SPS-DI/PA/EJNW/jf

20 April 1977

SPS COMMISSIONING REPORT NO. 56

Subject : SPS Storage - Tests at High Intensity

Date of Exp. : 30 March and 15 April 1977

Experimenters : B. Angerth, P.E. Faugeras, H.K. Kuhn, R. Lauckner, T. Linnecar, A. Millich, W. Mills, J.D. Pahud, S. van der Meer, E.J.N. Wilson

--oOo--

1. Vacuum pressure

At the time of writing Commissioning Report No. 52, which described the first coasting beam experiment, we had to rely upon indications of vacuum pressure recorded in the main control room.

Measuring locally in auxiliary buildings, we find typically a few times 10^{-9} Torr. This is so far below the full-scale reading which gauges and data transmission systems were designed to handle, that we can discard control room indications as dominated by noise and believe the local measurements. Even in the auxiliary buildings, gauges and pumps barely give a reading, nevertheless on the basis of the local survey of the ring (Table 1) we feel confident that the average pressure is below 10^{-8} and probably lower than 7.5×10^{-9}, the value computed from the table.

From the point of view of storage ring proponents this is good news, since one can hope for scattering lifetimes of more than 1000 minutes at 200 GeV and twice this at 270 GeV. However, we are no longer able to explain the results of the first coasting beam experiment with lifetimes of 100 to 200 minutes by Coulomb scattering.

2. The Experiment

Apart from the re-establishing data obtained in the first run we intended to vary a few of the more obvious machine parameters to give more information about the loss mechanism and to investigate its dependence on local and average proton density. One must bear in mind that the antiproton-proton proposal requires storage times of many hours with a low total current $\sim 10^{12}$ protons concentrated in a few short bunches held with r.f. on. Measurements made with r.f. off are therefore relevant only insofar as they might give a clue to the loss mechanism, perhaps through comparison with ISR results.

3. Machine Conditions

The data was taken in two separate M.D. sessions during which conditions were as identical as might be hoped for :

Cycle	:	200/400 GeV
RF voltage	:	840 kV
Bucket half height	:	5.6×10^{-4}
Synchrotron frequency	:	97 Hz
Sextupoles, Octupoles, Skew Quadrupoles	:	off

Date	:	30/3/77	15/4/77
Q_H	:	26.62	26.63
Q_V	:	26.57	26.56
ΔQ (ripple)	:	1.5×10^{-3}	
Mean pressure	:	7.5×10^{-9}	5×10^{-9} (Torr N_2 equiv.)
Coast numbers	:	11 to 19	20 to 23

4. The Data

Figures 1, 2 and 3 show the logarithmic decay of the coasting beam measured by a BCT whose resolution (1 bit) is 3×10^{10}. In some cases we show the time variation of the reciprocal of the slope of the decay - the instantaneous lifetime. In others we indicate its value during the coast. Further experiments will be needed to identify the cause of decay when high intensities are requested from the PS but a few general comments may guide the reader through the data.

a) Coast 11 with r.f. off reproduces results obtained in the earlier run when the active transverse damper was on.

b) Coast 13, where it overlaps coast 11 shows twice the instantaneous lifetime which developed eventually to 400 minutes, nearly 7 hours. We suspect that the improvement was due to the damper being off. Low level amplifier noise applied to the damper may disturb the coasting beam.

c) Coasts 18 and 14, with r.f. on, are longer lived than the others where the r.f. is off. The data without r.f. all have a rapid initial decrement. This decrement is very pronounced as one injects a higher intensity (19) and one is tempted to speculate about brick-walls. The ISR brick-wall was a resistive wall instability and one expects an improvement with the damper on. Comparing coasts 16 and 19 we find this to be the case.

d) Even in the most favourable condition with both r.f. and damper on the decay rate of a high intensity (coast 18) is considerably more rapid than at low intensity (14). This comparison is even more marked in the data from the second series of coasts where, at low intensity (20), the BCT fell only 3 $\times 10^{10}$ after twenty-five minutes - a lifetime of 12 hrs and comparable with Coulomb scattering. At high intensity (21), even discounting a short period where power supply regulation went astray, the lifetime is less than one hour.

e) To try and find whether the decay was due to just the total number of protons injected, as one might expect from an instability caused by neutralisation by electrons, or dependent on the local current density, as one might expect from an instability affecting a small number of bunches, we packed over 10^{12} protons into 1/5th of the SPS circumference. Coast 23 shows the decay rate to be high and comparable with what one might expect from the local proton density. Within errors it resembles (21) much more than (20) for which the total circulating current was the same.

