOPPER, RF SEPARATORS etc.) Bits 14 to 17 contain addresses for sub-selection of 1 to 15 secondary elements within each selected device.

The action and sub-selection are decoded and sent (gated by appropriate device selection) separately to different controls via output multiplex.

Registers 3 and 4 each contain 3 decades BCD-coded preselected values 1 and 2 respectively, for devices like collimators etc. Single word devices like currents use preselected value 1 only, plus additional 4th BCD decade from register 2. There are some exceptions concerning sign: For devices using position encoders in range ± 49.9 mm the signs replace the most significant bits of preselections 1 and 2.

The register 5 contains in bits 16 to 17 a return address used in the procedure of reading the data into the computer for selecting either word (value) 1, 2 or flags. During the transmission verification procedure this selection is vetoed.

Fig. 22 shows the timing diagram of one typical SEND cycle. Prior to generation of the IOT CHECK the data to be sent are put onto the External I/O bus lines. The CHECK IOT sets a flag and triggers a one-shot with 4 μ s pulse width. During this time interval the CHECK instruction should arrive to the beam multiplex, strobe the data into the buffer, return and reset the flag, which is verified by another IOT, READ RETURN FLAG. The data link hardware transmission delay is approximately 1 μ s one way.

When strobing-in the buffer, another one-shot is triggered, which after 6 μ s opens CHECK gates and enables the way for the OUTPUT instruction. 1 μ s afterwards the contents of the buffer register is ready at the External I/O bus lines. After small software delay the data are read into the computer twice by repeated INPUT instruction (IOT 2(OO)) and compared. The comparison of sent and received data follows and if no error is detected, IOT OUTPUT is issued and the correct data are transferred into one of the registers 1 to 5. After instruction transmission check the system is reset into the original state and a new cycle can start. The cycle length is strongly dependent on the chosen program sequence and on the number of interrupting higher priority routines. The minimum length is about 75 μ sec, which corresponds to a transmission rate of about 1.3×10^4 18-bit words/s or about 2.4×10^5 bits/s. The upper limit for occurrence of errors was tested out to be about 1 in 10^8 transmissions. When the computer has finished its task, it relinquishes control with the RELEASE instruction.

4.2 Data link to the Siemens 301 computer

As stated above, the monitoring and control of the generators for the East Experimental Area is undertaken by a SIEMENS 301. This computer is used locally for data logging, alarm recording, etc. [9]. It has the facility to increase and decrease the current in each generator under program control. A parallel data link has been constructed to gain access to this computer from the beam control room. Current values are read in the beam control room by requesting

the Siemens computer to read a shunt voltage via an ADC and then sending the digital value. This method avoids the noise problems of an analogue transmission with separate ADC (digital voltmeter) at the beam control room and avoids also the disadvantage of having two ADC's giving different readings.

Commands to the Siemens computer (read, move, change polarity) are sent in coded form together with the required device/sub-device (magnet or quadrupole number) and the preselected value of current required. For safety the three commands are also sent on separate lines to three "alarm entry" ports of the computer. After the requested action has taken place and the generator is stabilized, an END OF ACTION signal is returned to signal completion. Commands can be given manually or from the PDP-9.

An older system using a separate A/D converter has in fact been kept as a stand-by in case of breakdown, but is practically no longer used.

4.3 Multiplexing

Fig. 23 gives a general idea of the input multiplex circuitry for each of 18 bits. The first 8 devices (selection 1 to 8) have 2-word data inputs and the devices 9 to 11 have single word inputs. The selection 12 is accessible for the computer only and serves for fast reading of the request panel.

The values coming from the position encoders are converted and compared with the desired preselected values in hardware comparators. The BCD data then goes to the line drivers and across to the computer via gates selecting WORD 1, 2; FLAGS (choice via return address register) or CHECK.

Fig. 24 shows an example of separate and mutually exclusive manual/computer access to the selection address part of the register 1. The push-button signal from the central manual selection is decoded (after pulse-shaping) from 1 out of 11 into pure binary code;

the appropriate 4 flip-flops are first cleared and after inserting sufficient delay for elimination of the contact bouncing the selection address is strobed in through the preset inputs. After decoding the flip-flop outputs, the information is used for indication and for distribution of actions and preselections to the selected device via the output gate multiplexer. The selection can be reset by a special button. There is a fixed hierarchy incorporated in the central manual control : any selection will reset both sub-selection and actions, any sub-selection will reset (= stop) the actions. This organization is necessary to avoid the possibility of making erroneous manipulations which could have catastrophic consequences. The computer access to the selection is provided independently via D-inputs and clock strobing of the flip-flops.

