BEAM INTENSITY AND SPILL CONTROL BY A PERSONAL COMPUTER SYSTEM AT INS 1.3 GEV ELECTRON SYNCHROTRON

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ABSTRACT

A personal computer system for controlling beam intensity and beam spill has been introduced to the electron synchrotron at Institute for Nuclear Study, University of Tokyo. When the beam intensity deviates from the initial value beyond the upper or lower limits, a pulse motor system is operated to restore the beam intensity within the limits. The beam spill is monitored by sampling the spill wave form at two points in the spill time and when an unbalance between the intensities at two monitoring points, an analog signal to correct the unbalance is sent to the rf system. With this system, we can keep the beam intensity and beam spill stability for more than 10 hours with no manual tuning of the synchrotron parameters.

INTORODUCTION

The 1.3GeV electron syncrotron (INS-ES) has been operated since 1961. Due to extensive improvements, the operation stability as well as the beam intensity and the duty cycle of the beam have been much improved. In current experiments by using the synchrotron beam, so-called photon tagging method is often employed. For these experiments, it is needed to maintain the beam intensity at a certain constant value during an experimental run. Also the stability of the beam spill from the machine is very important to reduce accidental coincidences in the particle detection system. We can attain the duty cycle of the beam as high as 10-20% by using special devices introduced in 1985 [1]. Since the repetition rate of the synchrotron is about 20Hz, above duty cycle corresponds to a beam spill time of 5-10msec. The beam spill should be uniform during this spill time, and it should be also stable throughout the experimental run.

The tuning of the machine for providing the beam with above conditions is made once a week, usually on Tuesday morning after one-day shutdown on Monday for maintenance work. However, perfect stability can not be attained until the temperatures of the room, cooling water and every machine components reach constant. Even after the initial instability has damped, various disturbances can occur such as fluctuations of line voltage, temperature and so on. We can, in principle, suppress instability due to these disturbances by introducing an appropriate feedback loop. The most simple way may be to introduce a single feedback loop connecting the final output and the parameter that gives the most strong influence on it.

Under these considerations, we have introduced a simple feedback system by use of a personal computer to keep the beam intensity constant and to maintain the stable beam spill. The feedback loop to control the beam intensity was originally developed 9 years ago [2].

PRINCIPLE OF BEAM INTENSITY CONTROL

The major origin of the fluctuation of beam intensity at INS-ES is the energy variation of the beam from the injector linac. The beam from the linac, whose standard energy is 15MeV, is deflected by an electrostatic inflector to be guided on the injection orbit of the synchrotron. The injection timing is determined in such a way that the guiding field of the synchrotron at injection is just for the linac beam energy. The successful injection occurs when both of the inflector voltage and the injection timing are correctly adjusted to the linac beam energy. For maintaining the beam injection stable, we must keep the linac beam energy constant, or adjust the inflector voltage and the injection timing to follow the energy variation of the linac beam. For the low-energy electron linac, in which the accelerated electrons are not perfectly relativistic, it is not possible to adjust the beam energy without changing other beam parameters such as intensity, emittance and so on. Thus we have chosen the inflector voltage and the injection timing as parameters for which feedback is to be applied. Manual operation experience shows that we can keep the final beam intensity constant by adjusting above two parameters only.

Obviously there exists a correlation between the correct values of the inflector voltage and the injection timing in accepting the linac beam. So we can, in principle, adujst these two values by a single parameter. But the inflector voltage and the injection timing circuit themselves are not perfectly stable. So we treat them as independent parameters to compensate possible instabilities accompanying them.

PRINCIPLE OF BEAM SPILL CONTROL

At INS-ES, the final beam is spilled by controlling the rf for acceleration. When the final beam energy is high (>700 MeV), where the synchrotron radiation loss is large, the beam spill can be well controlled only by amplitude modulation in the rf voltage. For the lower energy beam, we must apply rather sophisticated method to get smooth spill during long spill time (5-10 msec), as described below [3].

