AP/mh

PS/ML/Note 89-1
10.01.1989

EPA MACHINE EXPERIMENT NOTE

ION SHAKING TESTS

A. Poncet and Y. Orlov

A. *FIRST TESTS ON 15-12-1988*

In a bold move to exploit the beneficial effect seen on AA, a 600 W, 5 to 50 MHz, RF power amplifier was used in conjunction with one of the vertical electrodes of the ETF 82 kicker to vertically excite the EPA electron beam at a single frequency.

The machine was operated at 500 MeV and 8 bunches of electrons. The clearing electrodes were ON throughout the tests.

The expected vertical amplitude of the beam (away from resonance) is :

600 W on 50 Ω electrodes → 173 V RMS, giving a RMS field of 173/0.08 ∽ 2 kV/m maximum.

An RMS kick of :

$$\Theta = \operatorname{atan}\left\{\frac{E.l}{p\beta} \times 10^{-9}\right\} \quad (\mathrm{m},\ \mathrm{V},\ \mathrm{GeV}/c)$$

$$= \operatorname{atan}\left\{\frac{2000 \times 0.8}{.5} \times 10^{-9}\right\} = 3.2 \times 10^{-6}\ \mathrm{rad}$$

and an RMS average maximum amplitude of the beam of :

$$\hat{x}_{RMS} = \beta v \Theta = 7.9 \times 3.2 \times 10^{-6}$$

$$\simeq .03\ \mathrm{mm}.$$

In the first experiment, the RF amplifier was fed by a single frequency signal from the spectrum analyser normally used for transverse mode observation ; the beam emittance was obtained from the analog signal of the video camera, the clearing current from the special electrode in location 32, and the vacuum performance of the machine fully recorded (for a total beam dose of ∽ 55-60 Ah to date).

The excitation level was initially set at 200 W.

The machine tunes were roughly measured at $Q_v = 4.38$, $Q_h = 4.58$, and and the exc. frequency was varied from 800 kHz up to 970 kHz, that is around the n = 0 (fractional tune) vertical mode measured at 928 kHz.

RESULTS

a) Qualitatively, it was found that :

$f_{exc} \leqslant 890$ kHz : little or no influence on emittances

$890 \leqslant f \leqslant 930$: resonances and beam losses with excitation

$930 \leqslant f \leqslant 980$: large reduction of emittances.

Record stack of 9.2×10^{11} e⁻.

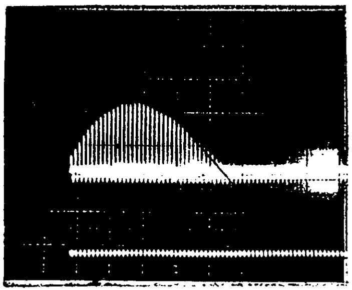
b) Quantitative emittance measurements

Frequency	Beam Intensity	εh (πmrad)		εv (πmrad)	
kHz	10^{11} e⁻	no exct.	with exct.	no exct.	with exct.
970	6	$2\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.1\cdot10^{-7}$	$6.3\cdot10^{-8}$
950	6	$1.8\cdot10^{-7}$	10^{-7}	10^{-7}	$6.9\cdot10^{-8}$
945	4.1	$1.7\cdot10^{-7}$	$8\cdot10^{-8}$	$9\cdot10^{-8}$	$3.9\cdot10^{-8}$
940	6	$1.7\cdot10^{-7}$	$8\cdot10^{-8}$	$8\cdot10^{-8}$	$6.3\cdot10^{-8}$

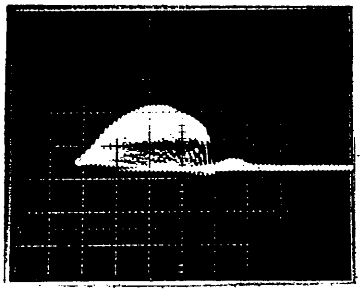
emittances obtained from the following video signals.

$6\,10^{11}$ e⁻
excitation 950 kHz ; 400 W

VERTICAL HORIZONTAL

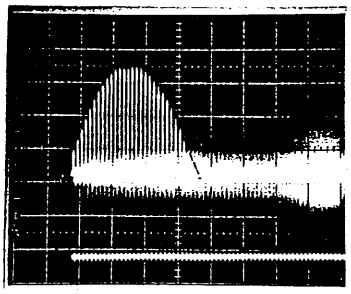


NON EXCITE

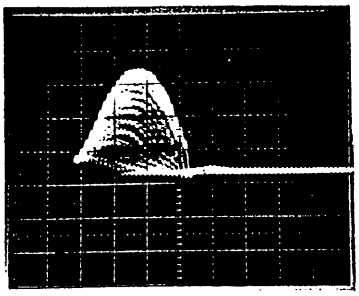


$4\sigma_v = 2.5$ msec
$\sigma_v = 1.15$ mm , $\varepsilon_v = 10^{-7}$ mrad

$4\sigma_H = 5.3$ μsec
$\sigma_H = 1.17$ mm , $\varepsilon_H = 1.8\,10^{-7}$ mrad.