The partial filling was achieved by asking the CPS for 6 x 10^{12} and mistuning the inflector to kick only the last 4 μsec of beam into the SPS. It cannot be ruled out that the larger longitudinal and vertical emittance of a high intensity CPS beam may be the origin of the difference between (20) and (23) and the similarity between (21) and (20). We hope to persue this hypothesis in a a future run.

5. Additional Results

Figs. 4 and 5 show the same bunch sampled near the beginning and end of coast 14. In later coasts a bunch spreader was used but here we see little discernable longitudinal dilution, only the decay of the peak signal. A similar conclusion can be drawn from Figs. 6 and 7 which show the circulating beam structure during run 20. The kicker timing which produced this partially filled ring can be seen in Fig. 8.

At the end of coasts 14 and 18 we were able to steer over 90 % of the beam with radial r.f. control. Surprisingly most of the beam left the machine during the first millimeter of radial displacement; the rest, only when it hit the vacuum chamber after several centimeters displacement.

We saw no evidence of head tail or resistive wall instability in the circulating beam signals or in the spectrum analysis (Fig. 9) of a transverse pick-up once the coast had developed. However, we did see a little sporadic self bunching at the r.f. frequency and at 628 MHz during r.f. off runs. One of the unusual features of these runs was the long time ($\sim$ 1 minute) which the revolution frequency signal takes to decay. This represents about ten "debunching times" at 43 kHz for the momentum spread quoted.

6. Conclusions

Each run brings longer low intensity lifetimes and fortunately the best conditions is with r.f. on (12 hours decay time).

The origin of the much more rapid loss at high intensity is more likely to be found in the larger emittance of the CPS beam or some collective affect with a short memory rather than in the interaction between electrons and protons. Further study is needed to resolve this.

Reported by : E.J.N. Wilson

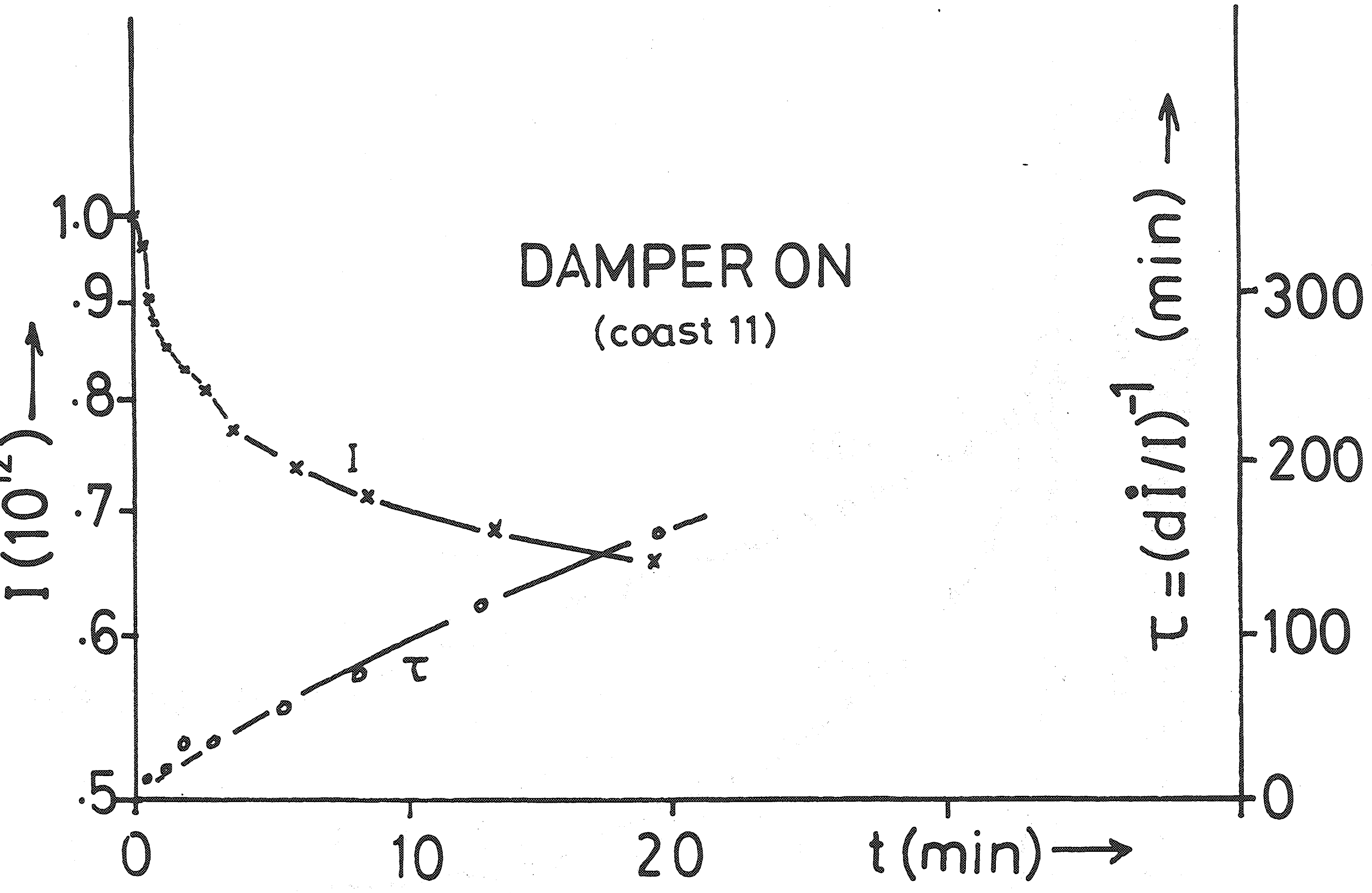
Table 1 **Pressures in the SPS Vacuum System** (28.3.1977)

