INS-NUMA-33

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April , 1982

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ABSTRACT

The computer network in TARN is composed of a central main frame computer, two different minicomputers and several microprocessors. It has been used for the beam control and the beam diagnosis; support for adjustment of elements of the transport line and the ring, generation of RF voltage function, measurement of beam profile at RF stacking, on-line measurement of ν-value, and observation of Schottky signal. By the use of this computer system, the operation of TARN has been effectively and steadily performed, and additionally it has contributed to measuring the beam characteristics precisely in the ring.

1. Introduction

In 1976, a study group of NUMATRON started the work on high energy heavy ion accelerator at the Institute for Nuclear Study, University of Tokyo. NUMATRON is proposed as an accelerator complex, which accelerates heavy ions such as uranium up to several hundreds MeV per nucleon. For the purpose of verifying the feasibility of such a heavy ion accelerator, a small storage ring called TARN (Test Accumulation Ring for the NUMATRON project) has been constructed. The main subject of TARN has been

1) beam injection and RF stacking,
2) ultra-high vacuum system,
3) beam monitoring and handling technique with relatively low intensity.

The application of computers to the accelerator control has been also one of the most important subjects to be studied at TARN, because computer control is inevitable for such a complex machine as NUMATRON.

Two minicomputers (HP-1000 system and PANAFACOM U400 with 64 k words real memory respectively) are introduced into TARN. Due to hardware limitation of various power supplies for TARN, the surveilance and control of the TARN are mainly performed manually at present and the computer system is used actively for supplying parameter patterns to equipments and beam diagnosis.

In the present paper, the computer system and its application to beam control and diagnosis for TARN are described in Sections 2 and 3, respectively. Contribution of the computer system to the TARN control and the beam diagnosis is summarized in Section 4.

2. Computer System

Due to limited time for machine construction, the surveilance and control of the TARN were decided to be mainly due to manual operation at the start. In parallel with the construction of the TARN, however, study of computer control system in the TARN has been put forward to study the feasibility of accelerator control by a computer system. The TARN computer network has been developed and it now consists of two minicomputer systems (HP-1000 and PANAFACOM U400), the central computer (FACOM M180 II AD) and several microcomputers, as shown in Fig. 1. The capabilities of two minicomputer systems are listed up in Table 1. The network is constructed so that each of computer systems of three different ranks may organically perform its own full capability and may use other computer resources. On the network, task access is designed to be able only both at the TARN operation console shown in Fig. 2, and at the graphics terminal of HP-1000, after IPL of each computer.

Main frame computer M180 II AD is used for calculations which need large memory size or use its utility libralies. Among two minicomputers, U400 is used as a real time processor and HP-1000 is used for demand processing. Microprocessors are distributed locally to perform a single job of accelerator control or data acquisition for beam diagnosis.

2-1. Computer Network

As described above, the computer network is composed of the central main frame computer and two minicomputers together with microprocessors. The advantage of making such a network is effective utilization of other computer's resources such as I/O devices, interfaces and graphics display terminals etc., and organic utilization of the network without operation anywhere except for at either of two task access operation points, the TARN operation console and the graphics terminal.

To make such a network, PANAFACOM U400 is connected with M180 II AD by a MODEM with the effective transfer speed of 1500 BPS. The linkage between HP-1000 and U400 is realized through a microcircuit 12566B of HP-1000, which is 16 bit I/O parallel interface, and digital devices (DI-AA, and DO-AC of PANAFACOM ICU) of U400. The transfer of commands (or task numbers) or data between these minicomputers is executed synchronously by a handshake mode. The rate of the transfer is effectively 320 words/sec. Local microprocessor TK-80 (NEC) is linked to a microcircuit of HP-1000 through its programmable peripheral interface Intel 8255.

2-2. Interfacing with Equipments

The interfacing with external equipments is made though CAMAC system on U400 side, except modules in PANAFACOM ICU (Interface Circuit Unit) used for the data logging of accelerator parameters. By the use of CAMAC, the control and measurement system can be easily constructed and operated. Further, it can be easily expanded with parallel branch highways and serial highways. At present, the CAMAC system consists of two crates, one of which is linked to U400 via a branch highway and controlled by a type A-1 crate controller, and the other is controlled by a type L-2 crate controller driven by a serial driver in the former crate. In near future, the latter is to move adjacent to the TARN ring to reduce complexity of the cabling, as all cables from equipments and monitors are concentrated at the control room. This system enables the data acquisition from any modules anywhere at the interval of time shorter than 10 m sec. Further, the installation of an auxiliary crate controller with a microprocessor (ACCM) provides much faster data acquisition time as 10 μ sec.

HP-1000 system is connected to external devices via HP-IB line. The merit of adopting HP-IB is the fact that most of RF measurement and control devices and other instrument for high precision measurement include such interfaces in commertial base and the interface cable connection can be realized quite easily, though there are some demerits, the slowness of data acquisition and the complicatedness of the commands.

2-3. Graphics Display Terminal

As interactive input/output devices, two different kinds of graphics terminals are used. They are main man-machine interfaces between the operator and the TARN computer network.

The one is HP 2648 A which has a microprocessor, alphanumeric memory, and graphics memory together with a keyboard. Graphic data is stored as a dot pattern containing 259.200 points (720×360) in a graphics memory. In the CRT is used the raster scan deflection method, similar to that used in television sets. It carries out data transaction with a hostcomputer in ASCII characters and graphics characters. It is linked to HP-1000 with RS 232·C as an operator console. The other is a monitorscope HP 1317A coupled with a numerical keyboard. In this CRT is used the electrostatic forcus and deflection method with high writing speed. The control signal for coordinates (x,y) and brightness (z) are supplyed by U400 with PANAFACOM ICU monitorscope interface. Graphic data has to be stored in real memory area, and its size is 16 K words. Two-word memory is used to display a point on the CRT. Resolution of the CRT itself is 690 × 510, but now it is used by resolution of 100 × 100 because of the limitation of the memory area. The numerical keyboard is used as an input device interactive to the scope through ICU DI-AA.

In addition to the hardware difference between them, exists the software difference. For example, to draw a line on the CRT, a write statement (WRITE (1,100)···/ 100 FORMAT(···)) is used to send a command's character string to the terminal at HP-1000. However, a subroutine DSPLIN at U400 is executed to store the line information of both end points and internal dividing points into the real memory. It is desirable that the programming in both minicomputers is made in the same way. For the purpose, some common subroutines are developed.

