AUTOMATED OPERATION OF AURORA

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Abstract

A fully automated operation of the compact synchrotron light source, AURORA, is an essential demand for an industrial use. AURORA is primarily developed as a light source for VLSI production. The standby processes, tuning and optimization of the system, injection and acceleration, fault diagnostics and fault trend analysis are the required functions to be automated. We have completed the computer control system and most of the operations are now carried out from the central console. The operations such as standby, injection, acceleration are carried out automatically. In this paper we also present some experiences of the automatic tuning of the system, particularly of the injector microtron. The microtron is optimized automatically in the way to reference the beam current and to feed back to magnetic steerers.

1. Introduction

The control system of AURORA must be useful not only for the development of such a new accelerator, but also for the routine operation of the machine at a semi-conductor factory. Thus the control system must meet two different functions. One is that the system can be operated flexibly under various conditions for the development and the other is that it can be operated fully automatically for users unfamiliar with accelerators. The system has been developed under such a philosophy that it can be operated not only manually, but also automatically in a sequence.[1] For instance, a complex sequence for beam injection and acceleration can be executed in a single sequence by using a newly developed interpreter.[2]

2. System configuration of AURORA

The synchrotron light source system AURORA consists of a racetrack microtron[3] as an injector and a superconducting electron storage ring.[4][5] Electrons are accelerated up to 150 MeV with the microtron and then injected to the storage ring. The beam is boosted up to 650 MeV and stored.

2.1 Microtron

The microtron consists of a 120-keV injection system, linac, two 180° bending magnets (main magnets) with reverse-field magnets and beam focusing elements.

The injection system consists of an electron gun, three rf components (a 100-keV single-gap cavity and two bunchers located on upstream and downstream of the single-gap), a chicane magnet and several focusing elements. Electrons emitted from the electron gun at an energy of 20 keV are accelerated up to 120 keV by the single-gap cavity.

The accelerating condition prior to the linac is determined by phases and supplied powers of the three rf components. The chicane magnet bends the 120-keV electrons by 45° with regard to the injection line. The focusing elements are five solenoid magnets, four X-Y steering magnets and two pairs of quadrupole magnets. Tuning these elements at various combinations, the electrons are guided to an optimum trajectory.

The electrons are accelerated by the linac at an energy gain of 6 MeV per lap and are circulated by the two main magnets. Focusing elements are located between the two main magnets.(Fig.1) A pair of quadrupole magnets are on the linac line and a pair of horizontal steerers are on each lap (24 pairs) and vertical steerers are on several laps except on the linac line. It is necessary to tune these focusing elements in order to maximize the beam extraction.

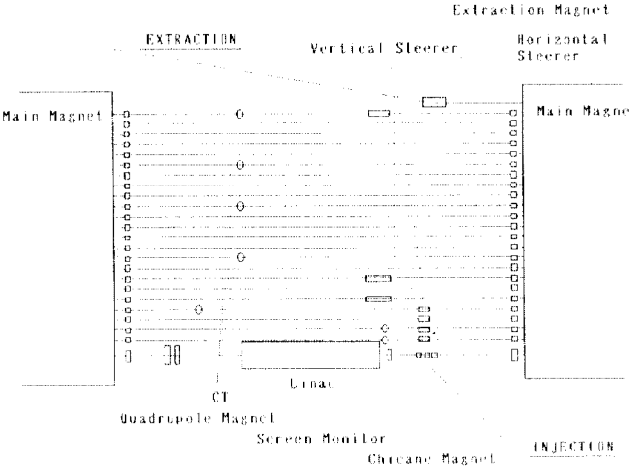


Fig.1 Focusing elements and beam monitors installed between the main magnets of the racetrack microtron.

2.2. Superconducting electron storage ring

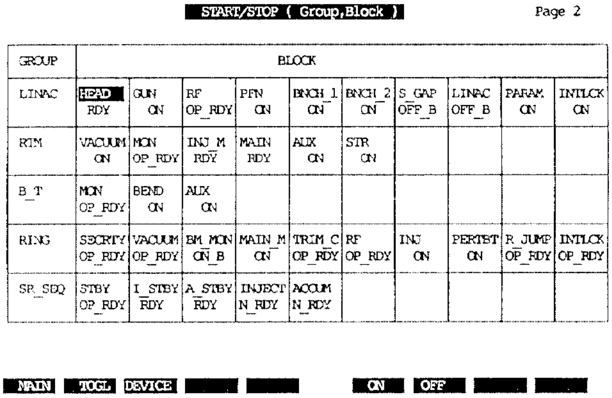
The storage ring consists of only one superconducting weak-focusing magnet with trim coils, injection devices, a resonance jumper, and a small high-power rf cavity.[4] The main magnet generates a strong magnetic field, which varies from 1.0 Tesla at the injection to 4.34 Tesla at the storage. The injection system is composed of two magnetic channels, a electrostatic inflector, and a perturbator. The perturbator is to generate half-integer resonance orbit[6], whose field is superimposed to the field of the main weak-focusing magnet. That is excited synchronously to the pulsed injection beam. The resonance jumper magnet has been prepared to prevent beam losses at some resonance points during ramping process. The rf cavity installed on the circular orbit generates an electric field of 120 kV.

