THE 40 KA DUMPING SYSTEM FOR THE ISR BEAMS

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Introduction

The kinetic energy of the proton beam of each ISR is $W = I \cdot E \cdot T_{rev}$. With the maximum value of current achieved so far in the ISR I ≃ 30 A, a proton energy E = 26 GeV and a revolution time T_{rev} = 3,15 µs, this results in a maximum kinetic energy of W = 2,45 MJ. Such an energy, if suddenly lost and instantaneously dissipated in any part of the ISR would cause a major breakdown. It has therefore been necessary to build a fast and reliable system which can dump the beam whenever safety monitors indicate a hardware fault or a beam loss.

The beam in each ISR is dumped by means of four fast pulsed magnets [1,2] deflecting the particles vertically onto an absorber block situated in the same long straight section. In 1970 when the ISR were first put into operation each of the four magnets in each ring was energized independently by its own 3 Ω pulse generator. Now, by means of a special spark-gap developed for that purpose and switching together the four 3 Ω pulse-forming networks [3], it has been possible to improve significantly the reliability of the system. The 0,75 Ω,40 kA pulse generator now energizing the four fast pulsed magnets is described with special attention to the principles and technological solutions which were adopted in order to achieve the necessary reliability of the system for each type of operation, and particularly during long colliding beam experiments.

1. Efficiency of a dumping system

In the ISR dumping system the beam normally goes through a hole machined in the absorber block. When triggered the fast kickers deflect the beam vertically (downwards) and the particles are eliminated in the material of the absorber block, which is off-centered vertically upwards. To achieve the highest efficiency the deflection Δz has to be above a certain minimum value according to the following formula $\Delta z = a - 2z_b + 2z_{c.o}$ where a is the absorber hole height, z_b the absorber position and $z_{c.o}$ the closed orbit distortion. During the field rise-time the increasing kick is not enough to send the particles on the absorber block input face; when the beam is unbunched the fraction of the beam not dumped is the ratio of the rise-time to the revolution time T_R/T_{rev}. These particles are lost along the absorber hole or around the ISR vacuum chamber. However some of them (depending on the limiting aperture they meet) are dumped after one more turn because the field pulse length (3,5 µs) is longer than the duration of one revolution (3,15 µs) in the ISR. For reasons of simplicity one defines the dumping efficiency as the fraction of the beam which is dumped on the absorber block input face during the first turn. In the ISR this efficiency is 94,3%.

2. Reliability of the dumping system

The reliability of the dumping system is also of primary importance, not only because of the risk for the ISR, but also because any malfunctioning or spontaneous triggering of the system causes the loss of the stacked beam and the restarting of the long process of filling

(which is not always possible when the injector is off). Besides the traditional ways to achieve a high reliability (oversize of the equipment, no moving parts, minimum number of items, etc..) it is worthwhile pointing out several special aspects of the reliability of the system. When the four magnets are fed by independent pulse generators (as was originally the case), any self-triggering of a single pulse generator gives the beam one fourth of the required kick. The beam is then lost in the vacuum chamber. This problem was partially solved by synchronizing the four pulse generators, but the resulting rise-time in case of self-triggering of one of them was strongly impaired by the triggering delay of the other three (which is about 0,5 µs). The only definitive solution is to have only one switch for the four pulse generators [3]: a spark-gap has been developed to handle the higher resulting current and specially designed for long DC voltages holding without self-triggering.

The response-time (the time between triggering and dumping) is also very important; the system has to be faster than any cause of breakdown in the ISR or in the Beam Dumping System itself. A system in which capacitors store the energy needed for the dumping is faster than any other dumping principle such as resonance excitation, fast orbit bump or resonant power supply charging the capacitors before use. The response-time of the ISR system is about 1 µs and is mainly given by the delay in transmission cables. Any internal breakdown or mains switch-off is preceded by an 'ultimate' triggering. Therefore the system is always ready to dump the beam. If it breaks down it has a sufficiently short response-time to dump the beam once more before going off.