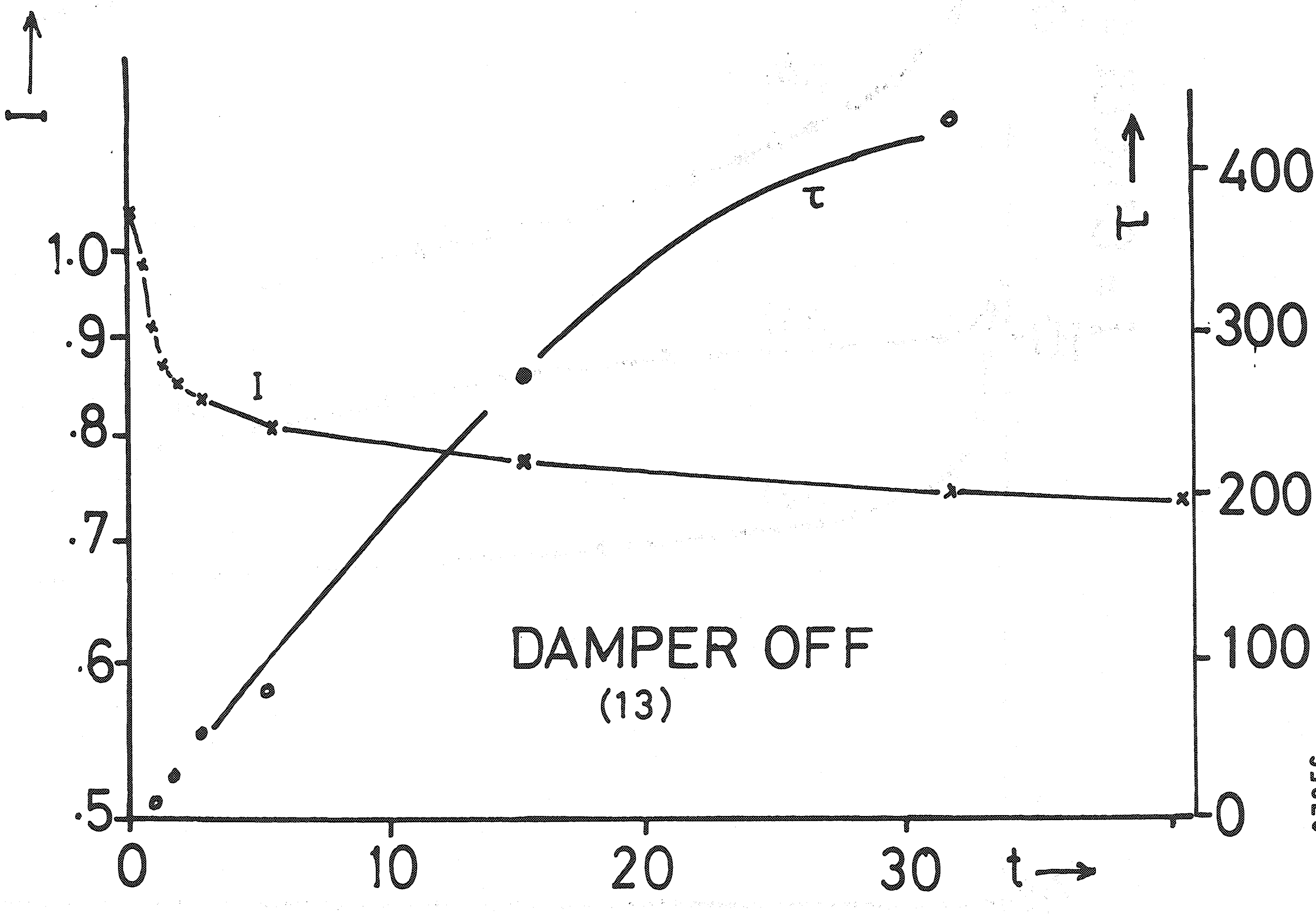
	MINUS SECTOR - 0101 to - 1301		MINUS SECTOR - 1301 to - 1601		LONG STRAIGHT SECTION - 1601 to - 2001		PLUS SECTOR - 2001 to - 2301		PLUS SECTOR - 2301 to - 0101	
	ion pumps	gauges	ion pumps	gauges	ion pumps	gauges	ion pumps	gauges	ion pumps	gauges
TS 1 *	$1{,}9 \times 10^{-8}$	6×10^{-9}	$9{,}8 \times 10^{-9}$	3×10^{-8}	(1×10^{-7}) $2{,}5 \times 10^{-9}$ ∿15 m at 1×10^{-7} torr	(3×10^{-8}) 6×10^{-9}	$1{,}2 \times 10^{-8}$	9×10^{-9}	7×10^{-9}	6×10^{-9}
TS 2	$3{,}7 \times 10^{-9}$	8×10^{-9}	$2{,}7 \times 10^{-9}$	7×10^{-9}	4×10^{-9}	7×10^{-9}	$3{,}3 \times 10^{-9}$	8×10^{-9}	3×10^{-9}	7×10^{-9}
TS 3	7×10^{-9}	9×10^{-9}	$1{,}9 \times 10^{-9}$	** $\sim 1 \times 10^{-9}$	$3{,}4 \times 10^{-9}$	6×10^{-9}	6×10^{-9}	6×10^{-9}	$3{,}8 \times 10^{-9}$	6×10^{-9}