It is clearly beyond the scope of this report to go into all details of such a complex system, so we will concentrate on the operational aspects as outlined below.

4.4 Central manual access panel

Fig. 25 and 26 show the concentrated display and control elements of the on-line system. In the top part of the panel there is the main power switch and power indications. Below that follows a line of status indications : COMPUTER FAULT; COMPUTER/MANUAL CONTROL (the multiplex could be either in "no control" quiescent state or under computer or manual control, the latter being established by manual selection), indication "RESET DEVICE, PLEASE", which flashes when the computer cannot gain access to the multiplex due to established manual control. The MANUAL CONTROL button, when pressed, locks out the computer access continuously.

Next come two groups of Nixie indicators: for word 1 and 2 including signs, with thumbwheel switches below for preselection of values 1 and 2. Three rear-projection indicators illuminate additional information concerning the meaning and range of the corresponding display as each device is selected. e.g. POSITION JAW 1 $\pm$ XX.X mm, SCALER CONTENT etc. The indicator in the middle projects HORIZ./VERT.

position of the wire chambers, IN/OUT, LIMIT REACHED, device on LOCAL CONTROL, ERROR messages, etc. The next group contains the selection of devices 1 to 11 with RESET button and EMERGENCY STOP button, which might be used to stop any action started even under computer control and which always forces manual access. Pressing this button during computer control causes an automatic priority interrupt on the PDP-9 and sets a special flag to identify itself. There are also buttons 1 to 15 for sub-selection and finally there are actions: MOVE I, II, I + II, TURN H/V, IN/OUT, CHANGE POLARITY, COUNT, STOP COUNT, RESET SCALERS. The set of those 12 manually accessible instructions could be extended if needed.

The next part contains a Tektronix type 611 storage display with the larger dimension of the screen horizontally oriented. To the right there is an additional Nixie display of the preselected and already counted PS cycles for the wire chambers. As already mentioned, for wire chambers and scalers which might accumulate events for rather long intervals of time, it was considered necessary to liberate blocked access to the other devices. An additional buffer was provided which, on issuing the COUNT instruction, locks in the selected wire chamber number (sub-selection), its position (H/V), manually or computer-controlled operation (M/C) and preselected number of PS bursts. It is now possible to choose another device whilst continuing to count on the wire chamber. Incorrect operations are blocked - e.g. it is impossible to select another wire chamber without previously resetting the scalers (otherwise, two different profiles would be added together) and the counting started manually (by computer) could be interrupted only by manual (computer) action. In case of a program crash when under computer control, the manual access could be restored by an "accidental-touch protected" button. If the counting is stopped either by reaching the preselected number of PS bursts or by scaler overflow, the END OF COUNTING light above the WIRE CHAMBER selection button will start flashing and, under computer control, this will be signalled to the PDP-9.

The 611 scope controls for ERASE and VIEW were connected externally via appropriate inhibiting gates for computer control. The PLOT button starts an automatic histogram plotting routine (see below) for wire chamber profiles. RANGE SELECTION buttons change the display sensitivity over three orders of magnitude. The ERASE, PLEASE indication is set flashing when the computer-generated display of some automatic scanning routine result is finished and the program needs a confirmation that the result was accepted.

The AUTOMATIC SCAN panel is used to input requests and data to the computer. A set of thumbwheel switches is used for fast error-free introduction of numerical values, it is supplemented by a set of 6 FUNCTION buttons. Pressing the REQUEST button causes an automatic priority interrupt and sets the AUTOSCAN flag for identification. Read-in of all information is in 7 words. The use of the read-in information is to a large extent self-explanatory from the labels and will be discussed in detail together with the software.

The Fig. 26 shows at the top another panel called STANDARD DEVICE TEST BOX. It contains all indications of selection, sub-selection and actions for a given device, together with indication of data present on both preselection 1 and 2 bus cables. This box could be connected to the multiplex in place of any device, for testing purpose. The position, current etc. values can be introduced by a corresponding set of switches together with other information like multiplexed device flags (DEVICE ON MANUAL, LIMITS, ERROR) or direct flags (e.g. MANUAL, COUNTING etc.).