3. Description of the system

The pulse generator (see fig. 1.) is built up of 4 'Pulse-Forming Networks' (PFN) of 3 Ω impedance put in parallel and switched together by a tetrode spark-gap (see fig.2). The PFN's are L-C delay-lines made with 20 nF low inductance capacitors immersed in oil. The matching of impedance is achieved with 20 short HV coaxial cables between the spark-gap and the PFN's and with 20 long transmission cables between the pulse generator (located in a service building) and the fast magnets and their termination resistors. These resistors are carbon, metal plated, resistors of 3 Ω insulated and cooled by an oil flow. Bakeable coaxial feedthroughs having nitrogen pressure on one side and ultra-high vacuum (2 x 10^{-11} Torr) on the other side are situated on the bottom of the vacuum tanks. These tanks are made of low carbon stainless-steel with gold O-ring seals for the large flanges, one 500 ℓ/s Vacion pump and two titanium sublimation pumps. The parallel plate kicker magnets have a very simple structure in stainless-steel supported by pure alumina insulators. The shape of the magnet itself has already been described in [2]. Special lossy barium titanate capacitors and ferrite rings are inserted between the magnets and the vacuum tank in order to reduce to an acceptable level the coupling impedance with the beam and damp unwanted oscillations which could result in an instability of the beam.

The switching problem deserves a special comment. In the first version of the system high voltage thyratrons were used, one for each magnet. These thyratrons were used beyond their rated capabilities for the maximum current (10 kA), and the rate of rise of current (120 kA/μs) which resulted in a cathode mean life-time of only 5000 h, an important drift in anode delay up to 100 ns and (more important for our application) a relatively high spontaneous firing rate under DC voltage [5]. More suitable tubes not being available on the market, a special spark-gap was developed at CERN [4] and has now been in operation in the ISR since May 1973. It is a field distortion tetrode spark-gap without ionisation pin but with two trigger electrodes (fig. 3.); the air overpressure (ratio of the working pressure to the breakdown pressure) is 2,25 resulting in a very good D.C. voltage holding. The current not being limited in a spark-gap as in a thyratron by a heated cathode, and the inductance being very low (diminishing with increasing load) it was possible to use only one spark-gap for four PFN's. The triggering is achieved with a R.C. circuit switched by a deuterium thyratron (used here with medium current and low rate of rise). The electronics provides the low level triggering, counting, safety controls and spark-gap flushing. A Faraday cage allows noise-free measurements of all fast pulses.

4. Operations and performances of the system

The system is used for :

1. Repetitive injection and dumping : it is triggered in synchronism with the injection of the PS beam in the ISR, allowing the injected beam to circulate during about 2 s in order to make precise measurements of the beam characteristics after which the ISR are cleared of all protons.

2. Manual triggering at will, e.g. when the beam is no longer needed at the end of a physics run.

3. Automatic dumping when one of the following fault occurs in the ISR : magnet breakdown, mains breakdown, vacuum pressure increase, sector valve closing, tunnel access door opening and beam loss. In the same way there is an automatic dumping when an internal fault occurs : HV power supply off, spark-gap pressure leak, low level of the oil and fire detection.

HV settings depend strongly of the absorber block position and for an optimal use it has been necessary to establish two lists of HV values and absorber block positions, the first for the machine development runs (repetitive injection and dumping) where the limitation is the heating of the termination resistors and the other for physics runs where spontaneous firings are forbidden.

The performances of the system are the following:

Maximum current	40 kA
Characteristic impedance	0,75 Ω
Maximum D.C. voltage	60 kV
Pulse power	1,2 GW
Rise-time (10% - 90%)	185 ns
Stored energy in PFN	4,8 kJ
Pulse duration	4 μs
Plateau duration	3,5 μs
Repetition period (min.)	2 s
Maximum deflection angle (31 GeV)	2 mrad
Maximum deflection (on absorber block)	20 mm

The estimated efficiency of about 95% is indirectly confirmed by several ion-chamber recordings made in the nearby I 4 region which show that dumping contributes less to the losses than other operations as injection, acceleration and scraping [7]. The efficiency is unfortunately impaired for physics runs at 26 GeV or more : it has been discovered that the absorber block must be centered on the beam to minimize the nuclear background noise. A development programme to study in the laboratory the feasibility of 50% increase of the beam deflection has then been undertaken and it has been recently decided to install the improved version of the system as soon as possible.