TS 4	$5{,}5 \times 10^{-9}$	$7{,}5 \times 10^{-9}$	$7{,}8 \times 10^{-9}$	7×10^{-9}	$4{,}4 \times 10^{-9}$	6×10^{-9}	$5{,}6 \times 10^{-9}$	1×10^{-8} near dump	$4{,}5 \times 10^{-9}$	7×10^{-9}
TS 5	1×10^{-8}	1×10^{-8}	4×10^{-9} 1×10^{-9} near BIBS ∿10 m	8×10^{-9}	2×10^{-8} 1×10^{-7} near BIBS ∿10 m	2×10^{-8}	4×10^{-9}	7×10^{-9}	2×10^{-9}	7×10^{-9}
TS 6	5×10^{-9}	7×10^{-9}	$4{,}4 \times 10^{-9}$	7×10^{-9}	ZS $4{,}8 \times 10^{-9}$ MST $4{,}6 \times 10^{-9}$ ∿ 20 m MSE $7{,}5 \times 10^{-9}$	7×10^{-9} $3{,}5 \times 10^{-8}$ 7×10^{-9}	$4{,}3 \times 10^{-}$	7×10^{-9}	6232 → 6248 6248 → 6268 6268 → 6284 6284 → 63001 63001 → 68601	$6{,}3 \times 10^{-9}$ 3×10^{-9} Leak 30 $4{,}2 \times 10^{-9}$ 1×10^{-9} Leak 30 7×10^{-9}
AVERAGE	8×10^{-9}		$7{,}6 \times 10^{-9}$		$7{,}6 \times 10^{-9}$		$7{,}5 \times 10^{-9}$		$5{,}4 \times 10^{9}$	

