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BEAM DIAGNOSTICS AND DATA ACQUISITION SYSTEM FOR ION BEAM TRANSPORT LINE USED IN APPLIED RESEARCH

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Introduction

Applied research in condensed matter physics using high-energy heavy ion beams has been in progress since the early eighties at the U-400 cyclotron of Laboratory of Nuclear Research in JINR, Dubna. Serial irradiations of polymer films just as metal and semiconductor samples of up to tens square centimeters area had required to develop special ion beam leading line with the appropriate beam parameter evaluation and control set-up. The first computer-controlled system which had been used in applied research on U-400 cyclotron is described in works [1-3]. The aim of this paper is to describe the main elements of beam leading line and the present status of the analogue signal and digital data treatment in the data acquisition system related to the beam diagnostics.

Ion irradiation facility

General scheme of ion beam leading line for applied research at U-400 cyclotron is given in the Fig. 1. The first experimental section presented in this figure (following the beam direction) was designed to investigate the Single Event Effect in semiconductor devices. This section includes a movable ion scattering foil holder (1), a surface-barrier semiconductor detector (2) and facility for irradiation of integral circuits in vacuum or in air (3). In the last case ions are extracted from vacuum through a stainless steel foil of 13.8 μm thickness. Ion flux on the tested targets can be up to 5×10^3 ions $cm^{-2}\,s^{-1}$. After the quadrupole duplet (4) and the deflection magnets (5) the ion beam intensity and spatial beam distribution are measured in the diagnostic section with a movable Faraday cup (6) and rotating wire detector (7).

The conditions of continuous control of intensity and particle beam distribution on an transport line used for applied research demand special beam detectors, which do not distort essentially the spatial distribution of the ion beam on the target. In the experimental practice usually wire detectors are used. These detectors are inconvenient for ions with energy ranging from 1 to 10 MeV/nucleon, because such detectors distort the beam which leads to some shading of the target. On the other hand, in the case of high intensity ion beams these monitors are unreliable because of the overheating and consequently the destruction of the wires. One more disadvantage is that the wire detectors require several preamplifiers (one for each wire) or multiplexed switching is to be used which also has difficulties when measuring small currents of the order of nA.

