FEEDBACK IN RF-SEPARATORS

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(presented by H. Lengeler, CERN)

Abstract

It has been shown that the feedback in the RF-separator increases the particle deflection by ~ 15%. These operating conditions were studied with the 1 m model of the deflector. The 60 MW power level (415 kV/cm) was achieved for a pulse duration of 10 μs.

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In usual RF-separator operation, 30-50% of the power is lost in a resistive load. The reason for this is that, on the one hand, it is not advantageous to choose a small group velocity due to the fast rise in field strength, and, on the other hand, one is limited in the deflector length. Therefore, from the point of view of the separator efficiency, the use of power feedback is of interest.

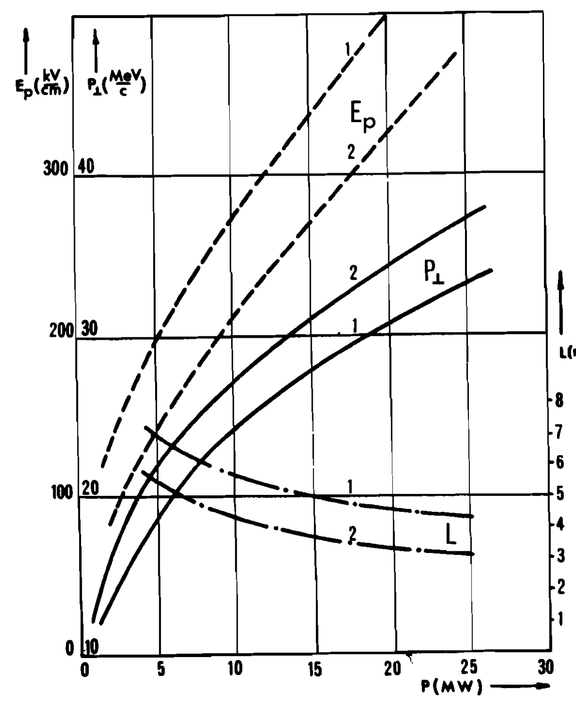

Fig. 1: Dependence of deflector parameters on power in normal operation (1) and feedback operation (2). Computations have been made by method[1,2].

We have computed the optimised parameters for deflectors (see Fig. 1) with and without feedback. For example, with a generator output of 20 MW and 20 GeV/c particles, it is possible to obtain a 13% increase in particle deflection and at the same time a decrease of the maximum electric field strength from 400 kV/cm to 325 kV/cm, a reduction in the length of the deflector from 4.5 m to 3.2 m, and an increase in the relative group velocity from $\beta_g = 0.015$ to $\beta_g = 0.04$. Alternatively, at a fixed particle deflection the feedback method will decrease the required generator power by 30-40% compared to normal operation.

Experimental investigations of the feedback principle have been carried out using a 1 m section of a disk-loaded waveguide (hybrid wave: EH_{11}, $\pi/2$ mode, $\beta_g = 0.032$, 2a = 46 mm, 2b = 119.8 mm, normalised equivalent field strength = 1.63 MeV$\sqrt{\text{MW}}$, ratio $E_p/E_\theta = 3.3$). A block-diagram of the set-up is given in Fig. 2. As a directional coupler, a magic Tee has been used with the E and H-arms matched by inductive posts (SWR = 1.05 in frequency band ± 10 MHz).

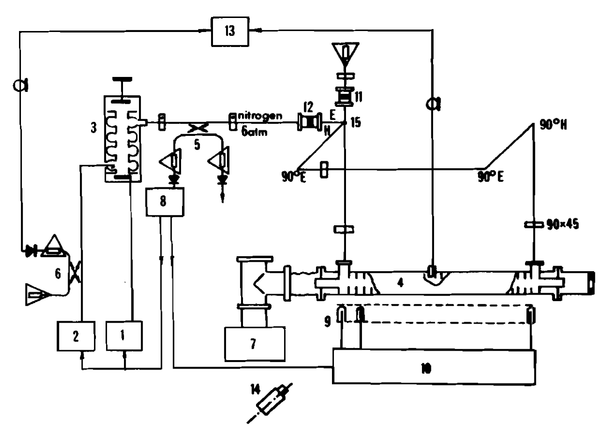

Fig. 2: Block-diagram of measuring set-up.