4.5 Display

The hardware structure for the display was developed as an integral part of the wire chamber system for visualisation of the beam profiles; the main reason for a local hardware approach was the restriction caused by the heavy workload on the computer with its stringent real-time fast response requirements. This excluded staying in a closed program loop for point-by-point plotting as well as the use of a priority interrupt after each point.

The hardware fixed format histogram plotting (see Fig. 27) works as follows: In the quiescent state the writing beam of the 611 storage scope is deflected to the lower left corner of the screen. When the PLOT instruction is issued, the wire chamber scaler read-out receives the address of the first scaler and its content is compared with the previous scaler content (zero at the beginning of the histogram). A 3 decade BCD up/down scaler is advanced by clock pulses and a vertical line formed by overlapping points is written until the value of the wire scaler content is reached. The range selection can select 3 combinations of 4 wire chamber scaler decades to be connected to a 3 decade BCD-to-binary convertor, followed by a 10-bit DAC in the vertical deflection chain. The full vertical deflection can be chosen to represent 10^2 , 10^3 or 10^4 counts respectively.

Conserving the vertical position, a horizontal line segment is then written by advancing an X address binary scaler by 16 clock pulses. After that, the next wire chamber scaler content is taken for a new Y value and so on. The resolution is 1024 points in X, corresponding to about 3.3 mm bin size for each of 64 wire chamber scalars. The vertical resolution (10 bit DAC) was kept equal for further use of a character generator. A display overflow line is generated at 760 vertical points. Each 8th wire chamber scaler address is labelled in the middle by a vertical dotted line. The histogram bin 32 which corresponds to the beam axis, is labelled by a double density dotted line. The writing of zero content channels is inhibited to prevent burning the screen on this line. To complete a typical histogram, on the average about 100 ÷ 200 ms are necessary. The limiting factor here is essentially the 20 μ s long pulse needed for writing each point and the rather slow response of the scope deflection system.

The above described histogram plotting sequence is accessible to the computer through the WRITE STEP instruction. This instruction together with the next Y value causes one whole step of the histogram to be written starting from the last value of Y, thereby greatly reducing computer interaction.

Nevertheless, the computer has an access to the display on the point-by-point plotting basis by sending X and Y coordinates and a WRITE POINT instruction. There is also an open possibility to add a hardware character generator.

5. REALIZATION OF HARDWARE

A very small part of the PDP-9 interface was made using standard DEC cards. For the rest of the data link and multiplex a different card format and "termi-point" wiring technique were used. All interconnections were made by flat cables (see Fig. 28). Some standard cards developed previously in another CERN division [10] were utilized. Necessary special cards (parts of the display hardware, wire chamber scalers and read-out etc.) were developed in the TC Beam Group. The multiplex with corresponding part of the data link circuits contains some 270 cards, mounted not very densely in two standard closed racks.

Fig. 29 shows the general layout of the beam control room elements. From left to right there are the RF separators controls, then the controls for the collimators and wire chamber selection; follows a rack containing the beam stopper control and H.T. power supplies for the scintillation counters. Next comes flash trigger and target monitor circuitry with bubble chamber frame and roll number indications and H.T. power supplies for the wire chambers. The fifth rack contains scalers and printer for the scintillation counters and the data acquisition analogue electronics for the wire chambers. The next two racks are the beam multiplex with built-in 64 scalers and read-out circuits for the wire chamber system. In racks 8 and 9 the emergency controls for currents are placed, and the last two racks are for the electrostatic separator controls (not included in the on-line system).

6. LOCAL INTERFACE

Besides the central control system, a group of scalers are locally connected to the PDP-9 computer via a digital input system (Fig. 19) to gather data from the BCl counter in front of the bubble chamber for flux measurements, to read the target monitor, etc. They are fed by pulse trains from fan-outs in the beam control room, data from 1st and 2nd pulses in double pulsing being read sequentially into the same scaler. Read-in is activated by a priority interrupt request (input separate from the multiplex and on a higher level for fast response) which is triggered after each ejection either via a delayed fast ejection prepulse or with the help of the last pulse in the target monitor pulse train. The latter method proved useful in cancelling the difficulties caused by the varying arrival time of the target monitor information. Scalers are always reset after each ejection by the following fast ejection prepulse, the read-in cycle being short enough to allow for two cycles in double pulsing. In this way data accumulation over a given number of pulses as well as separation between 1st and 2nd pulse can be done inside the computer via software.