3. Hardware Configuration of the Control system

The computer control system of AURORA is a three-layered hierarchical architecture.[1] The top layer is called Central Intelligence System (CIS) and the second, Autonomic Control System (ACS). Both are based on Micro VAX II and linked by the Ethernet. The bottom layer is composed of local controllers called Universal Device Controllers (UDC's) distributed over more than 50 devices, and are linked to the ACS through an optical network. The UDC consists of the INTEL i8344 microprocessor, 48k bytes of PROM, 16k bytes of RAM, and 80 bits of photo-isolated I/O. The CIS is used for a data taking through a GP-IB interface, for an image-processing of beam profiles obtained by screen monitors, and telescope systems,[5], as well as for the backup system of the ACS.

4. Software

In this control system, the accelerator elements are classified into four groups by their roles, and each group is divided into several blocks. These four groups are "LINAC", "RTM", "B_T" and "RING" as shown in Fig.2. The "LINAC" group, for instance, consists of rf components of the microtron. Blocks in the above four groups are prepared to manage and operate individual devices by the unit of block. But the "SR_SEQ" group on the fifth row is specially added, which is to classify the injection and acceleration procedures into different steps.



START/STOP (Group,Block)

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GROUP	BLOCK									
LINAC	HEAD RDY	GUN ON	RF OP_RDY	PFN ON	BNCH_1 ON	BNCH_2 ON	S_GAP OFF_B	LINAC OFF_B	PARAM ON	INTLCK ON
RTM	VACUUM ON	MON OP_RDY	INJ_M RDY	MAIN RDY	AUX ON	STR ON				
B_T	MON OP_RDY	BEND ON	AUX ON							
RING	SECRTY OP_RDY	VACUUM OP_RDY	BM_MON ON_B	MAIN_M ON	TRIM_C OP_RDY	RF OP_RDY	INJ ON	PERTBT ON	R_JUMP OP_RDY	INTLCK OP_RDY
SR_SEQ	STBY OP_RDY	I_STBY RDY	A_STBY RDY	INJECT N_RDY	ACCUM N_RDY					

Fig.2 Groups and blocks displayed on the console terminal of ACS.

In this system, each block stays in one of seven states distinguished by the statuses of the devices as shown in Fig.3. The "Not Ready" state means that more than one devices in the block are not ready. The state becomes to the "Ready", when all of the devices become ready. The "Operation Ready" state means that all of other block's conditions are all right for the operation of this block. These conditions often depend on the states of other blocks. Checking the ready and the operation ready conditions are carried out by installed tasks. Furthermore, operation procedures are written in a newly developed interpreter named OPELA (Operation Language for Accelerator)[2]. Using this language, the following three OPELA sequences have been prepared for all above blocks. The "On" sequence starts up the devices when the "On" key is pressed. When the "Off" key is pressed, the "Off" sequence, which shuts down the devices, is executed. If a fault occurs, the "Fault-off" sequence is executed automatically in order to shut down the devices immediately. Checking the fault statuses are also carried out by a installed task.

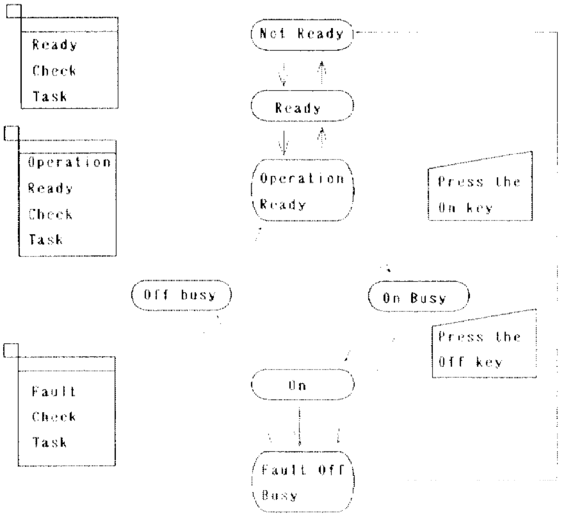

Fig.3 States of the block and transition schemes. Checking the ready conditions, operation ready conditions, and the fault statuses are stationarily performed.