2-4. Task Initiation System

The TARN computer network is based on task initiation system of

U400 shown in Fig. 3. On-line tasks of priority level 4 and 6 are to be initiated by the following three ways.

i) The operator selects a task number, whose task will be executed, among the menu of registered tasks displayed on the monitorscope, and enters it from the numerical keyboard at the TARN operation console. The task is initiated in the priority level 4 and result obtained by the task is displayed on the monitorscope. During this process, GETJOB makes the menu displayed and carries out task scheduling according to the task number which is taught by REQKEY which manages data input through the numerical keyboard.

ii) A task in HP-1000 initiated by the graphics terminal 2648 A transfers a given task number to CONNCT of the batch level of U400. CONNCT starts the corresponding task, which is executed in the same priority level 4 as that of the task initiated in the way i) to avoid competitive use of CPU with this task. The result obtained by the task is transferred back to HP-1000, and is displayed on the graphics terminal.

iii) Several request keys of the operation console are assigned to initiation of particular tasks for data logging of various parameter groups.

A task in HP-1000 system is started by giving a command through the keyboard of the console of the graphics terminal 2648 A. At present, task initiation from U400 is not adopted for HP-1000.

Under the control of the loader in ROM, the load module of a microprocessor is down-line-loaded from the host computer and initiated.

After completion of the module, the loader is ready for a next down-line-load.

2-5. Software Development System for Local Distributed Microcomputers

Microcomputers are distributed for the TARN local control systems. They have been introduced in order that each microcomputer performs a single allocated task to reduce a heavy load on minicomputers. Further, by such a system the task can be carried out free from troubles of minicomputers. They are single board type microcomputers which have no software development tool by themselves. The load modules are developed by software development system mentioned in the paragraph after next, and are down-line-loaded from the hostcomputers, as shown in Fig. 4.

A CAMAC auxiliary crate controller with a microcomputer (ACCM) is used for faster data acquisition with CAMAC modules, since the overhead of CAMAC I/O handler of U400 takes a considerabley long time. As the ACCM is used for wide purposes, every time new acqusition is to be performed, the load module is down-line-loaded.

We have two software development facilities. The one is a cross-assembler system supported by M180 II AD. Source programs in assembler languages of target microcomputers are developed by a TSS of M180 II AD with editor, and filed in user's individual disc. The cross-assembler compiles them and generates load modules in the disc with lists of compiled results. Grammatical mistakes of the sources are checked in this step. This assembler is also initiated from U400. Then, the load modules and the sources are transferred and stored in the disc files of U400. They are down-line-loaded to target microcomputers from U400, and, if needed, through HP-1000. In the case of modification, sources in the disc are updated by editor on the U400 side, and reassembly and reloading are carried out as above.

The other cross-assemble system which is equipped in U400 by our group is also used for Intel 8080 series. A source program for the target processor is made and editted with utility program EDIT. By the assembler, the load module is stored into a user's disc file, the resulting list being printed at the line printer. It is down-line-loaded to the target processor with the current of a given task of U400. Although the processor is not oriented for general application and has some restrictions in writing sources, this system is quite useful for our application because the development of sources and load modules is possible only with U400.

3. Beam Control and Measurement by the TARN Computer Network

The TARN computer network is used for various purposes. At first, it was used mainly for voltage pattern generation of RF and data logging of accelerator parameters. However, as the study of accelerator physics proceeds at TARN, more quantitative data are needed and fast data acquisition is required, which necessarily leads to utilization of a computer. Now almost all beam diagnoses are made with the use of the computer network.

3-1. Tuning of the Beam Transport Line

It is necessary to tune the beam ellipse at the inflector position so that it can match the injection system.[1] The transport system from the SF cyclotron to the TARN is designed to satisfy this condition.[2] But it is very difficult to know the beam ellipse at the exit of the cyclotron exactly, because it largely depends on the acceleration and extraction condition. So it is important to measure the shape of the ellipse experimentally at some point in the transport line, because once the shape is known at the position the shape of the beam ellipse can be traced to the injection position with transfer matrices.

The apparatus for the emittance measurement is located about 10 m upstream from the injection position of the TARN. The emittance monitor consists of multi-slits and a beam current detector of coaxial pin-probe type.[2] The detector is driven by an air cylinder which is controlled by relay circuits. CAMAC modules are used for the control of the relays and digitization of signals from the detector and a potentiometer for position measurement of the detector.

The measurement is initiated from the operator at the console display of HP-1000. Digitized data displayed on the CRT is shown in Fig. 5. The central slit is twice as wide as the other ones, and the operator can identify which of 15 slits the beam passes through.

Between the emittance monitor and the injection position of the TARN, there are eight elements (four quadrupole magnets, two bending ones, and two electrostatic inflectors). These elements are tuned with the aid of the central computer M180 II AD as follows. It is desirable that the beam ellipse in phase space is well matched to the spacing of the septa of the inlfectors. In order to realize this condition, the results of the emittance measurement and the logged data of the elements of the transport line are transferred with MODEM from U400 to M180 II AD. They are used as a boundary condition and as initial values in the calculation for parameter search, respectively. The transfer matrix from the emittance monitor to the injection position is known from these values and the geometrical values of the alignment of these elements.

The desirable parameters of the eights are searched by the above calculation with M180 II AD, and obtained results are sent back to HP-1000 through U400. The typical example is shown in Fig. 6.

3-2. Measurement of the Beam Orbit

TARN has eight straight sections which are named S1 to S8 along the beam stream from the beam injection section. For the first tuning of the injection orbit, single rod monitors[3)] located at S1, S3, and S6 are used under CPU control, as well as multi-wire profile monitors of manual operation at S2 and S8. They are used for the observation of the radial position of the single turn beam and the four-turn beam when ν-value is tuned to be 2.25.

The rod is made of a berrium copper of 3 mm in diameter. It is driven by an air cylinder in the radial direction. The stroke length is 20 cm or 14 cm, and the scan speed is set about 3 cm/second. A linear potentiometer is used for the position detection of the rod.