The frequency of rf, 138MHz, is frequency-modulated during the spill time desired by the beam user. When this modulation frequency concides with the synchrotron oscillation frequency of the electron bunches in the synchrotron, or multiples of it, the electrons in rf backets undergo the parametric resonance, and gradually spilled out of the backets. Since the synchrotron oscillation frequency changes according to the acceleration, even in the spill time, we have to change the modulation frequency during the spill time to obtain a smooth beam spill. For this purpose, a voltage-controlled oscillator (VCO) is used. By applying a programmed voltage pulse, whose width is to be the spill time, to VCO, we can generate desired modulation frequency in any point of the spill time. To avoid too much complication, we employ a exponentially decreasing voltage pulse with an appropriate bias.

Thus the instantaneous spill intensity depends on many parameters such as the rf amplitude, the amplitude of the frequency modulation, the electoron beam intensity at that instant, and so on. An example of the beam spill obtained by the above mentioned method is shown in Fig.1.

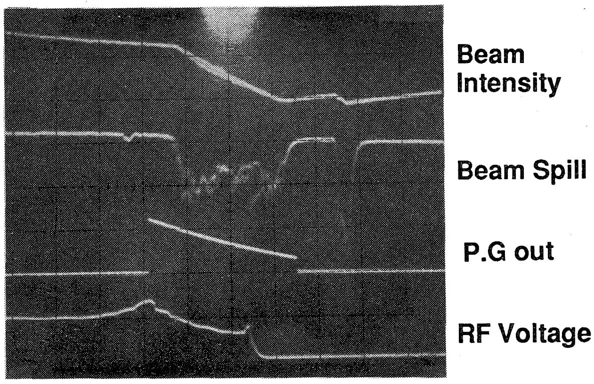

Fig.1 An expample of signals of beam intensity, beam spill, voltage pulse for frequency modulation on rf, and rf voltage. Small beam spill behind the main spill is not relevant for this work.

Since the beam spill is affected by many parameters, it often suffers from the instability. The most typical case is such that the spill is enhanced at the begining of the spill time and is diminished at the end, or vice versa. We have found that this "asymmetry" of the spill can be corrected by adjusting the voltage pulse for VCO, simply varying the bias of it. Thus the feedback to correct the beam spill asymmetry is applied to the voltage pulse generator. By this simple way, we can expect to have a stable beam spill for fairly long time.

APPARATUS

A block diagram of the beam intensity and the beam spill control system is shown in Fig. 2. The 2222 circulating current in the synchrotron is monitored by a current transformer installed in a straight section of the ring. Using an amplifier, the output of 1V corresponds to the circulating current intensity of 100 mA. Whereas the beam spill is monitored by a scintillation counter located at the beam channel, which measures the time structure of the beam sent to the experimental hall. Examples of these signals are schematically shown Fig. 3. The final beam intensity is measured as the difference of the voltages sampled at the points A and B in the figure. Difference of the voltages at A and B is sent to ADC. To know the asymmetry of the beam spill, the intensities at points C and D, which are at, for example, ±2msec from the end point of the acceleration, are measured by use of sample-hold circuits.

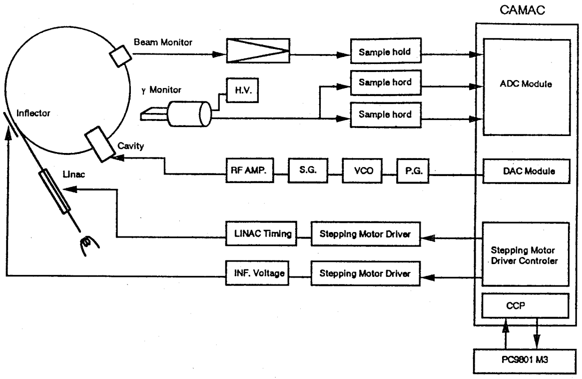

Fig.2 Block diagram of beam intensity and beam spill control system.

