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IMPROVEMENT IN LUMINOSITY, BACKGROUND AND CHAMBER PROTECTION WITH BEAM SCRAPERS IN THE ISR

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Summary

The Intersecting Storage Rings (ISR) are equipped with beam scrapers used for various purposes such as improving luminosity, reducing background, beam diagnostics and for protection of machine components. A description is given of the different types of scrapers and of the results in the various applications obtained during the last year. In particular, the substantial improvements in luminosity and background by scraping are described.

1. Introduction

General Purpose Scrapers^{1,2} were originally installed in the ISR for the following reasons:

- a) to avoid thermal distortion of the inflector shutter by protons spilt out of the RF buckets during the stacking process,
- b) to remove the beam halo caused, for example, by multiple Coulomb scattering of protons by the residual gas, and
- c) for measurements of beam size and diagnostics.

In order to improve operational flexibility, a series of scrapers was added, each with a different purpose but all housed in a common vacuum chamber. Edge Scrapers were placed at each side of the beam (Fig. 1a) and a Vertical Scraping Blade below the beam (Fig. 1b) to remove horizontal and vertical haloes. These scrapers are also used as probes to locate the beam edges. A fourth scraper at the inner side of the beam serves to protect the shutter of the inflector (Fig. 1c). A fifth scraper provides simple, back-up security to the existing automatic beam dumping system by protecting the outer side of the vacuum chamber (Fig. 1c). This side is particularly vulnerable since:

- a) the stacks are made in the outer part of the vacuum chamber,
- b) the stack will spiral outwards if, by accident, the main magnetic field decays, and
- c) protons striking the outer part of the vacuum chamber tend to make many traversals, since their betatron amplitudes increase as their closed orbits shrink.

Following a proposal by K. Johnsen, the scrapers have also been used to increase considerably the luminosity of the ISR by reducing the vertical height of the injected pulses. This shaving operation is done using the General Purpose Scraper in conjunction with the Vertical Scraping Blade.

2. Principles of Operation and Construction

All the ISR scrapers work on the same principle². Each scraper consists of a thin scattering foil located at an azimuth near to a quarter betatron wavelength before the dump block and where the ratio of vertical to radial betatron functions is large. Buildup of betatron oscillation amplitude is then predominantly vertical, around 2 - 3 mm per foil traversal, and protons are absorbed by the limiting vertical

aperture of the dump block.

Figure 2 shows the assembly of the new scrapers. The Edge and the Shutter Protection Scrapers consist of 0.2 mm thick tungsten foils ① which are given a rocking motion by a stepping motor ② acting through gears ③ ④, flexible metal bellows ⑤ and electrical feedthroughs ⑥. The motor has basically 200 steps per revolution but these are interpolated electrically to give 1000 steps each corresponding to a blade movement of 0.1 mm at the plane of the proton beam. This electrical interpolation also reduces the vibrations of the foils and increases the reliability of the scraper positioning. A spring ⑦ ensures that the foil moves out of the beam in the event of a power failure. The foils can be positioned with a speed of 100 mm/s and a precision of 0.1 mm; the full stroke takes less than one second.

The Chamber Protection Scraper is similar to those described above except that the foil (3) is inclined to the axis of the beam. In this way, the protons are intercepted by a large part of the 130 mm long foil edge, so that a relatively large surface area is available to radiate the heat developed. Also, the foil is welded to a heat sink (9) at a distance of only 5 mm from the edge to aid heat conduction. Calculations show that the foil should withstand a beam interception rate of 60 A/s and even if this rate is exceeded the







Fig. 1. Configuration of Scrapers in One Ring.

heat sink will intercept the beam and provide additional protection.

The foil of the Vertical Scraper Blade ① is subdivided into 10 mm wide strips with a 0.1 mm spacing between them so as to avoid distortion when the proton beam heats a part of the blade. Other features are similar to the other scrapers except that vertical motion is given by a rack ① and pinion ① . In this case, the speed is 25 mm/s. A second bellows ① is used to compensate the air pressure on the bellows ① .

Also shown in Figure 2 is a clearing electrode (1) which removes secondary emission electrons. Resistors (1) damp cavity resonances excited by the circulating beam.

An electronic feedback system causes the scraper foils to enter the denser part of the beam at a reduced speed to protect the foils from melting. This mechanism is controlled by a signal obtained from the charge collected on the insulated scraper foils. A second feedback system prevents destruction of a stacked beam by stopping the stepping motor once a preset charge corresponding to a given amount of beam loss has been reached.

3. Operational Experience

3.1 Background Reduction by Beam Scraping

Typically 1 in 10⁵ of the protons in the ISR beams are lost per minute and interact with the vacuum chamber. This background is dependent on the vacuum and the efficiency with which electrons are removed from the beam. Often the background is characterized by fluctuations as short as a few milliseconds and modulations as long as twenty minutes. Individual bursts can be identified on recordings made anywhere around one ring and very often in the other ring as well. Beam scraping to reduce this background has proved to be a complex problem.