The maximum current induced on the rod is some nA on beam continuous injection. The output current from the rod is converted to voltage by a fast current amplifier (KEITHLEY 619) with the gain of 1.0 V / 1.0 nA. The setting time of the amplifier is 50 msec. This monitor is effective for observation of the profile of the continuously injected beam, because the rod is sufficiently strong against the irradiation of the beam. But, it is not sufficient for observation of the profile of the multiturn or stacked beam, as the beam induces too small current at the rod.

Next in order to tune the parameters on the multiturn injection, the signal of the electrostatic beam monitors at S 3 and S 6 are referred to on the oscilloscope. The survival of the beam for a long time over one second is confirmed by using the scintillation monitor at S 7.

The senser of the scintillation monitor is a plastic scintillator of 5 mm in diameter. It is aligned vertically, and moved radially by an air cylinder. It takes one second to carry out the scan of the stroke length 20 cm. The position detector is the same as that of the rod monitor. The scintillator is connected with a photomultiplier through a light guide made of glass. An integration amplifier is used to get a voltage signal. This monitor, which will be referred at Section 3-4, is efficient to measure the profile of a very weak current beam, especially the debunched multiturn beam and stacked beam.

The CPU control of the monitor system is able through the monitor-scope terminal with the numerical keyboard at the operation console. An example of the display on the CRT is shown in Fig.7a and b.

3-3. RF Voltage Pattern Generation

The RF stacking into the longitudinal phase space is performed by a repetitive stacking method.[1] The function generation of the RF voltage and the frequency sweep (correctly speaking df/dt) is carried out by the HP-1000 and TK-80 CPU network.

The RF stacking process is composed of a series of four processes;
1) a capture process where the beam with some momentum spread is captured with the bucket of the area as small as possible not to induce large momentum spread of the beam in deposit,
2) a transient process where the beam is carried to a next deceleration state with as little dropout of the bucket as possible,
3) a deceleration process where the beam is decelerated with the synchronous phase ϕ_s remained constant until the bottom of the stacked region,
4) a deposit process where the beam is brought and depostied at the top of the stacked region where the bucket height must have been reduced as small as possible not to bring about undesirable large momentum spread of the stacked beam.
By the repetitive stacking method, it is important to accomplish the high stacking efficiency and the high phase space density of the beam accumulation. A simulation of the RF stacking process where the injected beam is captured and deposited to the stack top is carried out with the central computer (M180 II AD) to find out the best functions of the RF voltage and frequency.[4]

The operator can provide a set of the programmed functions of different parameters with HP-1000, which can be assured to be truely the ones he wants with use of the graphics terminal HP 2648A. The programmed functions of the RF voltage are generated in consideration of the fact that the RF cavity has the frequency dependence, as shown in Fig.8.

The load module of TK-80 which outputs the programmed functions through DAC is down-line-loaded from HP-1000. By this module TK-80 shakes hands with HP-1000 for data handling and carries out the following jobs,

1) input the data of a set of the programmed normal functions from HP-1000,

2) input the data of a set of the programmed stretched functions, which hold the voltage of the RF fixed and do not sweep the frequency during a given time on the stacking's way,

3) choose one of the set of normal functions, and supply the data through DAC to the RF system,

4) choose one of the set of stretched functions, and supply the data through DAC to the RF system,

5) continue the job described in 3) or 4) locally, i.e., without a handshake with HP-1000.

The programmed functions are supplied to the RF system synchronously with the trigger pulse generated by the stack-wait controller. Two kinds of 8-bit data of the voltage and frequency sweep are output to the DAC's at intervals of about 50 μsec, which is necessary for instruction steps to perform such an output, during 25 msec.

Before this system, was used a pattern generation board which had 48 vertically movable linear potentiometers arranged horizontally.[5)]

A pattern of RF voltage was manually set with the potentiometers, and was output through an analog multiplexer at an interval of 500 μsec during 25 msec.

Improvements of the RF function generation using the new system are made as follows,

1) ten times increase of the number of data per pattern (10 times better time resolution),

2) easy generation of two functions of RF voltage and RF sweep (df/dt) in consideration of the frequency dependence of the cavity,

3) selection among programmed functions.

3-4. Measurement of the Beam Profile and the Stacking Efficiency by a Scintillation Monitor

The RF stacking experiment is carried out to analyse the dependences on the RF voltage and sweep functions, and the capture frequency in pursuit of the high stacking efficiency. A scintillation monitor is used to measure the radial beam profile.

Beam profile after only multiturn injection is shown in Fig.9a. It is known that the injection beam locates 2 cm outside from the central orbit. Beam profile is also studied after RF stacking in succession to multiturn injection, and the typical example is shown in Fig.9b. It should be noted that the stacked beam locates in the region from 1 cm to 6 cm innerside from the central orbit because of RF deceleration during the stacking process.

The integration of the output signal of the monitor can be considered to correspond to the intensity of the total circulating beam.

By this observation is also studied the stacking efficiency. The output signals obtained by the scans after multiturn injection and after various times RF stacking in succession to multiturn injection are shown in Fig.10. The relative intensity obtained by the integration is shown for stacking number in Fig.11. It is evident that the intensity of the stacked beam linearly increases with the stacking number up to 15 stackings.

3-5. Observation of Schottky Signal

As the preparatory work for the construction of a stochastic cooling system at the TARN, observation of Schottky signals is performed.

The level of the Schottky current is given as[6)]

$$i_{SC} = 2\,e\,f_0\sqrt{\frac{N}{2}} \ , \qquad (1)$$

where N is the number of ions with charge e circulating in the ring, and f_0 is the revolution frequency. The usual bunched beam current is written as

$$i_B = e\,f_0\,N \ . \qquad (2)$$

In the present case where N and f_0 are $\sim 10^8$ and $\sim$ 1.2 MHz, respectively, i_{SC} and i_B are calculated at $\sim$ 3 mA and $\sim$ 20 μA, respectively. The Schottky current is more than three orders smaller compared with the bunched beam current. While the currents are picked up through a delta-type electrostatic monitor,[7)] the thermal noise is induced at the input resistance of a preamplifier. The noise current, using a preamplifier with noise figure of ν dB, is given as

$$i_N = \sqrt{10^{\frac{\nu}{10}} k\, T\, B \,/\, R} \quad , \qquad (3)$$

where k, T, B and R represent Boltzmann constant (1.38×10^{-16} erg$\cdot$K^{-1}), temperature in Kelvin, bandwidth in Hz and input impedance in Ω of the observing system, respectively. The noise current is estimated at 0.7 mA for the present case where ν, T, B and R are 2.5 dB, 300°K, 3 kHz and 50 Ω, respectively.