1. Klystron modulator; 2. Klystron driver;
3. Klystron; 4. Deflector;
5,6. Directional couplers; 7. Titanium pump;
8. Fast protection system;
9. X-radiation detectors; 10. Display;
11,12. Ceramic windows; 13. Phasemeter;
14. Photomultiplier with NaI-crystal;
15. Magic Tee

The power gain in the resonant ring was 3.95 and the SWR, as measured by the nonresonant perturbation method[3] was equal to 1.12. The tuning of the resonant-system frequency to the operating frequency of the deflector has been done by selecting the length of the waveguide between the output of the coupler with the H-arm of the magic Tee. The present system of thermo-stabilising of the deflector makes unnecessary a phase-shifter in the ring.

a)

b)

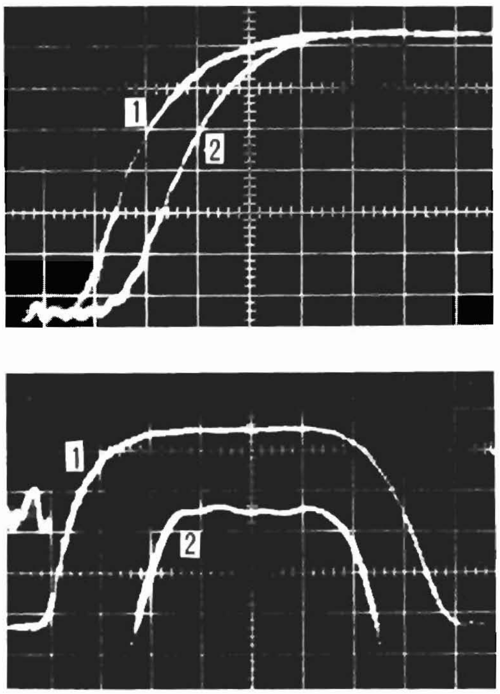

Fig. 3: Signals in feedback operation.

a) Signals at the klystron output (1) and at the pick-up of the deflector (2) (0.5 μs per division).

b) Signal at the klystron output (1) and the phase shift (2) between the pick-up signal and that of driver (1 μs per division, 5° per division).

Fig. 3 shows oscillograms of the RF amplitudes at the pick-up located in the center of the deflector and at the klystron, and of the relative phase between the pick-up signal and that of the klystron driver. The phase measurements were performed using the phasemeter described in[4]. Similar curves have been obtained by computation using the assumption that the deflector is a dispersion-free delay line with $\tau = L/V_g$ (τ = delay, L = length of the deflector). Then the wave B(t) in the deflector will be determined by the wave A(t) at the output of the klystron through the formula

$$B(t) = \frac{1}{\sqrt{2}} \sum_{k=0}^{N} A(t-k\tau)(T/\sqrt{2})^k$$

where T is the transmission coefficient in the deflector, N is the number of the wave circulations in the ring. The RF phase of the klystron driver is taken as a reference for the phases A(t) and B(t).

The discrepancy between the measured and computed values of the amplitudes and phases does not exceed 1% and 2°, respectively. Furthermore, it confirms the validity of the assumption used in the computations. Similar estimates have been made for the 4 m deflector. If the signal rise time at the klystron output (up to 98% level) is 2 μs, the rise time (to the same level) at the deflector is increased by 1.2 μs. The operation of an RF separator in feedback mode is possible at the expense of a comparatively small increase in the duration of the pulse.

a)

b)

c)