To this should be added information on the roll, frame and expansion number as well as the date, which are passed on via memory transfers from bubble chamber control programs, which in their turn read the needed values from separate interfaces.

7. PRIORITY INTERRUPTS

There are two separate priority interrupt entries, one connected with the read-in of the local interface and activated by each P.S. burst, the other connected (on a lower level than the former) with the central multiplex. The origin of interrupts from the latter is tested with the help of the FLAGS word which is read in when an interrupt occurs. The following occurrences on this interrupt line are implemented:

- autoscan panel REQUEST button pressed;
- end of computer-initiated action;

- EMERGENCY STOP pressed during computer-initiated action;
- end of computer-initiated count on wire chamber;
- end of computer-initiated count on multiplexed scaler.

This set-up economizes on the number of interrupt ports necessary at the computer level. The somewhat longer latency time is no drawback, since it is strongly reduced by the possibility of stacking requests via the monitor (see below).

8. SOFTWARE CORE ORGANIZATION

The software consists of a set of routines which are called at different stages of the tuning and monitoring of the beam. It would be beyond the scope of this report to give a detailed description and users guide of the whole program system. Instead we will try to give an outline of its possibilities and concentrate on some points of interest in the general approach to the problem.

The system of programs runs under the Background/Foreground Monitor [11] and has 2.5k of core memory in the foreground at its disposal, the rest of core being taken up by the monitor itself with its associated resident device handlers, the overall control system of the bubble chamber and background programming. The restricted core space has necessitated the installation of an overlay scheme operating from DECTape.

Since all resident programs are loaded at start-up time in relocatable binary format with the loader doing the linking, this poses some problems for the positioning of the overlays. For the beam, we have decided on using the CHAIN [12] program to produce absolute, non-relocatable resident code and overlays. To reserve a fixed space for these at start-up time the simple trick is used of loading a large empty program, REGION, as the first good-sized relocatable program in the loading chain. Since the loader finds insufficient space left in memory bank zero, it invariably positions it at the same starting location at the head of memory bank 1.

Under this condition non-relocatable overlays can be produced to fit into specific parts of REGION, into which they are called on request. To allow for contact with relocatable subroutines outside of REGION a table of globalized variables is appended to REGION, which is linked by the loader to the outside programs and whose absolute positions in core are known, thereby allowing calls from within REGION.

The resident code and the overlays are loaded into REGION via a strongly modified version of the program EXEC [12] which has been rewritten in subroutine form and is loaded by the linking loader at start-up time. EXEC loads the resident code and the beam overlay KEYBOARD LISTENER into core on first being entered. The latter is the master overlay to which the subsystem always returns when no command remains to be processed. The subroutine form of EXEC has been chosen since it was not wished to give this routine executional power over any but the routines contained in REGION, thereby keeping the perturbations to the rest of the system to a minimum. This containment has also lead to error handling for DECTapes read errors etc. in the form that all errors induce a return to the KEYBOARD LISTENER and not, as is usually the case, an abort and return to the Monitor. This same return is also used - after having stopped all input/output - in case of an EMERGENCY STOP pressed by a beam operator.

Calls for overlays are buffered, so that one program can call another to overlay itself. In fact, with this buffering aid we have restricted ourselves to one overlay space, into which all our non-resident code is overlaid.

To sum up, we have introduced into the Background/Foreground monitor a simple one partition multitasking scheme, which allows for flexible overlaying while leaving the rest of the B/F programming system intact.

9. RESIDENT CODE

The main parts of the resident code are the interrupt handler and the input/output handler for the multiplex. For the interrupt handling full use is made of the powerful multilevel software priority level handler of the B/F Monitor. Effectively, all interrupts lead to the request of a subroutine (inside REGION) via the desired level handler. Since the use of the interrupts and the corresponding entry routines vary with the active overlay, all external interrupts in the quiescent state lead to the request of a DUMMY subroutine. The overlay itself replaces the DUMMY entry by its own entry to its interrupt subroutine before use. It is again detached after each interrupt for security.

In par. 4.1 we have described the hardware echoing facility that is employed for transmission security. For efficient use this has lead to a centralization of all multiplex input/output into core resident INPUT, OUTPUT and PULSE routines. Input is read twice and compared, output is sent, echoed and compared, all pulses are checked for correct pulse echo. In case of error found this procedure is repeated three times before giving up and returning to the KEYBOARD LISTENER. This leads to a very safe transmission which is fast enough for our purpose.