The observation of these currents is performed by a spectrum analyser. In order to estimate the signal to noise ratio, it is necessary to study the coupling strength of the Schottky current with the electrostatic pick-up. From calibration by a pulse generator, the effective gain of the pick-up is ∿ 0.6 (Ω). Considering the gain of the preamplifier 50 dB, the voltage levels at the input of the spectrum analyser are estimated at 0.5 μV and 10 μV for Schottky signal and the thermal noise, respectively. The Schottky signal level is much lower than the noise level. The data from the spectrum analyser must be averaged to improve the S/N ratio by cancellation of the thermal noises with random phases. For this purpose, the spectrum analyser is used by the external mode, i.e., the voltage to sweep the frequency is applied from an external device and the output level of each channel is digitized by an external ADC, as is illustrated in Fig.12.

At first, the data acquisition was made by HP-IB devices through a serial data link terminal (HP 3070A) within HP-1000 system. The single scan of 200 channels takes 12 seconds, so it takes 500 times of this value to make 500 successive scans for averaging, which is not practical. This time is reduced to 125 seconds by making a single scan, in which 500 times averaging is applied to each channel. For the purpose of speedup, HP-IB devices are replaced by CAMAC modules under U400 except a frequency counter. In order to reduce the overhead due to CAMAC I/O handler, ACCM is used for the scan. The scan task is initiated at HP-1000 with the graphics terminal, which becomes an input/output device of the task. As the ACCM is used universely, the load module is down-line-loaded from U400 through the computer network. During the observation, U400 becomes a data transformer between HP-1000 and the ACCM. At last, the scan time for 500 times averaging is reduced to 8 seconds. New product instruments called FFT (Fast Fourier Transformer) are released, and have merits to be able to carry out the averaging of data in the time domain. But, the scan averaging speeds are much slower than that of the system above mentioned. Also a digital oscilloscope with the averaging function does not have such a high speed.

The longitudinal Schottky signal is observed by the averaging, as shown in Fig.13. The noise signal is also analysed without the beam on the same surrounding condition as that where the beam is circulating in the ring. The Schottky signal is found to be about 0.6 μV by subtracting the averaged data without the beam from that with the beam. The result is in quite good agreement with the estimation from the calibrated result above mentioned.

3-6. On-line Measurement of ν-value

The number of betatron oscillation per turn (ν-value) has been measured by an RF knock-out method.[8] Due to the development of a beam diagnostic system with a spectrum analyser linked to the computer system described in the previous section, it has become possible to measure the ν-value without disturbing the beam motion in TARN.

The output signal of a delta-type electrostatic pick-up is analysed by the spectrum analyser. The pick-up detects the dipole mode (S_D) together with the longitudinal mode (S_L) as

$$S = kI(x_0 + x_\beta) = S_L + S_D , \tag{4}$$

$$S_L = kIx_0 , \tag{5}$$

$$S_D = kIx_\beta , \tag{6}$$

where k, I, x_0 and x_β denote a constant gain, beam intensity, the radial position of the equilibrium orbit at the pick-up and beam displacement from the position due to betatron oscillation, as shown in Fig.14a, respectively. Here x_β and I of a single particle can be written as

$$x_\beta = \sqrt{\beta\varepsilon}\; e^{j(2\pi\nu f_0 t+\phi_0)} , \tag{7}$$

$$I = I_0 \sum_{n=-\infty}^{\infty} e^{j(2\pi n f_0 t+\phi_1)} , \tag{8}$$

where f_0 is the revolution frequency of the beam, and ϕ_0 and ϕ_1 are arbitrary phases. Substituting Eqs.(7) and (8) into Eqs.(5) and (6), the following equations are obtained,

$$S_L = kx_0 I_0 \sum_{n=-\infty}^{\infty} e^{j(2\pi n f_0 t + \phi_1)} \ , \qquad (9)$$

$$S_D = k\sqrt{\beta\varepsilon}\ I_0 [\sum_{n=0}^{\infty} e^{j[2\pi(n+\nu)f_0 t + \psi_0]} + \sum_{n=1}^{\infty} e^{j[2\pi(n-\nu)f_0 t + \psi_1]}] \ , \qquad (10)$$

where ψ_0 and ψ_1 are initial phases. These signals give spectral lines as are illustrated in Fig.14b. From the spacing, Δf, between the transverse and longitudinal modes, the fractional part of ν value, q, is given as

$$q = \frac{\Delta f}{f_0} \ . \qquad (11)$$

The typical example of the obtained spectrum is shown in Fig.15. From the result, the ν-value at the injection orbit is calculated at 2.245, which is in good agreement with the value 2.241 obtained by an RF Knock-out method.

3-7. Data Logging

It is important to record the operation parameters corresponding to various operating conditions in order to obtain objective view of the algorism of the operation of the accelerator. For this purpose, data logging is carried out both for elements of the beam transport line, the injection system, the ring and the RF system and for beam monitorings and measurements of experiments.

For the system data logging, the commercially available interface unit, ADC-BB of ICU, is used to measure voltages and currents. Analogue multiplexers with relay contacts driven by MPX-BC of ICU are also used. The frequency characteristics is below 26 Hz to avoid the line noise. The logging task is performed periodically on the second lowest priority level 6, the results being stored into a disc file. An on-line task is made to compare the present operation condition with the past one. The detailed description of the system logging is given elsewhere.[9]

When tasks are executed for beam monitorings or other measurements, all the raw digitized data are always recorded on a disc file. Some day the data are to be analysed in the way different from that of the on-line analysis, and used to study the correlation between the operation parameters and beam characteristics.

4. Summary

Contribution of the computer system to the TARN control and the beam diagnosis is summarized as follows.

At the first stage, the computer system was used only for system data logging. As the study of the beam characteristics proceeds at TARN, it has been necessary to use the computer system for beam diagnosis and RF function generation etc.

The computer network consists of two minicomputer systems, microprocessors and a main frame computer. Main interface with equipments is CAMAC and HP-IB. Interface between the operator and the network are two graphics display terminals. The one which is set at the TARN operation console is used mainly to support the adjustment of elements. The other is used for measurements and analyses of machine studies, and pattern procedures.