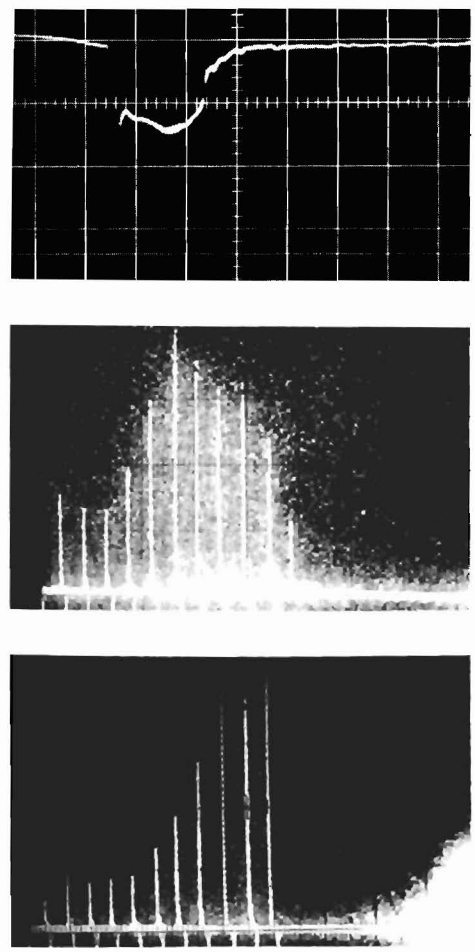

Fig. 4: X-ray radiation during breakdown.

a) Pulse of X-ray radiation (1 μs per division, obtained from a photomultiplier).

b) Distribution of X-ray radiation along the deflector during breakdown in the middle.

c) During breakdown at the end.

Tests on feedback have been performed with a vacuum of 3×10^{-7} torr at the input of the deflector (near the titanium pump) and with 1×10^{-6} torr at the output. In order to decrease the energy fraction dissipated in the breakdown, the set-up was equipped with a fast protection system which switches off the drive within 0.8 μs after the breakdown occurs[5].

Breakdowns inside the deflector were registered by means of eleven X-ray detectors, situated along the deflector and operated in the proportional region (see Fig. 4). The spectrum and intensity of the X-ray radiation were determined by using a photomultiplier with a NaI scintillator. Fig. 5 shows the dependence of the number of breakdowns per hour on the power level in the deflector for different forming times. The duration of the RF pulse was 10 μs and the repetition rate was 2 Hz.

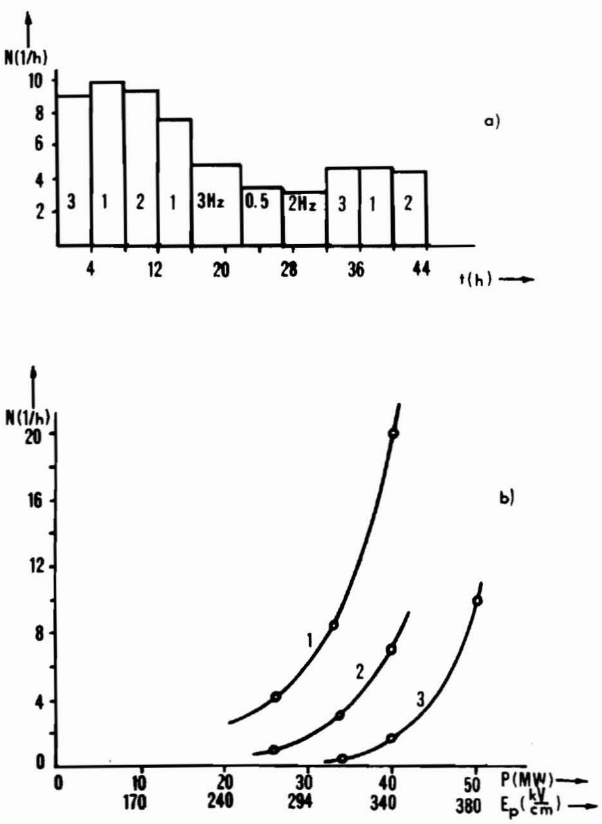

Fig. 5: a) Histogram of the number of breakdowns per hour in the deflector at different pulse repetition rates.

b) Dependence of the number of breakdowns per hour (N) on the power level and on the maximum field strength;

1 - after 100 hour running;
2 - after 300 hours, and
3 - after 500 hours.