10. OVERLAYS

The overlays available include programs for :

- scanning beam profiles via collimator, magnet, etc.
- change-of-focus calculations;
- phase scans (RF separators);
- logging of beam parameters and alarms;
- printouts of wire chamber profiles;
- flux distribution histograms at the bubble chamber;

The overlays consist of series of small subroutines chained together via requests to the software level handlers. Very often

this chaining is via an intermediate interrupt in the form that an action - e.g. a READ or a MOVE, is given after having attached to the interrupt a subroutine to be entered after completion; control is then given up. Only after the action has ended is the interrupt activated together with a flag to signify its origin, e.g. end of action. The attached subroutine now initiates the next action, and so on.

Initialization of an overlay sequence is via the KEYBOARD LISTENER, which announces itself via an "OVERLAY REQUEST" and waits for response via the keyboard (only first three letters are relevant). For all requests expecting numerical entries this will be the AUTOSCAN routine which reads in the Autoscan request panel on pressing the REQUEST button, does the necessary data transformations and then calls in the overlay to commence the requested job as chosen by the FUNCTION button. The following scans and movements have been implemented.

10.1 Scan

Scan a beam profile using a defined beam element and the parameters affixed on the panel. As seen in Fig. 25 the parameters entered are the DEVICE/SUB-DEVICE number to be scanned from a LOWER LIMIT to an UPPER LIMIT in a given size of STEPS for a chosen number of PS BURSTS per step. Value 1, 2, or both can be scanned and for collimators an OPENING of jaws (slit width) can be added. Counting is on BC1 counter. It is foreseen to add later the choice of DEVICE/SUB-DEVICE on which to count. (CODE and AUXILIARY INFORMATION are not used in this context but provide an entry of additional information where needed).

At each step the result is displayed on the scope with automatic rescaling of the whole plot if a value becomes too large. At the end of scanning scaled printouts are given. Fig. 30 and 31 show examples for a collimator slit and magnet scan followed by two beam stopper scans with different thicknesses (Fig. 32). As seen, all relevant data from the switches is repeated for logging purposes together with the results. It should be stressed here that one of

the advantages of the central multiplexing scheme lies in the possibility of using one and the same program sequence for such a wide variety of scans.

10.2 Focus

Any focus, identified by DEVICE/SUB-DEVICE, can be moved by a requested distance via the stored focusing coefficients by setting the required switches (Fig. 33). Rheostats in parallel are accounted for in reading, but they cannot be moved by computer.

10.3 Phase scan

The phase of the RF separators is varied according to the chosen parameters. The image of the unwanted particles is observed at the wire chamber in front of the beam stopper. Three wires symmetric to the maximum are monitored and the ratio maximum/mean of side wires is rescaled and plotted at every step (Fig. 34a). At the end of scanning a printout (Fig. 34b) is given on the teletype.

Added to these active sequences a series of overlays to record various parameters has been implemented, which are called via the LISTENER.

10.4 Wire chamber printout

This overlay gives a copy on paper of the profiles produced by manual manipulation of the various wire chambers (Fig. 35). Included is the possibility to eliminate non-interesting parts of the displayed profile from the printout.

10.5 Loggings

The logging of beam parameters is grouped as shown in Fig. 36. The whole set or parts can be requested at any time or a total logging produced at regular intervals. This logging includes the "Phase trio" ratio for fixed phase as described under phase scan. It gives a check value for the phase stability.

10.6 Flux density histograms

Flux density distribution histograms of the flux in front of the bubble chamber are given either automatically, starting at photo 300 of each roll of film, or on request. In double pulsing mode the pulses are handled separately. See Fig. 37 for the details. Totals and averages are given as well as the distribution of numbers of particles counted per pulse which, together, give a good indication of the efficiency of the beam in filling the chamber with a reasonable number of incoming tracks. Special commands to clear, abort or print the data augment the programs versatility.

10.7 Monitoring

A continuous sequence of total logging as seen in Fig. 36 and 37 followed for each roll of film by a histogram automatically starting at photo 300 can be achieved by chaining these overlays to one another via a command to the LISTENER. This cyclic chaining produces a convenient long-time monitor with no operator intervention necessary.

11. CONCLUSIONS

The above described beam on-line system has worked satisfactorily with high reliability over extended periods of time. The beam-tuning time losses have been considerably reduced, the work of the beam operators has been made easier and more efficient. Further development of the software system is in progress, aiming at more complex and more automated beam tuning and monitoring procedures.