Introduction of the computer system to the RF function generation has enabled to reproduce the patterns quite correctly following the analytically calculated results. More quantitative comparison between numerical simulations and experimental measurement has become possible. This process increased the RF capture efficiency quite well (up to more than 80 %).

For stacked beam diagnosis, the computer system is used for the beam profile measurement by a scintillation monitor, and it integrates the output signal from the photomultiplier. It has become possible to evaluate the stacked beam intensity for various stacking numbers. A typical example of the beam profiles is shown in Fig.10. This procedure with the computer system has enabled the quantitative analysis of the stacking efficiency.

Further, the capability of fast data acquisition and data accumulation in the computer system has enabled to average the spectra obtained by a spectrum analyser, which is found to be quite powerful for cancelling out the random phase thermal noise. As is described in the previous sections, this function has contributed largely to Schottky signal observation and on-line measurement of ν-value by simultaneous observation of longitudinal and transverse modes. The on-line ν-measurement is very useful, because by this method, ν-value can be measured without disturbance of the beam, while the RF knock-out method is a destructive measurement of ν-value.

At TARN, the computer system is used for the beam diagnosis as well as the accelerator control. In fact, the algorism of the operation of the accelerator cannot be known without quantitative analysis of beam characteristics. The TARN computer system has reached the phase where the correlation between the operation parameters and beam characteristics is to be studied. Further study is needed for automatic feed back to the accelerator from the observation of beam characteristics.

Acknowledgment

The authors would like to thank Mr. K. Kamakura of FACOM HITAC LTD. for his suggestions in utilization of U400. They would like to express their thanks to Prof. J. Kokame and the members of computer center for their support during the work. They are also grateful to the members of the Numatron group for their everyday aid.

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Table 1. Capabilities of minicomputer systems

1. PANAFACOM U400 system

Size of register	16 bits
Memory	128 K byte
Disc (PF6081A)	20 M byte
MT (PF7026A)	1600 RPI
TW (F807A)	10 characters/sec
LP (F6041)	190 lines/min
MODEM	2400 BPS between M180 II AD
ICU	DI-AA : 16 bit × 8 ch
	DO-AC : 16 bit × 8 ch
	ADC-BB: 32 ch
	PLS-BB: 8 ch
	IRT-AA: 4 levels
CAMAC	Parallel branch highway driver

2. HP-1000 system

CPU (2631A)	with RTE-III
Size of register	16 bits
Memory	64 K word
Disc (7905A)	4.7 M byte
TW (2648A)	Graphics console
LP (2631A)	180 characters/sec
MT	Mini cartridge type
Application terminal (3070A)	for HP-IB
Microcircuit (12566B)	DI/DO : 16 bit × 3 ch

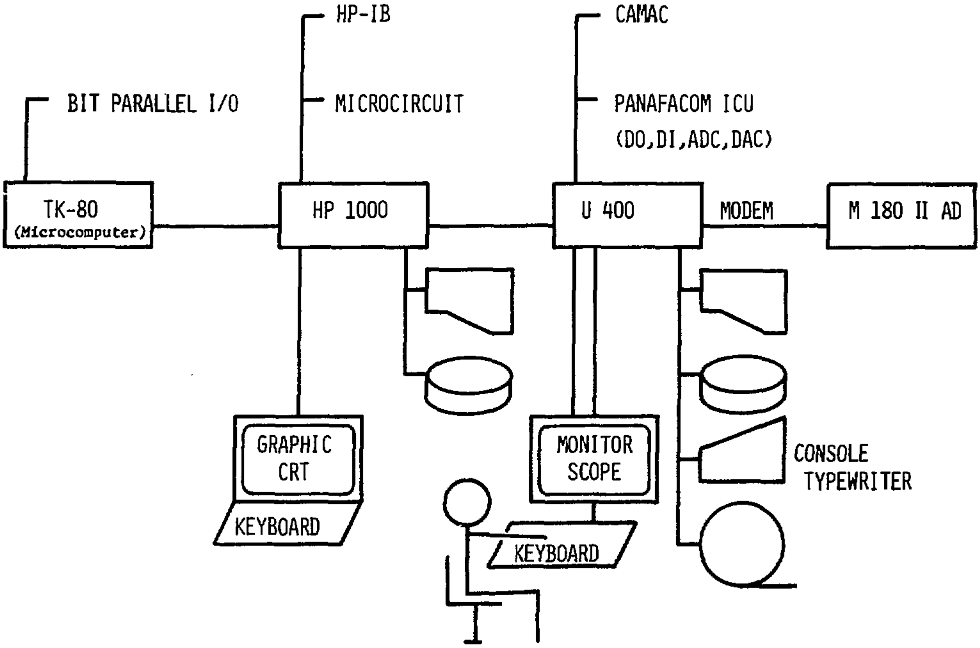


Fig. 1. TARN computer network.

Fig. 2. TARN operation console.

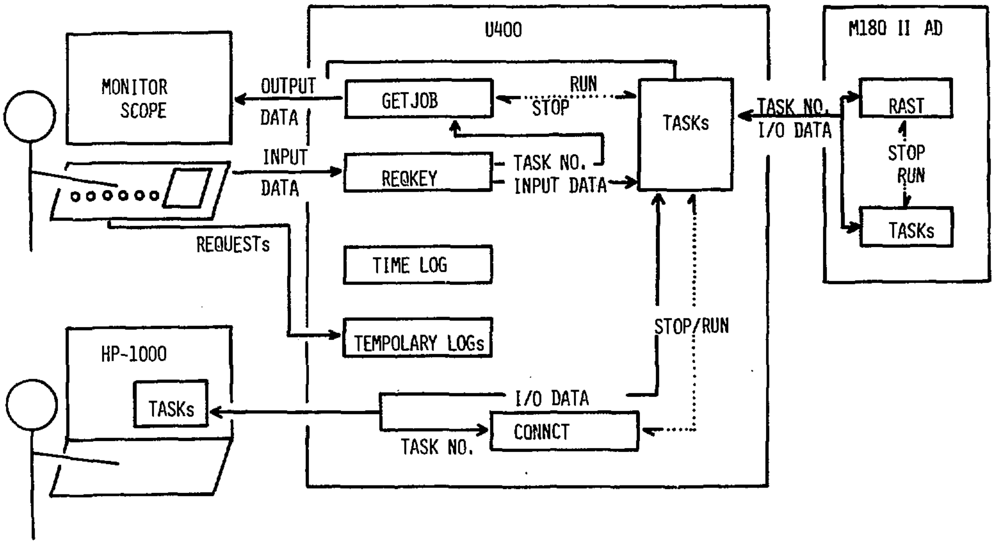


Fig. 3. Task initiation system.