EXCITE

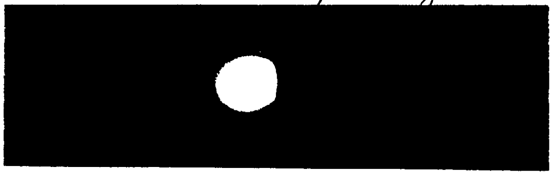


The best (most efficient) shaking frequencies were found to lie between 930-945 kHz. It allowed to reach the record stack intensity of $9.2 \cdot 10^{11}$ e^-, with very poor initial lifetime though.

Photographs below show the emittance reduction with shaking on, as seen on the TV screen giving the image of the beam in the zero dispersion station.

930 kHz . ON

945 kHz ON

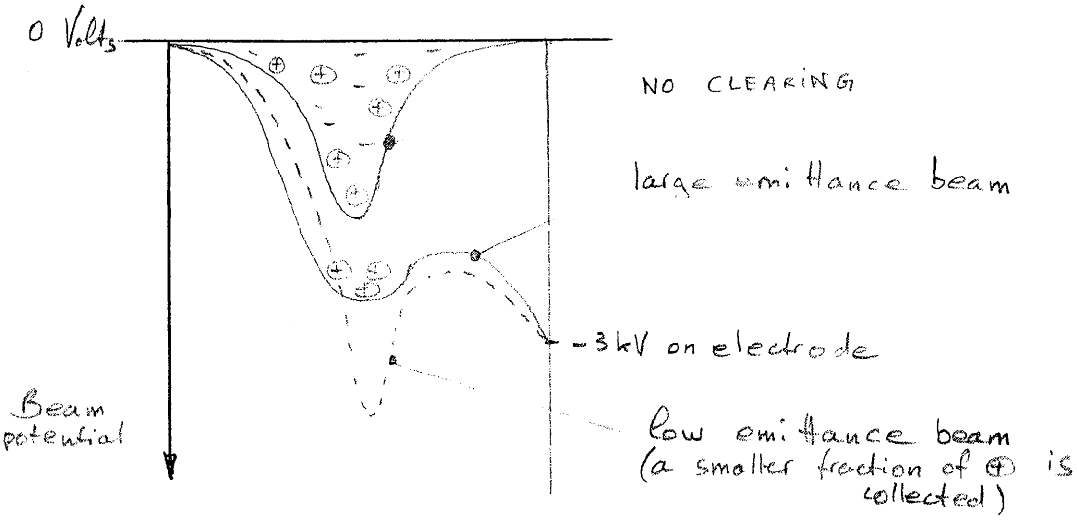


OFF

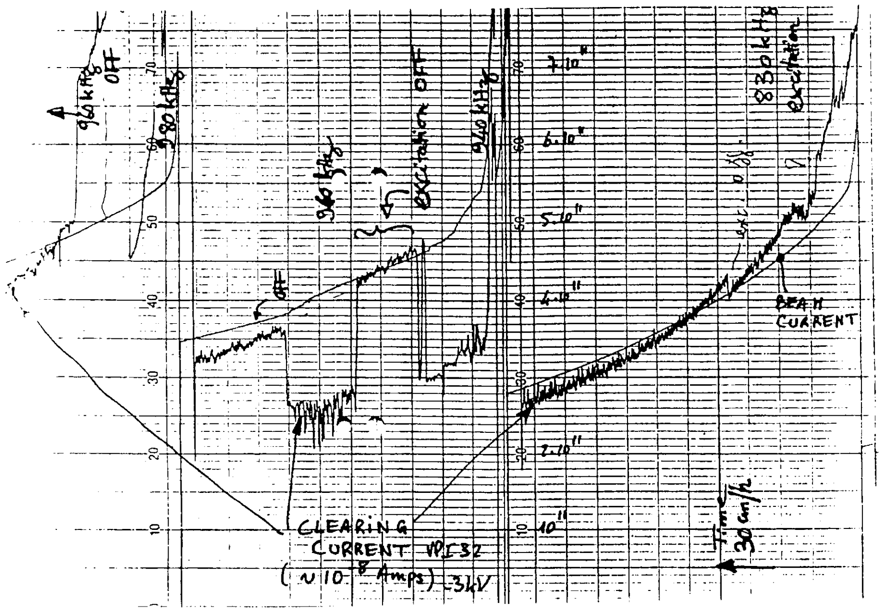
OFF

c) Clearing current measurement on electrode 32

The clearing current drawn by electrode no. 32, biaised at -3kV, was recorded throughout the experiment. For beam intensities above $\sim 10^{11}$ e-, this voltage is by far insufficient to draw out all drifting ions trapped in the beam potential. Thus only a fraction of the total ion current is collected, which depends strongly also on the beam emittance, as sketched below. Therefore the ion current is a sensitive relative measure of the beam emittance.



The ion current recordings as shown below with shaking ON/OFF illustrate this property : everything being equal, the ion current is minimum for the lowest emittance.



This recording confirmed that the best shaking frequencies were just above the n=0 (928 kHz) vertical mode. Rough tentatives to shake horizontally did not seem to yield any result. Neither did frequencies between 1 and 2 MHZ, vertically or horizontally. No dependence on the power between 200 and 400 W was observed for efficient frequencies.

d) Ion Frequencies

From the measured emittances at 945 kHz, the ion frequencies were calculated and are given below. It is found that (as for the AA) the operative excitation frequency corresponds to the bounce frequency of CO^+ ions.

```
EPA ION BOUNCE FREQUENCY AND LIFETIME.....
------------------------------------------
HORIZONTAL EMITTANCE/PI=                   .08  mm.mrad
HORIZONTAL TO VERTICAL COUPLING=                     48.75  %