Due to limited computer memory space and increasing danger of interference between bubble chamber and beam programs (both of them undertaking extensive development), the present shared computer system will gradually become difficult to operate. It is already foreseen to connect the beam multiplexer to a separate computer (second-hand PDP-9) in the near future.

A similar computer system has been recently put into operation for the RF separated beam for the Big European Bubble Chamber (BEBC) in the West Experimental Hall. A distributed multiplexer is connected to an 8K PDP-8/e computer which has a data link to a large PDP-15 in the BEBC control system. More details will be given in a separate report.

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Fig. 1 General layout of the bubble chamber beams in the East Hall.

Fig. 3 Simplified drawing of a magnetic collimator.

Fig. 4 Magnetic collimator on support, controls and selection bo

Fig. 5 4-decade position shaft encoder.

Fig. 6 Non-ambiguous code used for position encoding.

Fig. 7 Collimator system and controls.

Fig. 8 Principle of selection, multiplexing and preselection.

Fig. 9 Simplified drawing of the beam stopper.

Fig. 10 Example of a pencil ray method for focusing.

Fig. 11 Construction details of proportional wire chambers.

Fig. 12 Wire chamber assembly on rotating support.

Fig. 13 Mounting of the wire chambers under vacuum.

Fig. 14 Proportional wire chamber system, multiplexing and controls.

M W P C SYSTEM ANALOGUE ELECTRONICS

Fig. 15 Analogue electronic circuits for proportional wire chambers.

Fig. 17 Characteristics of proportional wire chamber of 2mm wire spacing, argon + 5% propane, 1 atm.

Fig. 18 a

Fig. 18 b

Fig. 18 a,b,c,d. Some examples of RF separated beam profiles.
e,f. Profile distortion due to a positive induced signal
on adjacent wires.

Fig. 18 c

Fig. 18 d

Fig. 18 e

Fig. 18 f

Fig. 19 Bloc diagram of the beam on-line system.

Fig. 20 Principle of the data link transmission ("echo").

Fig. 21 Buffer register configuration.

Fig. 22 Typical transmission timing diagram.

Fig. 23 Input multiplexing, simplified diagram for 1 bit.

Fig. 24 Example of manual and computer access to the buffer registers.

Fig. 25 Central manual access panel.

Fig. 26 Central manual access panel.

Fig. 27 Bloc diagram of the display hardware.

Fig. 28 Part of the multiplex cards.

OVERLAY REQ.:AUTOSCAN OF COLLIMATOR 3
SCAN OF DEVICE/SUBDEV 01 /03 /FROM/TO/IN STEPS OF/-16.0 16.0 2.0
PS BURSTS/OPENING/10 6.0

	05	10	15	20	25	30	35	40	45	50	55	60
	/	/	/	/	/	/	/	/	/	/	/	/
00												
01	X											
02	X											
03	XX											
04	X											
05	XX											
06	XXX											
07	XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#X											
08	←XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX											
09	XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX											
10	XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX											
11	XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX											
12	XXXX#XXXX#XXXX											
13	XXXX											
14	XX											
15	X											
16	X											

HITS PER X:62

Fig. 30 Collimator scan printout.

OVERLAY REQ.:AUTOSCAN OF MAGNET 3
SCAN OF DEVICE/SUBDEV 10 /03 /FROM/TO/IN STEPS OF/120.0 146.0 2.0
PS BURSTS/OPENING/15 0.6

	05	10	15	20	25	30	35	40	45	50	55	60
	/	/	/	/	/	/	/	/	/	/	/	/
00												
01												
02												
03												
04	X											
05	XX											
06	XXX											
07	XXXX#XXXX#XXXX#XXXX#XXXX											
08	XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX											
09	XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX											
10	XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX											
11	XXXX#XXXX#XXXX											
12	X											
13												

HITS PER X:63

Fig. 31 Magnet scan printout.

```

OVERLAY REQ.:AUTO BS WIDTH 27MM
SCAN OF DEVICE/SUBDEV 03 /01 /FROM/TO/IN STEPS OF/-5.0 9.0 2.0
PS BURSTS/OPENING:10 1.0

      05    10    15    20    25    30    35    40    45    50    55    60
      /      /      /      /      /      /      /      /      /      /      /

00 XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#X
01 XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#
02 XXXX#XXXX#XXX
03 XXXX#XXXX#X
04 XXXX#XXXX#X
05 XXXX#XXXX#XXXX
06 XXXX#XXXX#XXXX#XXXX#
07 XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#