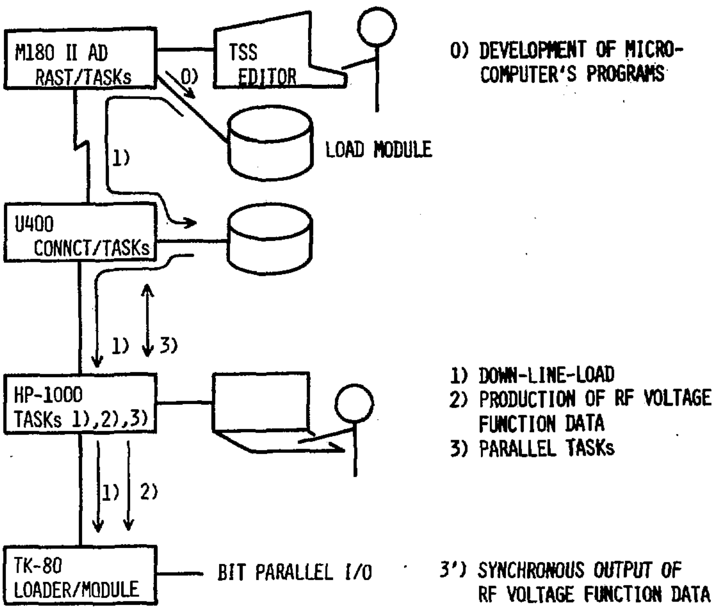
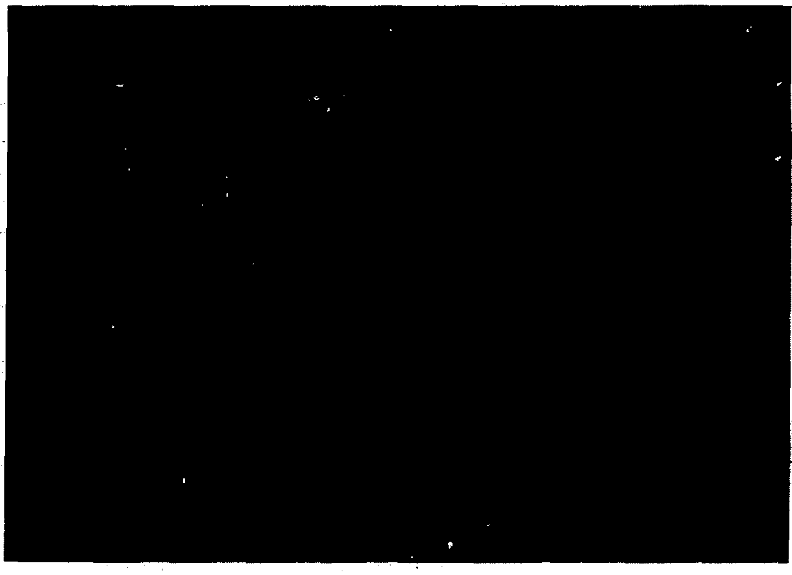


Fig. 4. Microcomputer's software development system with M180 II AD and task execution form HP-1000.



(a)

(b)

Fig. 5. Measurement of the emittance of the transport line.

(a) Digitized signal induced by tne beam through multi-slits.

(b) Three dimensional display of the emittance.

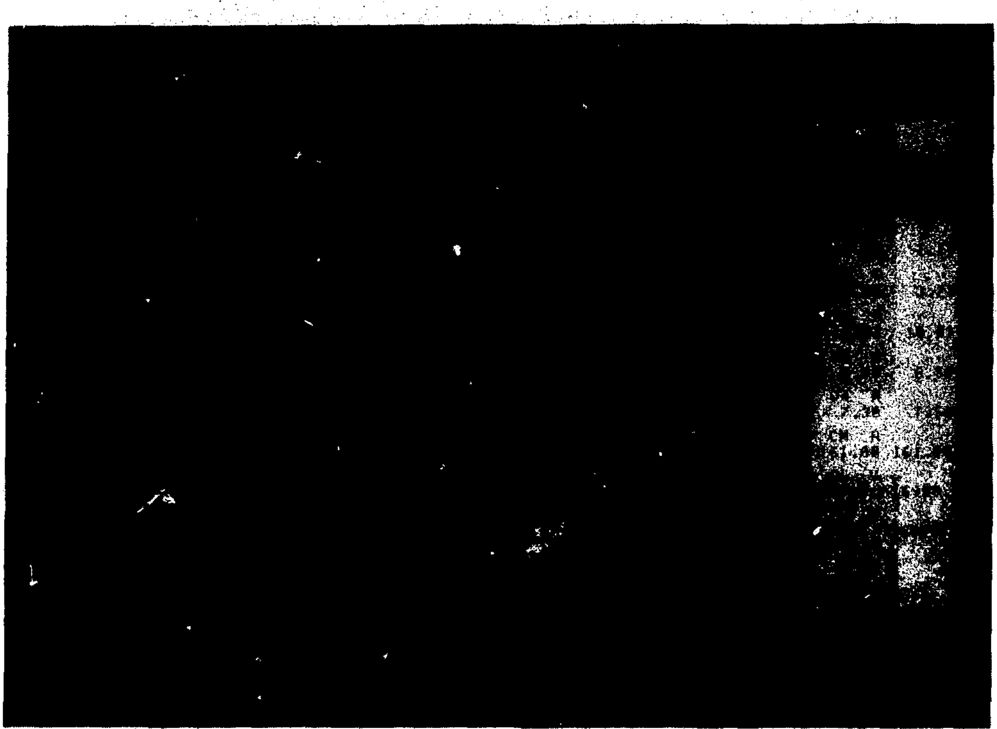
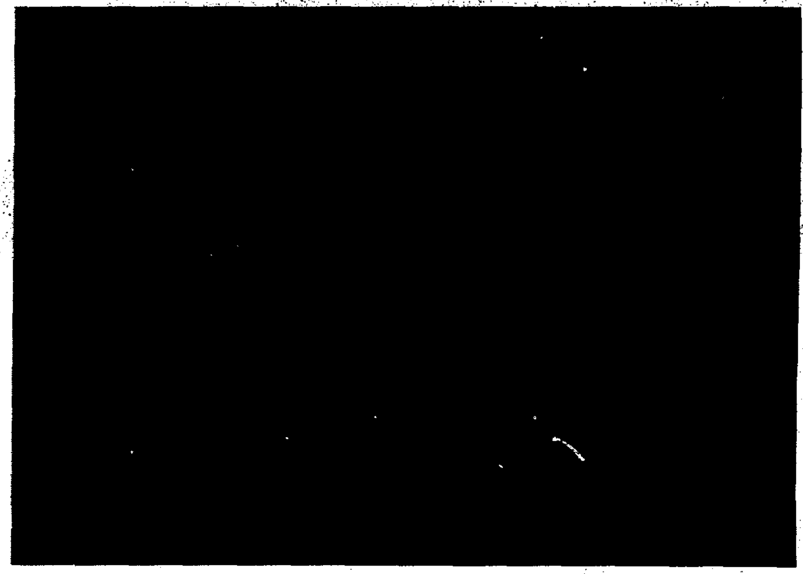