It is seen from Fig. 5 that the electrical reliability of the deflector was improved continuously during 500 hours of running. The maximum field strength of 400 kV/cm is probably not yet a limit at the RF pulse length of 10 μs.

Fig. 5 is a histogram of the number of breakdowns per hour after 200 hours of running at a power level of 35 MW and different RF pulse repetition rates. As can be seen from this figure, there is no direct correlation between the pulse repetition rate and the number of breakdowns. A satisfactory explanation of this fact has not yet been found. However, during the operation of an RF separator[6], the increase of the repetition rate should significantly decrease the probability of breakdown occurring during the pulses which correspond to the beam-burst.

The dependence of the intensity of the X-ray radiation on the power level in the deflector when no breakdowns occur, measured at a distance of 1.5 m from the coupler, is described by an exponential law (see Fig. 6a).

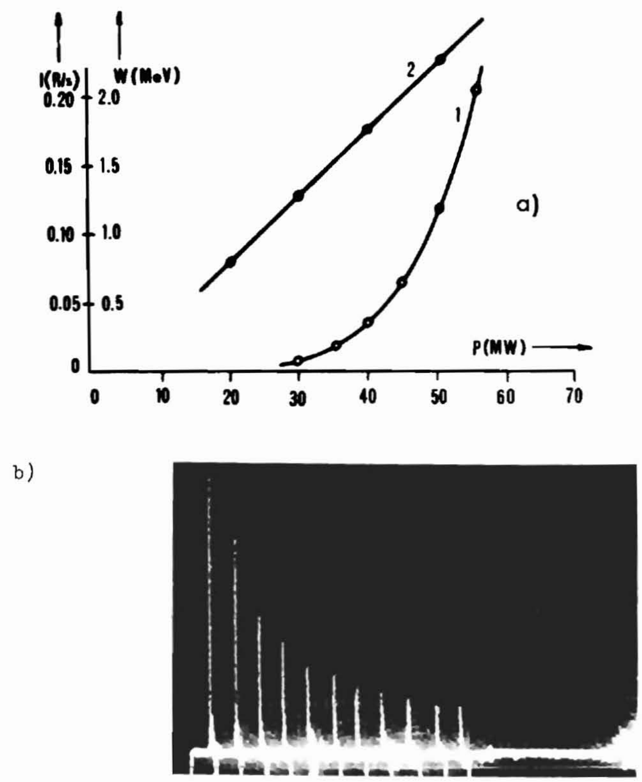

Fig. 6: X-ray radiation in the absence of breakdowns.

a) Dependence of the intensity (1) and energy (2) on the power level.

b) Distribution of X-ray radiation along the deflector. The sensitivity is 10 times less than in Fig. 4.

During breakdown, the radiation intensity increases considerably (see oscilloscope trace in Fig. 4a). After forming the deflector, the level of the X-ray radiation decreases substantially. The energy of X-ray radiation increases linearly with the power (see Fig. 6a). The maximum energy of γ-quanta reaches a magnitude of some MeV; this suggests an electron acceleration process in the field of the hybrid wave EH_{11}.

References

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3) V. G. Zarucheysky, I. R. Yampolsky IHEP 70-55, Serpukhov (1970).

4) A. M. Vishnevskaya, B. V. Prosin PTE, N1 Moscow (1971).

5) V. M. Levin et al., Proceedings, National Conference on Particle Accelerators, Moscow (1970).

6) H. Lengeler, CERN/TC/BEAM 65-4 (1965).

DISCUSSION

H. SCHOPPER : What pulse length can one hope to obtain in practice ?

H. LENGELER : Not more than the pulse length of the klystron !