* TS 1 heavily affected by leakage currents.

** UHV-gauge reading.

TOTAL AVERAGE (outside "bump" regions) : $7{,}5 \times 10^{-9}$ torr





67256

Fig. 1 Coasts with R.F. off

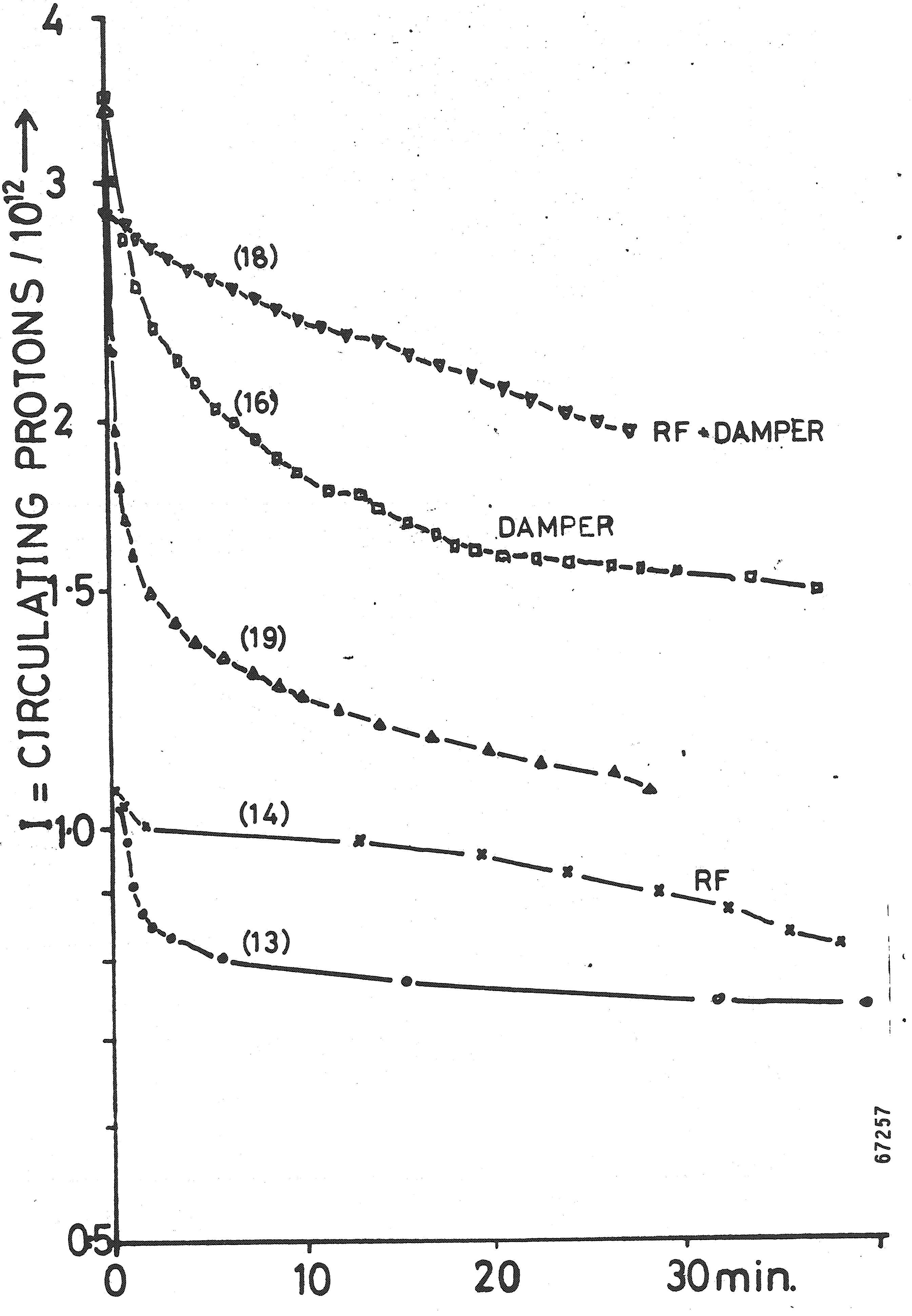