Fig. 6. Results of the calculation for the best parameter search. Calculated beam ellipses are displayed along the eight elements downstream of the emittance monitor (EM). Searched values of parameters are listed on the right side of the Table.

(a)



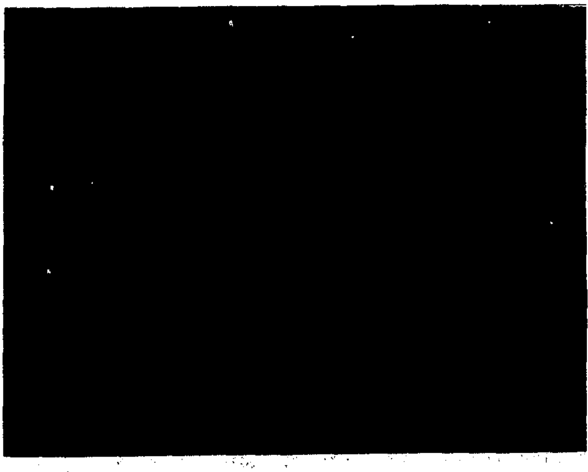
(b)

Fig. 7. Radial positions of the beam orbit measured by rod monitors. The central orbit locates at 10 cm.

(a) Single turn injection.

(b) Four-turn injection.

Fig. 8. Programmed RF voltage functions.
The voltage functions are generated with the frequency sweep ranges of 50 KHz steps from 0 KHz to 350 KHz.



(a)

(b)

Fig. 9. Beam profile measured by a scintillation monitor. The central orbit locates at 100 mm.
(a) Multiturn injection.
(b) RF stacking of 15 repetition times.

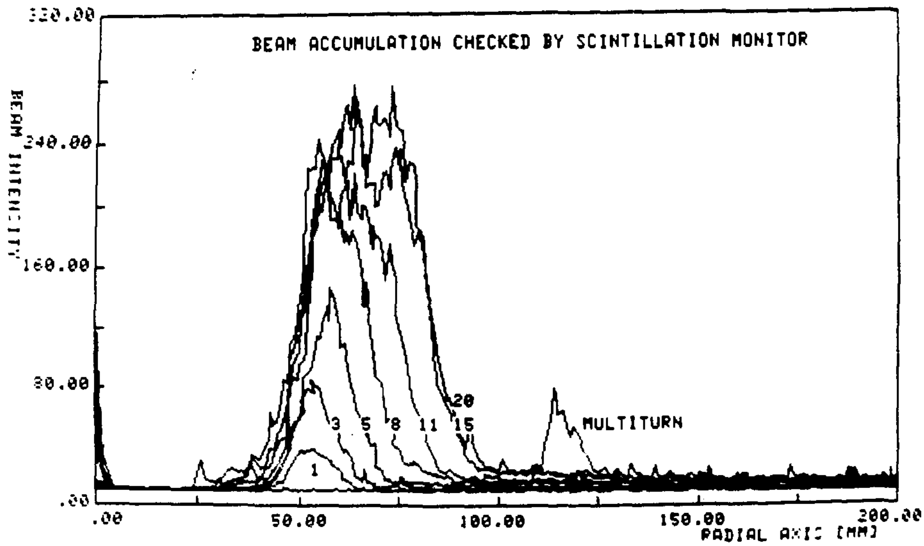


Fig. 10. Beam profile of the stacked beam.
The central orbit locates at 100 mm. The profiles are shown to be dependent on the repetition times of the RF stacking in succession to the multiturn injection.

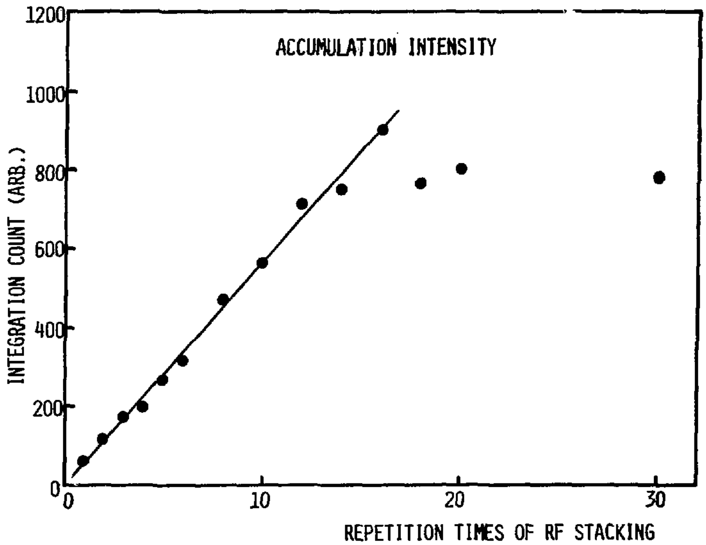


Fig. 11. Beam accumulation intensity versus the repetition times of RF stacking.