At first, the scrapers were used to remove the haloes around the beam (100 mA approx.). It became clear that most particles escaped vertically and by scraping away the haloes above and below the beam, the amplitudes of the background fluctuations could be reduced often with a reduction in the average level. This beneficial effect was not always assured and was sometimes of short duration (e.g. 2 minutes). It was found to be an advantage to leave the beam scraper against the beam for 2 - 5 minutes for the beam to stabilize. This stabilization is visible in the beam loss rate. Further investigations showed that an ageing beam developed a low-momentum tail which was limited by a group of non-linear resonances. The particles appeared to be lost vertically from these resonances rather than horizontally. By scraping into this tail (removing 500 - 700 mA) and clearing a 10 - 15 mm space between the beam and the resonances, an improvement in background was obtained. Leaving scrapers permanently against the beam did not give good results. Fast periodic halo scraping had the effect of increasing the loss rate while not giving any lasting improvement in background.

The adoption of beam shaving (see next section) for high luminosities and the steady improvement in the average ISR vacuum have led to low-noise high-intensity beams. It might be that removing, during stacking, particles, which have large transverse amplitudes, automatically eliminates those particles most likely to become unstable and create background.

3.2 Increasing Luminosity by Beam Scraping

The luminosity in the ISR is proportional to the current product of the two intersecting beams and inversely proportional to their effective height. At present, the luminosity is limited by the maximum current tolerated by the vacuum system. Without shaving, this current occupies only part of the available aperture.

By reducing the effective beam height and filling the full horizontal aperture with the maximum current acceptable to the vacuum system, the luminosity can be increased since it is independent of beam width. This is achieved by scraping the underside of the injected pulses which reduces their vertical emittance. It has become known as "beam shaving". For beam shaving the General Purpose Scraper is placed below the injection orbit. The degree of shaving is then equal for all pulses and independent of the final stacking orbit. The Vertical Scraping Blade is withdrawn by a few mm with respect to the General Purpose Scraper to remove the beam halo thus giving the best possible background conditions.

During the development of the beam shaving technique it was found necessary to avoid crossing the coupling resonance $(Q_V = Q_H)$ with the shaved pulses during acceleration, as this caused an exchange of the horizontal and the reduced vertical emittance. It is also necessary to avoid third order non-linear resonances which increase the emittance even when they are crossed very rapidly during the acceleration. In contrast, the fifth order sum resonances do not cause detectable blow-up.

When stacking for high luminosity using beam shaving, it is essential to fill the whole horizontal aperture at the maximum current density. Hence, the RF stacking scheme with suppressed buckets is used. In addition, the final bucket size is reduced to retain only the densest part of the bunch in longitudinal momentum space.

Beam shaving was immediately adopted for physics runs and has made it possible to almost double the luminosity for any given current. The record luminosity of 4.4 x 10^{30} cm⁻²s⁻¹, which exceeds the design aim by 10 %, was reached at the end of 1972. The currents were 11 and 12 A, the effective height was 3.2 mm and the beams occupied a 3.8 % momentum bite. The stability of these high currents was ensured by using space charge compensated working lines³ with a large Q-spread (AQ/(Ap/p)=3) and shaving of the injected pulses to 30% of their intensity. These stacks were successfully used for a 4-hour physics run.

3.3 <u>Beam Diagnostics</u>

The scrapers are used regularly as probes to locate the beam edges. For this purpose, the second feedback system in its sensitive mode stops and returns the scraper once 10 nC has been collected by the foil, corresponding to less than 3 mA beam loss.

The Vertical Scraping Blade is frequently used as a vertical, variable aperture limit for measurements of the beam diffusion and detection of resonances³. The General Purpose Scrapers have been used for beam diagnostics and measurements from the beginning of ISR running. They give an accurate, destructive measurement of beam density distribution in single pulses or in stacks, which makes it possible, in conjunction with RF scans in momentum space, to estimate the betatron amplitudes present inside a wide stack. Such measurements are usually made with the control computer logging the scraper position and the beam current. A later addition to the outer foil is a vertical 1 mm wire which has been used to make slots in stacks and to investigate diffusion-like processes such as intra-beam scattering between protons.

3.4 Protection Scrapers

The shutter protection scraper is made to swing into the protection position on every stacking cycle after the accelerated pulse has passed the open shutter. In contrast, the Chamber Protection Scraper is located in a fixed radial position. The nominal positions of these scrapers are adjusted whenever the closed orbit conditions change.

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References

 A. Barlow, J. Borer, S. Hansen, E. Jones, M. de Jonge, B.W. Montague, D. Neet. B. de Raad,
F. Schneider, W. Schnell, L. Thorndahl, S. Turner,
K. Unser, S. Van der Meer, H. Verelst -Instrumentation and Beam Diagnostics in the ISR -Proc.Int.Conf.on High Energy Acc., CERN, Geneva (1971), p. 426

A. Delizée, W.C. Middelkoop, B.W. Montague, B. de Raad, J.C. Schnuriger, J.P. Zanasco - Beam Dumping and Scraping in the CERN Intersecting Storage Rings - Proc.Int.Conf.on High Energy Acc., CERN, Geneva (1971), p. 511

R. Gueissaz - Construction Mécanique "Beam Scraper" Internal Report CERN ISR-GE/72-10 (1972)

- B.W. Montague Beam Scraping Targets in the ISR -Internal Report CERN ISR-DI/71-51 (1971)
- 3) B. Autin, J.P. Gourber, H. Laeger, L. Thorndahl -Measurement and Compensation of Space Charge Induced Q-shifts in the ISR - Paper presented to this Conference.



Fig. 2. Assembly of New Scrapers.