Fig. 2 Comparing high and low intensity

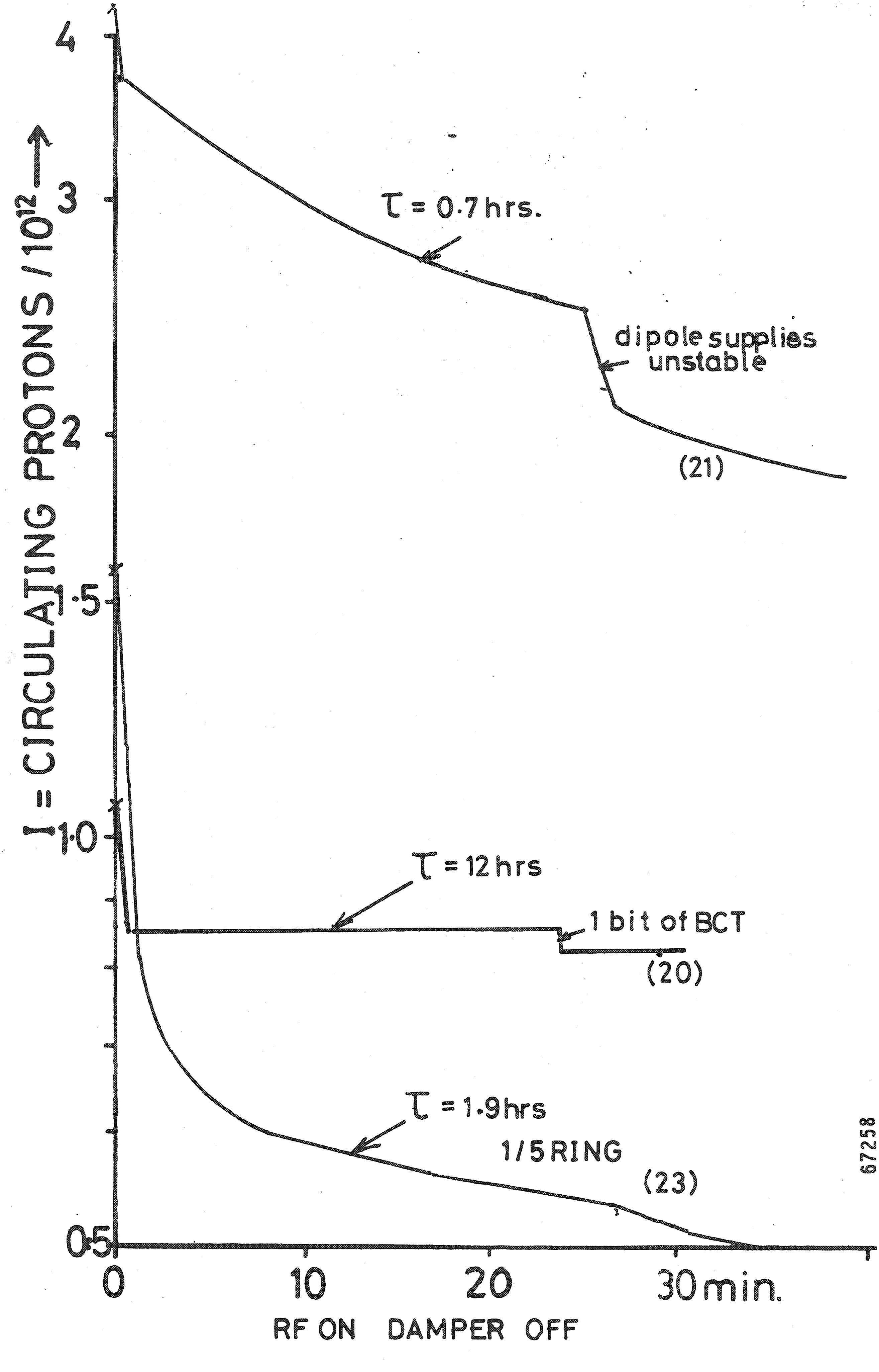


Fig. 3 Comparing partially filled and full rings

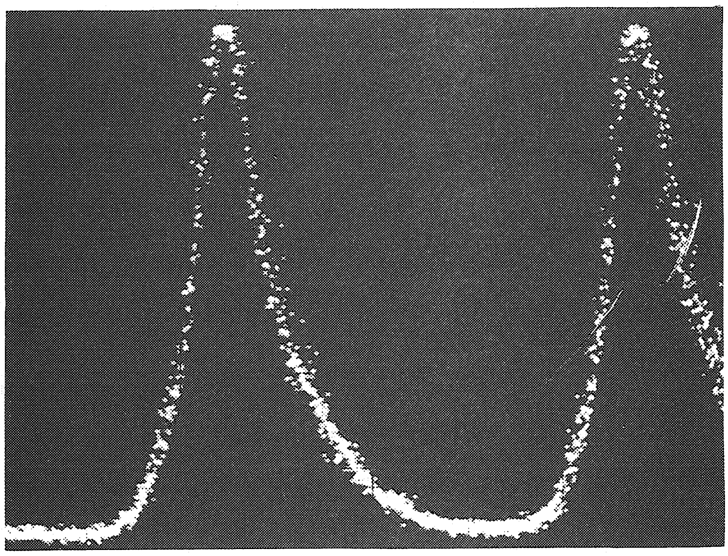


Fig. 4 1 ns/cm sampled AEW at 0416 hrs

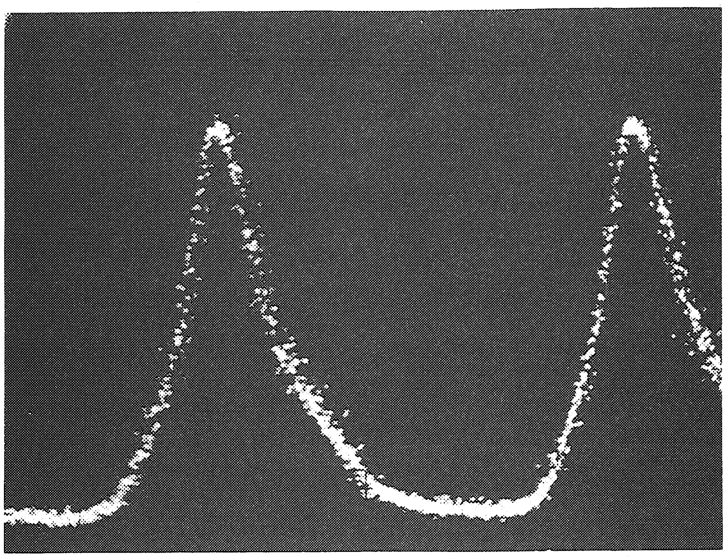