The erratic or spontaneous firings of the switches are no longer a problem : since the installation of the spark-gaps in 1973 no incidents of this type has been recorded. The erosion of the spark-gap which is sometimes alleged as a weakness of this type of switch is low : the electrodes are changed once per year.

In the same way an inspection is made every year during the yearly shutdown of all items which could be deteriorated : carbon resistors in the termination boxes, in the PFN's and in the HV power supplies, HV ceramic capacitors, HV plug-in connectors, rubber seals in the irradiated area; the oil providing the HV insulation in the PFN's, spark-gap boxe and termination resistor boxes is treated when necessary. Preventive maintenance is also made in the electronics, and in the air and nitrogen pressurization equipment.

Conclusions

The concluding remarks which we can make are :

- The design of a beam dumping system is different from the design of a kicker used for injection or ejection: independent switching of magnets is no longer possible as it would divide the reliability at least by the number of switches.

- The spark-gap switch is very versatile, safe and cheap if properly designed for the application in question and should be chosen for any similar application when the repetition rate is not high.

- Preventive maintenance is needed in the beam dumping system because it is the safest way to avoid long interventions during operations and to obtain the very high reliability necessary for a system used mainly for the protection of the ISR.

References

1) A. Delizée, H. Kuhn, W.C. Middelkoop, B. de Raad, J.C. Schnuriger, C. Schröder, J.P. Zanasco, "The design of the Beam Dumping System of the CERN Intersecting Storage Rings", VIIth International Conference on High Energy Accelerators, EREVAN, Aug. 29th - Sept. 2nd 1969.

2) A. Delizée, W.C. Middelkoop, B.W. Montague, B. de Raad, J.C. Schnuriger and J.P. Zanasco, "Beam Dumping and Scraping in the CERN Intersecting Storage Rings", VIIIth International Conference on High Energy Accelerators at CERN, Sept. 20th-24th, 1971.

3) J.C. Schnuriger, "Projet d'amélioration du système de décharge des faisceaux des ISR" Internal Report, CERN/ISR-PO/73-2 (1973).

4) J.C. Schnuriger, "A Tetrode Spark-gap for high current switching with a small time jitter". Internal Report, CERN/ISR-BT/69-50 (1969).

5) A. Delizée, "Results obtained with thyratrons used in the beam dumping system of the ISR". Internal Report, CERN/ISR-PO/73-51 (1973).

6) A. Dupaquier, "Etude du circuit de déclenchement des éclateurs utilisés dans le système de décharge des faisceaux ISR". Internal Report, CERN/ISR-PO/74-12 (1974).