```

HITS PER X:08

```

OVERLAY REQ:AUTO BS WIDTH 19MM
SCAN OF DEVICE/SUBDEV 03 /01 /FROM/TO/IN STEPS OF/-5.0 9.0 2.0
PS BURSTS/OPENING:10 1.0

      05    10    15    20    25    30    35    40    45    50    55    60
      /      /      /      /      /      /      /      /      /      /      /

00 XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXX
01 XXXX#XXXX#XXXX#XXXX#XXX
02 XXXX#XX
03 XXXX
04 XXX
05 XXXX#XX
06 XXXX#XXXX#XXXX#X
07 XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#

```

HITS PER X:64

Fig. 32 Beam stopper scan for 2 thicknesses.

```

OVERLAY REQ:AUTO
FOCUS AT B.ST. MOVED BY 0.6 METERS TOWARD CHAMBER
06 : OLD VALUE 150.4 NEW VALUE 150.1
07 : OLD VALUE 141.5 NEW VALUE 140.6

OVERLAY REQ.:AUTO
FOCUS AT C9 H MOVED BY 2.5 METERS TOWARD TARGET
14 : OLD VALUE 155.3 NEW VALUE 161.7
15 : OLD VALUE 113.3 NEW VALUE 121.1 MOVE ERROR!
      MOVE RHEOSTAT:21.9 → 24.3

```

Fig. 33 Focus calculation.

Fig. 34(a)

OVERLAY REQ.:AUTOSCAN OF PHASE
 SCAN OF DEVICE/SUBDEV 04/02 /FROM/TO/IN STEPS OF/161.0 175.0 1.0
 PS BURSTS/OPENING:10 0.6

	05	10	15	20	25	30	35	40	45	50	55	60
	/	/	/	/	/	/	/	/	/	/	/	/
00	XXXX#											
01	XXXX#XX											
02	XXXX#X											
03	XXXX#XXXX#XXXX#XXXX#											
04	XXXX#XXXX#XXXX#XXXX#XXXX#											
05	XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#											
06	XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XX											
07	XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX											
08	XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XX											
09	XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX											
10	XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX#XXXX											
11	XXXX#XXXX#XXXX#											
12	XXXX#XXX											
13	XXXX#XX											
14	XXXX#											

HITS PER X:10

Fig. 34(b)

Fig. 34 Display of phase scan (a) and printout (b).

OVERLAY REQ.:WIRE RF2 9MW DEFLECTION ONLY

WIRE CHAMBER: Ø7 VERT. IN-BEAM 1Ø BURSTS

	Ø5	1Ø	15	2Ø	25	3Ø	35	4Ø	45	5Ø	55	6Ø
	/	/	/	/	/	/	/	/	/	/	/	/


```

Ø9 *
1Ø
11
12
13 :::*
14 ::::::::::::::::::::::::::::::*
15 ::::::::::::::::::::::::::::::::::*
16 ::::::::::::::::::::::::::::::::::*
17 ::::::::::::::::::::::::::::::::::*
18 ::::::::::::::::::::::::::::::::::*
19 ::::::::::::::::::::::::::::::::::*
2Ø ::::::::::::::::::::::::::::::*
21 ::::::::::::::::::::::::::::::*
22 ::::::::::::::::::::::*
23 ::::::::::::::*
24 ::::::::::*
25 ::::::*
26 ::::*
27 ::*
28 ::*
29 ::*
3Ø ::*
31 ::*
32 ::*
33 ::*
34 ::*
35 ::*
36 ::*
37 ::*
38 ::*
39 ::*
4Ø ::*
41 ::*
42 ::*
43 :::*
44 *
45
46
47
48
49
SCALE FACTOR:Ø5

```

Fig. 35 Wire chamber printout.