Fig. 5 1 ns/cm sampled AEW at 0435 hrs

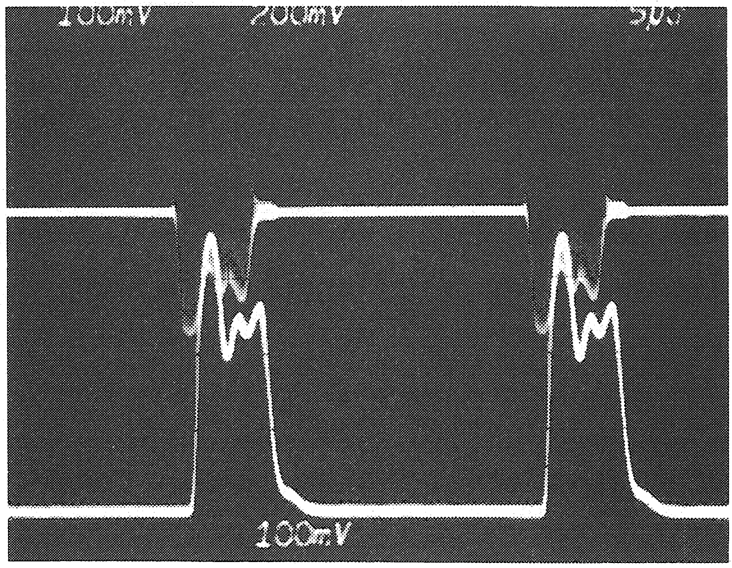


Fig. 6 AEW and Fast BCT at 1946

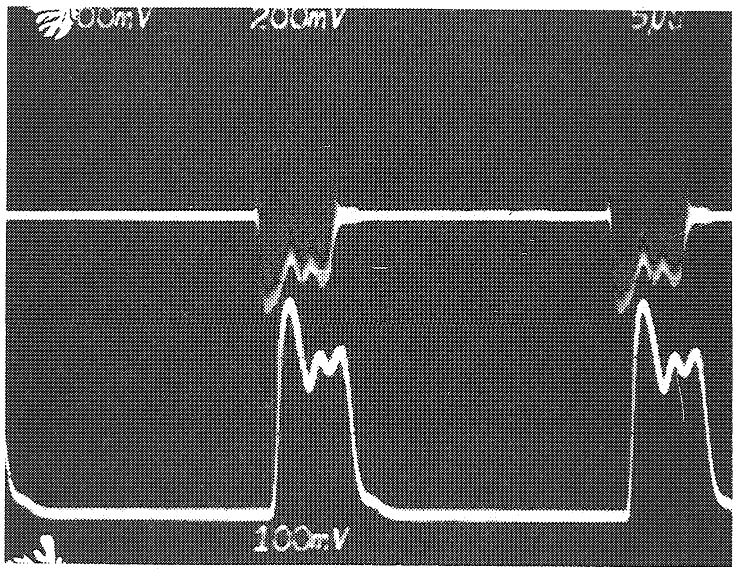


Fig. 7 AEW and Fast BCT at 2004

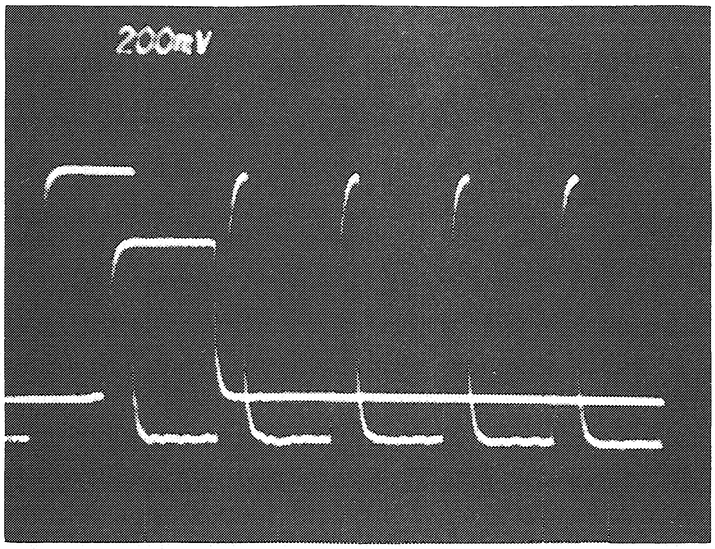