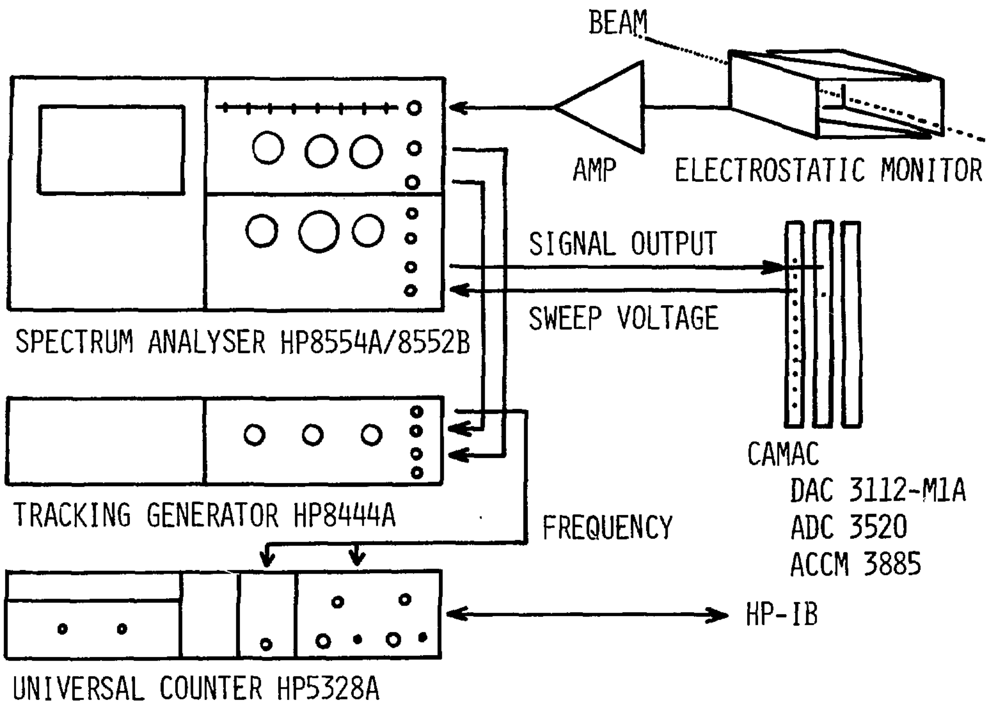
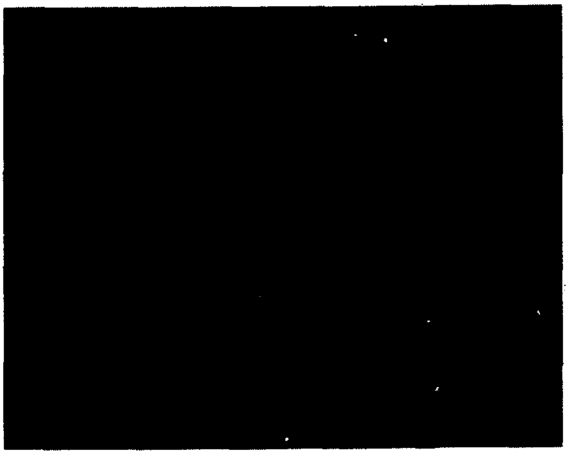


Fig. 12. Spectrum averaging system.

Vertical scale:
1 μV/div.
Horizontal scale:
250 KHz/div.
Averaging:
2500 times.
Band width:
3 KHz.

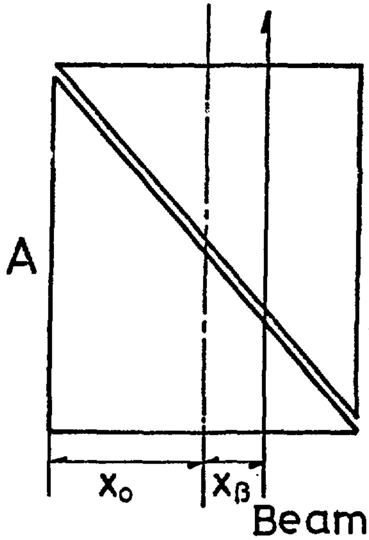
(a)



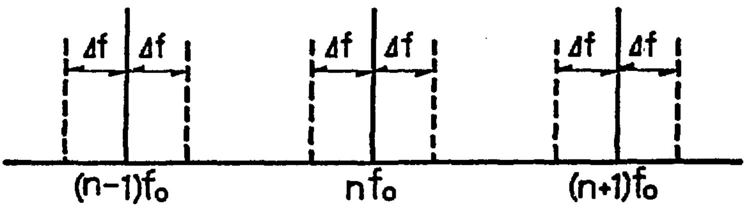
Vertical scale:
0.2 μV/div.

(b)

Fig. 13. Schottky signal observed at TARN.
The two longitudinal signals are for the harmonic numbers 72 and 73, respectively.
(a) The averaged signal with circulating beam.
(b) The results obtained by subtracting the averaged signal without the beam from that with the beam.



(a)

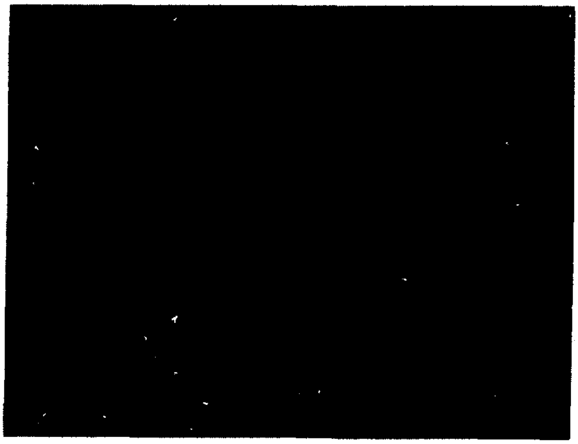


(b)

Fig. 14. Spectral signal induced by the batatron oscillating beam.

(a) The beam oscillating around the equilibrium orbit x_0 passes at the position x_β through the delta-type electrostatic pick-up.

(b) On the spectrum analyser a line for the longitudinal mode and two for the transverse mode can be seen in the interval of width f_0.



Vertical scale: Top -20 dBm,
Bottom -100 dBm.
Horizontal scale:
125 KHz/div.

Fig. 15. Observed spectrum of a longitudinal signal and two transverse signals.
The spacing Δf between the transverse and longitudinal signals is 278 KHz, while the frequency of the longitudinal s' '. is 32,882 KHz (harmonic number 29 .