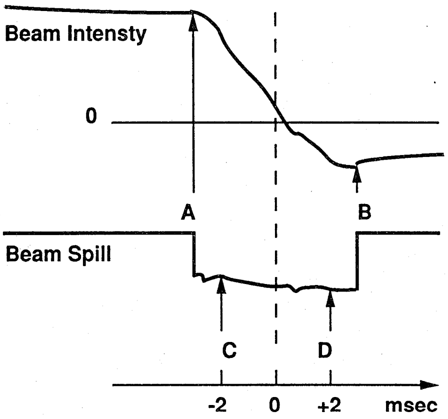

Fig.3 Schematic feature of the beam intensity and beam spill signal. Voltages at arrows are samled.

These analog signals are digitized by ADC circuits in a CAMAC system, which is controlled by a personal computer.

Stepping motors to adjust the inflector voltage and the injection timing are driven by the CAMAC system. On the other hand, a DAC module in the CAMAC system generates a dc voltage to control the baias of the voltage pulse to the VCO circuit for adjusting the spill asymmetry.

SOFTWARES

After manual tuning of the machine parameters to provide the beam as required by the beam user, the computer control program is started. The beam intensity and the spill intensities (voltages at two points C and D, Vc and Vd, as described in the preceding section) are read 100 times every 30 second. As for the beam spill, the following calculation is made for each read out :

$$S = \frac{Vc - Vd}{Vc + Vd}$$

For every 100 samples, mean values and standard deviations of the beam intensity and the asymmetry parameter S are caluculated. They are plotted in the graphic display. Initial values of them are memorized as references for the following control.

When the mean value of the beam intensity and/or the spill asymmetry parameter deviate from the reference value by f times standard deviation, where f is assigned beforehand, control commands are generated. All the above process is finished within 30 sec. If the beam intensity has decreased, the inflector voltage is optimized, followed by optimization of the injection timing. For the case of intensity increasing beyond the limit, the inflector voltage is shifted from optimum value until the beam intensity come back within the limit. It is usually needed several times of monitor and control cycle, each cycle is repeated every 30 seconds, before the correction is completed.

The logic to control the beam spill asymmetry is simpler than the one to cntrol the beam intensity. According as the spill asymmetry parameter becomes positive or negative beyond the limit, the bias of the voltage pulser for VCO is increased or decreased.

RESULT AND DISCUSSION

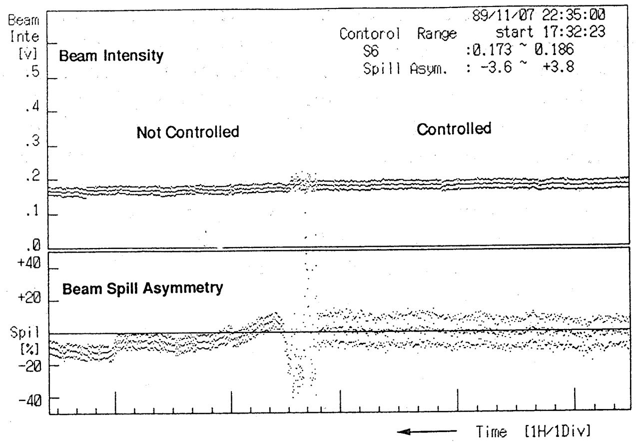

Fig.4 Beam intensity (upper graph) and beam spill asymmetry (lower graph) monitored for 5 hours. Mean values and their standard deviations are plotted. Right hand side is the result with the control, whereas the left hand side is the one without control.

Fig.4 is a hard copy of the computer display showing the variation of the beam intensity and the beam spill asymmetry during 5 hours. From this result, we can remark the following characteristics. (1) For the computer controlled period, the beam intensity is quite stable. (2) The beam spill asymmetry is also well controled to be kept around S=0. (3) The beam intensity is also stable even for the non-controlled period. It is known that the beam intensity becomes stable one or two days after starting the operasion, espescially at midnight. This data was taken just under such condition. (4) The beam spill asymmetry is very unstable when it is not controlled by feedback system.

It is seen in Fig.4 that the standard deviation of the spill asymmetry is large in the controlled region while the mean values are well controlled to be around zero. This is because present control system works with a time constant longer than 30 seconds, and has no ability to control short term deviations. Thus this system aims at keeping long term stability of the synchrotron beam.

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