7) H. Hoffmann, "Some data collected on induced radioactivity in I 4". ISR Performance Report, 17th January, 1974.
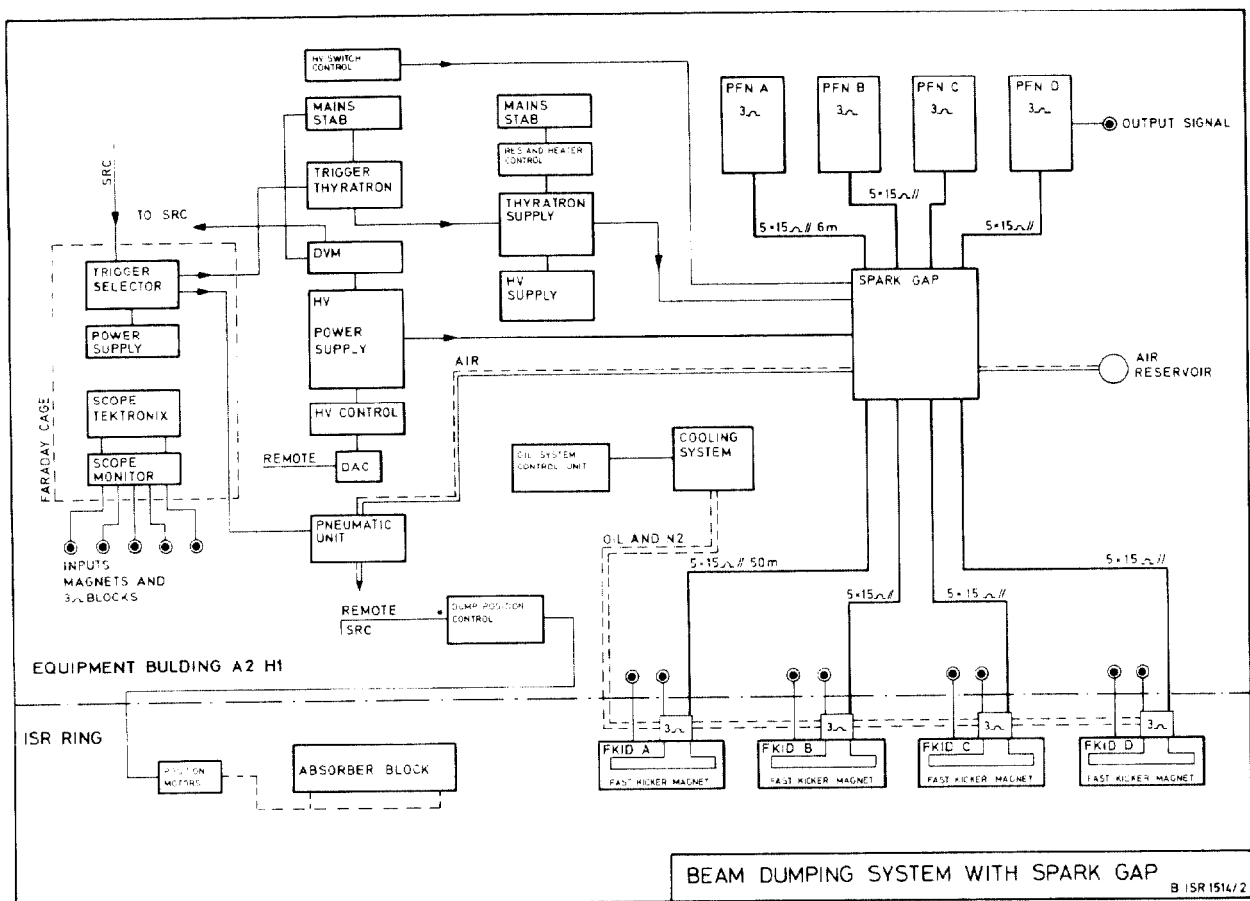
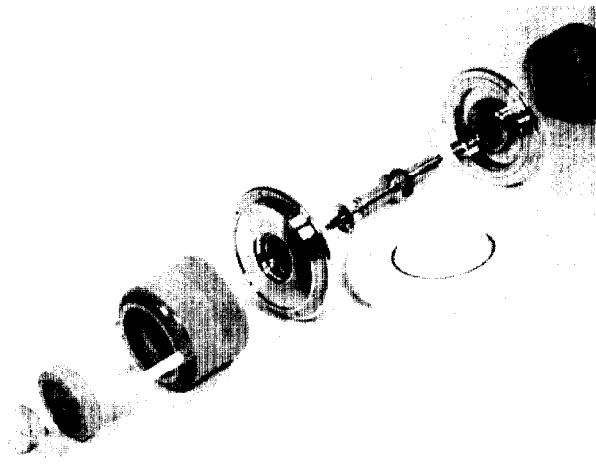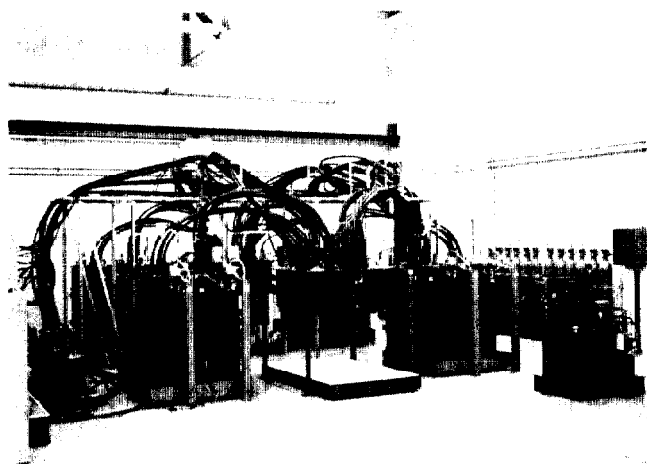Fig. 1. Schema of the beam dumping system

Fig. 2. Overall view of the HV equipment in the service building

Fig.3. Exploded view of the tetrode spark-gap