Fig. 8 Fast BCT shows first 4 turns with inflector waveform superimposed.

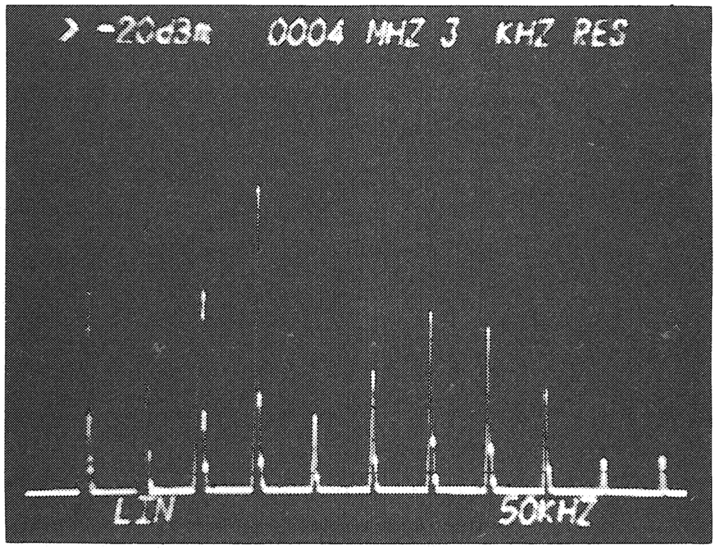


Fig. 9 Spectrum analysis of transverse pick-up showing first 10 harmonics of revolution frequency.