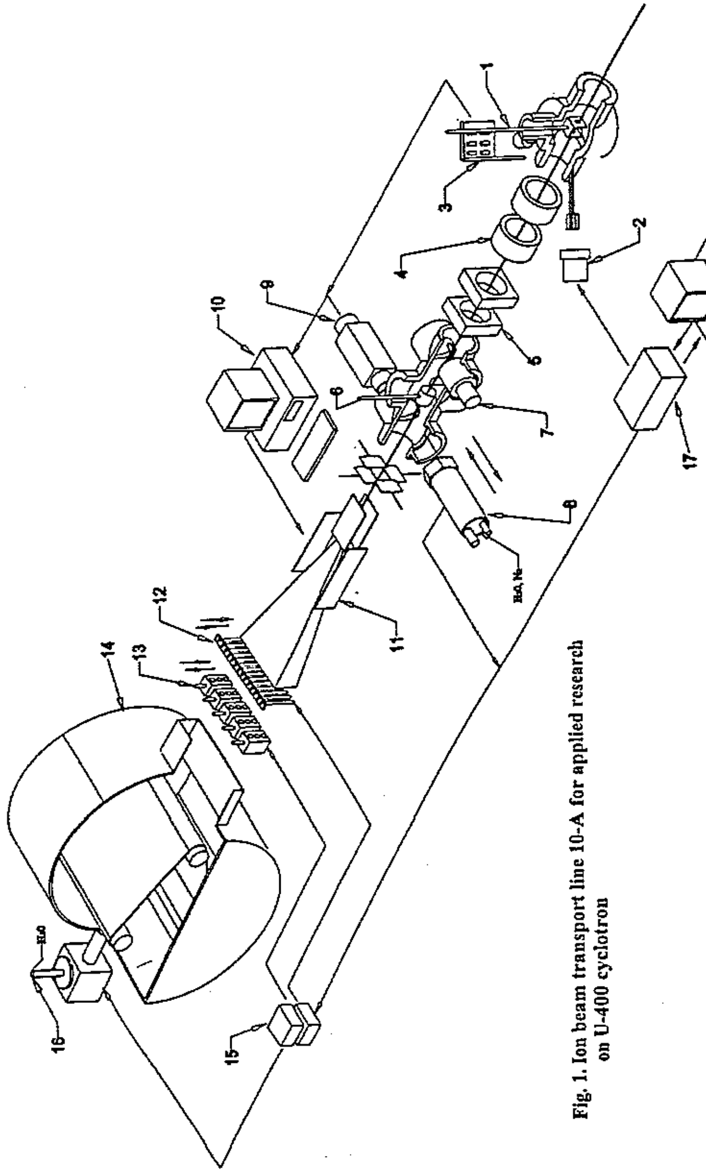

Fig. 1. Ion beam transport line 10-A for applied research on U-400 cyclotron

The secondary emission detectors (SED) have also been used for intensity and beam size/shape detection. A SED-based system for high-energy ion beam profile detection was described in [1]. A SED in a form of an array of metal foils was used, with foils thin enough not to shade the target and not to cause excessive ion dispersion. The beam profile was given by the sequential display of the signals from the ribbons. The working area of such a scanner is several cm^2. The main disadvantage of this construction is the mechanical weakness of the ribbons with thickness of the order of μm. Moreover, such a construction can not be used with ions of 1-2 MeV/nucleon energy because of the absorption of great part of ion energy. Furthermore, since the principle of the work of such monitors is based on surface phenomena, the secondary emission coefficient depends not only on the material but also, often even critically, on the cleanness of the foil surface.

An another diagnostic device is the "beam transformer" (by the older name Rogowski coil) which can not give the spatial distribution of the ion beam but allows only the determination of the electric current carried by the beam. Such detectors are not applicable in our case because of the small beam intensity (tens of nA) to be often used in the experiments. All other diagnostic devices, such as Faraday cup and scintillator screens are destructive profile detectors and exclude the possibility of a continuous monitoring of the spatial ion distribution and intensity during the irradiation experiments.

A rotating wire detector certainly in most cases meets the requirements of the continuous monitoring of the beam shape and intensity. This construction is free from the disadvantages described above. Such detectors are widely used at the U-400 cyclotron in the Joint Institute for Nuclear Research, Dubna. A single wire moving across the beam measures the intensity and the two-dimensional beam distribution. The wire moves in the beam in two X and Y direction in the perpendicular to the beam direction plane, so that it does not disturb the beam too much and information might be obtained about both X and Y spatial distribution.

In the case of irradiations up to high ion fluences ($\sim 10^{16}$ ions cm^{-2}) with focussed ion beam, water or liquid nitrogen cooled sample holder (8) is used, placed in the diagnostic section. This sample holder is a small stainless steel cryostat. Its temperature can be changed from 80 to about 450 K and this is controlled by a thermoresistance and a copper-constantan thermocouple. The sample is stuck on the copper block of the sample holder with silver conductive glue. The thermocouple is fixed to a control sample, located beyond the zone exposed to the beam. Under luminescence measurements the ion induced emission after a quartz lens on the entrance slit of the monochromator (9) focuses passing through a quartz window. The MCD-1 type monochromator has an operating range of wave length of 200-800 nm, a resolution of 1.5 nm at the entrance slit's width of 0.2 mm. Data acquisition and processing and monochromator operating have been performed by a measuring module on the basis of CAMAC standard equipment and a personal computer (10).

A homogeneous ion beam distribution on large irradiating area, up to 360 (60×6) cm^2, has been achieved using high-frequency (8 kHz) electrostatic (11) or low-frequency (of about 100 Hz) electromagnetic scanning systems.

Two additional movable diagnostic detectors serve the control of the scanned ion beam: wire detector (12) and a set of Faraday cups (13) as shown in Fig 1. The first one serves mainly for the initial ion beam adjusting and allows monitoring the beam position and homogeneity. The set of Faraday cups is used for continuous ion beam current and distribution detection during polymer film irradiations. It is to be noted that each of the five Faraday type detector sets (13) consists of three independently controlled Faraday cups in vertical position and such a construction allows us to observe both the vertical and horizontal ion beam distribution. If necessary, each of these five detector sets can be removed independently to avoid the target shading.