"PHASE TRIO"

WIRE# 27 30 33 CNTS: 126 662 86 RATIO: 6.25

MAGNETS (SHUNT VALUE, DRIFT IN MV)

Ø1 :	114.8	Ø.Ø
Ø2 :	114.8	Ø.Ø
Ø3 :	139.Ø	Ø.Ø
Ø4 :	95.Ø	Ø.1
Ø5 :	26Ø.Ø	Ø.Ø

QUADRUPOLES (SHUNT VALUE, DRIFT IN MV)

Ø1 :	119.1	Ø.Ø
Ø2 :	7.5	Ø.Ø
Ø3 :	83.1	-Ø.1
Ø4 :	11Ø.1	Ø.Ø
Ø5 :	85.6	-Ø.1
Ø6 :	15Ø.3	Ø.Ø
Ø7 :	14Ø.8	Ø.Ø
Ø8 :	15Ø.5	-Ø.1
Ø9 :	198.7	Ø.Ø
1Ø :	172.3	-Ø.1
11 :	172.8	Ø.Ø
12 :	15Ø.4	Ø.1
13 :	161.Ø	-Ø.1
14 :	137.9	Ø.4 *←
15 :	39.4	Ø.1

COLLIMATORS (LEFT OR TOP JAW, RIGHT OR BOTTOM JAW IN MM)

Ø1 :	4Ø.Ø	-4Ø.Ø
Ø2 :	4Ø.Ø	-4Ø.Ø
Ø3 :	4.6	Ø.4
Ø4 :	1.5	-1.5
Ø5 :	7.5	-7.5
Ø6 :	28.Ø	-28.Ø
Ø7 :	2.5	-2.5
Ø8 :	25.Ø	-25.Ø
Ø9 :	15.Ø	-15.Ø

BEAMSTOPPER (PLATE NUMBER, POSITION IN MM)

Ø1 :	Ø.6	-3.Ø	IN-BEAM
------	-----	------	---------

SEPARATORS (POWER IN MEGAWATT, PHASE IN DEGREES)

Ø1 :	12.4	Ø.Ø	IN-BEAM
Ø2 :	11.3	17Ø.Ø	IN-BEAM
Ø3 :	Ø.Ø	Ø.Ø	OUT-BEAM

Fig. 36 Automatic logging.

HISTOGRAM BC1, ROLL/PHOTO: 205 /300 TO/ 205 /1346

EXPANSION NO. 1 -X-
 TOTALS:PULSES/FLASHES/PARTICLES/EJECT FAILS/
 1250 1011 18572 00
 AVERAGES:FLUX/-ON FOTOS/TARG.MON./HST OVERFLOWS/
 14 12 504 03

EXPANSION NO. 2 -*
 TOTALS PULSES/FLASHES/PARTICLES/EJECT FAILS/
 1247 1174 10340 03
 AVERAGES:FLUX/-ON FOTOS/TARG.MON./HST OVERFLOWS/
 08 08 336 03

EXPANSION NO. 1&2 -#-
 TOTALS:PULSES/FLASHES/PARTICLES/EJECT FAILS/
 2497 2185 28912 03
 AVERAGES:FLUX/-ON FOTOS/TARG.MON./HST OVERFLOWS/
 11 10 424 06

VAR: FRQ:
 00 44 X *
 01 30 *
 02 86 XX *
 03 73 XXXX *
 04 109 XXXXXXXX *
 05 120 XXXXXXXXXXXX *
 06 130 XXXXXXXXXXXXXXXX *
 07 142 XXXXXXXXXXXXXXXXXXXX *
 08 147 XXXXXXXXXXXXXXXXXXXXXXXX *
 09 115 XXXXXXXXXXXXXXXXXXXXXXXX *
 10 157 XXXXXXXXXXXXXXXXXXXXXXXXXXXX *
 11 155 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX *
 12 170 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX *
 13 150 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX *
 14 142 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX *
 15 120 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX *
 16 98 XXXXXXXX*XXXXXXXXXXXXXXXXXXXXXXXXXXXXX *
 17 94 XXXXX*XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX *
 18 74 XXXXX*XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX *
 19 69 XXXX*XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX *
 20 58 XXX*XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX *
 21 43 X*XXXXXXXXXXXXXXXXXXXXXXXXXXXXX *
 22 39 *XXXXXXXXXXXXXXXXXXXXX *
 23 26 XXXXXXXXXXXXX *
 24 25 XXXXXXXXXXXXX *
 25 18 *XXXXXX *
 26 17 *XXXXXX *
 27 13 X*XX *
 28 03 X *
 29 05 XX *
 30 00 *
 31 02 X *
 32 04 XX *
 33 01 *
 34 02 X *
 35 01 *
 36 02 *
 37 03 X *
 38 02 X *
 39 02 X *
 SCALE: 02 20/11/72; 23 26

Fig. 37 Flux density distribution at the bubble chamber entry.