5. Automated procedure of injection and acceleration

The injection and acceleration procedures are divided into five steps as shown in Fig.4. In the first step, the main magnet, the rf cavity and the trim coils are excited for the injection. (We call this step "STAND-BY".) The second step is preparations for the injection. The magnetic channels and the inflector are lifted up to the injection orbit and excited. And then a power supply of the perturbator is warmed up. ("INJECTION STAND-BY") In the third step, the resonance jumper is prepared. ("ACCELERATION STAND-BY") The actual injection starts with the fourth step, the perturbator is triggered synchronously by the beam from the microtron. ("INJECTION") The last step is acceleration. The perturbator is stopped. The magnetic channels and the inflector are stopped, and are immediately set down from the injection orbit in order not to interfere synchrotron lights. After that, the main magnet and the rf cavity are furthermore excited up in order to boost the electrons up to the energy of 650 MeV. ("ACCELERATION") Finally the electrons are stored at the full energy.

These steps are so complicated that they must be executed automatically. Therefore, we have prepared the OPELA sequences to execute these steps. These steps are now executed by pressing only one function key.

6. Automatic tuning system for the microtron

Beam monitors installed in the microtron are current transformers (CT), screen monitors, and an SR light monitor.[7] Current transformers are allocated on the major beam lines of the microtron in order to measure beam currents non-destructively and simultaneously. The output signal of the CT is monitored and stored by a digital oscilloscope which is connected with CIS thorough a GP-IB interface.

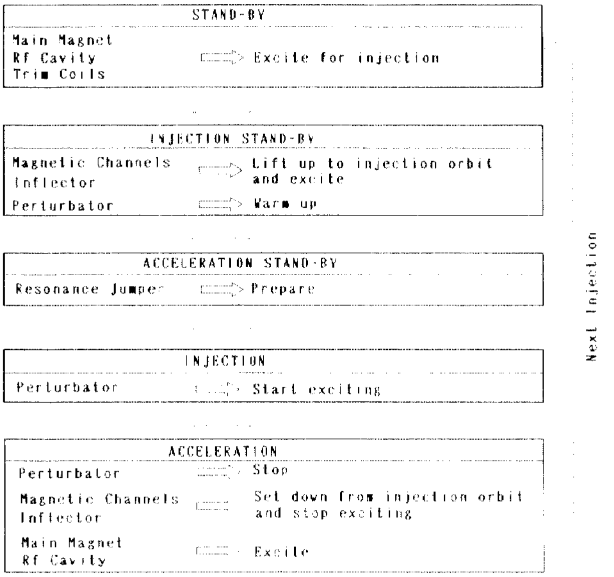

Fig.4 Injection and acceleration procedures.

An optimization process of the focusing magnets and the rf components is so complicated that we have developed an automatic tuning system of the horizontal steerers of the microtron. Fig.5 shows a schematic diagram of this system. Because the extracted current varies with the rf conditions, we have chosen a transmission rate between two CT's as a reference to optimize the strengths of the steerers. The optimization is accomplished by tuning a pair of steerers simultaneously which is located on the same lap. Current transformers are installed on the 2nd, 3rd, 5th, 10th, 15th, 19th and 24th laps. In order to obtain the transmission rate, output signals of the CT's are stored in the oscilloscope, and are processed by the CIS through the GP-IB. Then, values of the steerers are passed to the ACS through the Ethernet and are latched to the UDC by the optical network.

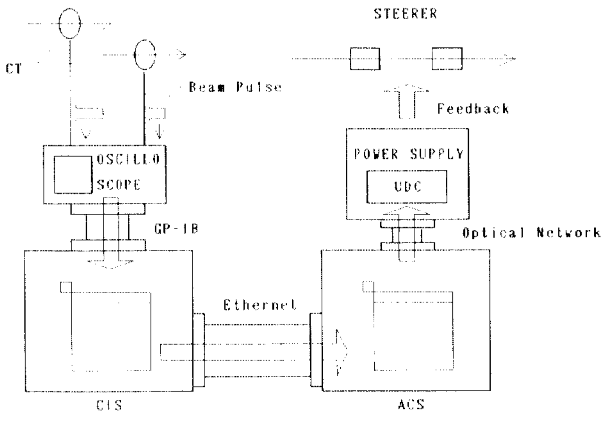

Fig.5 Schematic diagram of the automatic tuning system. Two CT's are monitored and strengths of a pair of steerers are changed simultaneously.

7. Summary

The AURORA system has been operated automatically, using the interpreter, OPELA. The injection and acceleration procedures are performed by pressing only one key. The automatic tuning system for the microtron has been developed using the CT monitors. These automations reduced loads for operators significantly, as it is required for an industrial use.

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