Irradiation chambers for the large area polymer films and the relatively small sample holder are indicated in Fig.1 as items 14 and 16, consequently. The polymer film irradiation chamber design allows irradiating polymer foil rolls of 55 cm width. The chamber (16) with five-position water-cooled sample holder is used for small sample irradiation at low and intermediate ion fluences in the range of 10^8-10^{14} ions cm^{-2}. The irradiated area is up to 30 cm^2.

Data acquisition system

The data acquisition system allows us to obtain information about the ion current distribution from each of the detectors, namely from the rotating wire detector (7), the set of Faraday cups (13) and the wire monitor (12). The system allows also measuring and controlling the beam current, as well as the irradiation temperature from the sample holders (8) and (16) and the polymer film irradiation chamber.

The data acquisition system (17) consists of the following parts: Control unit and a Pentium based PC, which are placed in the laboratory room; two low-noise preamplifier-multiplexers MPX-901 and MPX-902 (15) with 16 independent channels in each, placed near irradiation hall. The first multiplexer (MPX-901) collects the data from the set of Faraday cups and from wire detector while the second one (MPX-902) is used to measure the ion beam current (I_B) and irradiation temperature (TC and RTD). The block diagram of the data

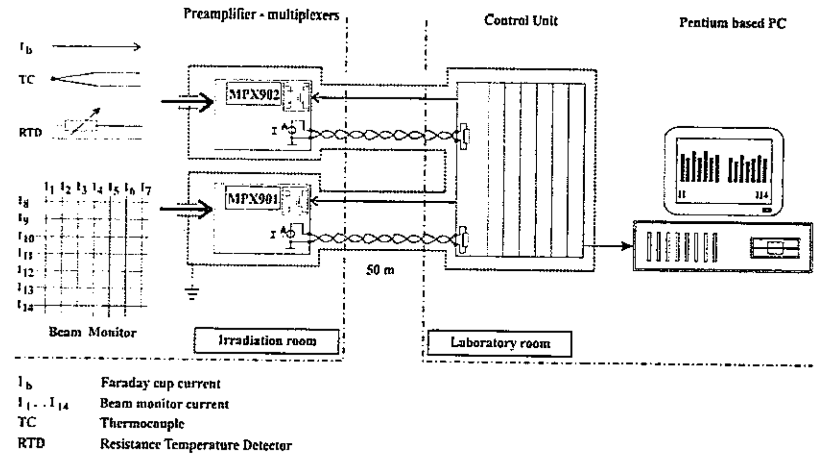

Fig. 2. Block diagram of the data acquisition system

Ion current is measured by current-voltage converters made up of operational amplifiers, with adequate noise suppression to reduce noise in current measurement. A 100 pA-1 μA range can be covered by changing the amplification.

A three-wire resistance thermometer at one channel and a thermocouple at an other channel are used for temperatures determination. A thermometer at the test card is responsible for the cold junction compensation of the thermocouple.

A preamplifier outputs are connected to the 16 channel multiplexer units, sequentially interrogated by the computer. The multiplexer outputs are connected to current transmitters. The current transmitter ensures that ground loops do not produce noises and consequently measurement data errors due to the long distances. This solution allows for a floating ground connection between the preamplifiers and the control unit. The shift of the multiplexers and the change of the amplification are performed via optical buffers. The part of the data acquisition system located in the laboratory room, near the computer, consists of the following units:

- -12 bit integrating AD converters,
- - 2 channel 12 bit D/A converter,
- -12 bit digital I/O module,

-4 channel 16 bit impulse counter module,

-step motor drive circuits,

-multiplexer control interface.

The computer and the control unit are linked by a "transmitter-receiver" interface. The wait-state generator on the interface ensures that there are no timing problems even when computers with different speeds of operation are used. Typically the PC and the control unit are connected by a 2 m (maximum length is 10 m) 25 pole shielded cable.

Due to the existence of considerable environmental noise generated by different systems of the cyclotron, it is quite difficult to process the low-level analogue signals. External noises reach the equipment inductively or capacitively through the 220 V mains and the connecting wires. In our case the noise from the mains is sufficiently reduced by applying mains noise filters in the power supply. On the other hand, integrating AD converter measuring circuits of integrating type were used. The external electromagnetic noise represents an another type of noise. Its effect is decreased by the following way: the whole system is provided with an extra shielding by placing the different units into a common, closed shielding system on the basis of the so-called Faraday-cage principle, using single-point ground connection and twisted pair connecting cables.

Prefilters connected to the measuring channels significantly reduce the noise of impulse type. Time constants of such prefilters should match the highest speed of changes of measured values. Low frequency noise can be suppressed by applying measuring circuits of integrating type. The used integrating type analogue-to-digital converters have a high degree of noise suppression capability for the low and high frequency noise components as well. It is known, that if the integration time is equal to, or is an integer multiple of the base harmonic of the noise frequency, then there is a very high suppression rate for this component as well as for its even harmonics. An integration time in the interval of 20 to 80 ms is well proven in practice, which can be pre-set in the control program.

The analogue measuring circuit does not contain any adjustment components; however, it has calibration channels connected to high-accuracy reference voltages. When starting measurements, the control program performs the calibration of the system. All measured values are converted to real physical values on such basis. Therefore, system errors, arising from the changes of the parameters of the measuring circuit (i.e. the temperature change, ageing) can be eliminated.

Software

The Windows-based version of real-time programme was produced on the basis of more than 15 years of measurement experience on U-300 and U-400 cyclotrons. In order to solve our measuring problems a real time multi-tasking programme was constructed.

As known, the basic feature of a real time programme is that the sequence of its actions is not determined by the programmer but by the environment, and the environment task (usually used phrase is *real-time clock task*) must not be delayed. In a multi-tasking operating system the real time programme has two parts, an *event driven environment task* and a *main task*, and they communicate between each other through the usual way (message queue, shared variable etc.). However, in multi-tasking operation systems the real time controls do not communicate with the environment by the usual synchronisation way, because the environment task must not be delayed. There are multi-tasking operating systems, which has built-in facilities to serve external event handling. These systems are often called *real-time multi-tasking operating system*. The cost of such systems is much higher then a normal most often used Windows operating system, which has not real time character. Under Windows systems (like Windows 3.1, Windows 95) every resource and device in the system is controlled by *Windows Kernel* and they communicate with the applications through the system message queue. In this way the real time character is not fulfilled. For example, if the DAS sends an interrupt signal about the data measurement ready event, the application can not serve this request. Of course, the application could scan the hardware for data with a predetermined period time, but the time will not be an exact value.

However, in the case of the ion beam control programme the time and the ion beam current have to be measured exactly. This is the reason that in our case a real time application was created.

Under Windows type operation systems, in principle, one can solve this problem in two ways. An environmental programme sequence can be built into the system Kernel, as a part of the operating system, which provides the real-time character of the control. This driver can serve the interrupt signals. As soon as the interrupt occurs (data ready or time end signal), this handler immediately serves this request, and the results pass through the normal message queue to the main application. Such a driver usually is called as a virtualised device driver, VDD.

However, in our case an another way was chosen in order to solve the problem of real time character. The environmental driver routine was built into a dynamic linked, do not movable library (DLL library). This method is more useful then the previous one, because this library is loaded into the RAM only when the appropriate applications are in use.

After having measured the current and time data by the environment task (real time DLL service, our system driver) it processes them and passes through the normal message queue to the main part of the application. After that, the non real-time tasks are processed by this part using the exactly measured values, and displays the main parameters of the irradiation experiment: the current, the fluence, the measuring time, the beam distribution on the target and the temperature of the sample.

Conclusions

An ion irradiation facility serving the complex requirements of applied research in condensed matter physics was constructed at U-400 cyclotron in JINR Dubna. This heavy ion leading line is suitable for irradiating large area polymer films just as small metal and semiconductor samples in well controlled circumstances. The leading line is equipped with different detectors in order to control the beam current and distribution on the target. The data acquisition system and the relating software give the possibility of convenient and precise measurements and fit to the complex designation of the leading line.

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