VERTICAL EMITTANCE/PI =                   .039  mm.mrad
RMS LONGITUDINAL SPREAD =                          .0005  (DeltaP/P)
NUMBER OF ELECTRONS.........................=  4.1E+11  IN  8  BUNCHES

                                RMS   RMS     Horizontal     Vertical     Max   Chr      Beam  Ion
                                Half  Half    frequency      frequency   Field  Hei      Poten crit
Dist.   BetaH    BetaV Alfap  width  height  CO+    H2+     CO+    H2+    Kv/    gt      -tial  mass
(m)     (m)       (m)    (m)    (mm)   (mm)  (Mhz) (Mhz)   (Mhz)  (Mhz)   m    (mm)     (volt)

  2.34  15.00    4.85   0.00   1.10   0.43    0.7    2.6     1.1    4.1    5.8  120.0    -33.0  0.9
  3.74   8.75   11.67   0.00   0.84   0.67    0.8    3.0     0.9    3.3    5.5   38.0    -22.3  0.6
  5.64   1.89   10.80   0.65   0.51   0.65    1.2    4.4     1.0    3.9    7.0  100.0    -33.9  0.8
  6.72   1.32    8.10   1.10   0.64   0.56    1.0    3.9     1.1    4.1    7.0   38.0    -24.5  0.9
  9.99   2.18    4.65   1.58   0.89   0.43    0.8    3.1     1.2    4.5    6.7   38.0    -23.6  1.1
 12.97   4.83   14.14   0.12   0.62   0.74    1.0    3.7     0.9    3.3    5.9   38.0    -23.3  0.6
 20.36   5.09   10.21   0.00   0.64   0.63    1.0    3.7     1.0    3.8    6.5  100.0    -33.0  0.8
 24.64   8.36    6.47   0.00   0.82   0.50    0.9    3.2     1.1    4.1    6.5  150.0    -36.5  0.9
 28.42   9.96    5.26   0.00   0.89   0.45    0.8    3.1     1.2    4.3    6.5  120.0    -34.2  1.0
 39.14   5.09   10.20   0.00   0.64   0.63    1.0    3.8     1.0    3.8    6.5  100.0    -33.0  0.8
 43.91  10.42    4.99   0.00   0.91   0.44    0.8    3.0     1.2    4.4    6.5  100.0    -32.4  1.0
 46.96  13.80    3.80   0.00   1.05   0.39    0.7    2.7     1.2    4.5    6.2  100.0    -31.9  1.1
 49.24   8.26   11.28   0.00   0.81   0.66    0.8    3.1     0.9    3.4    5.7   38.0    -22.5  0.6
 52.22   1.42    7.95   1.10   0.64   0.56    1.0    3.8     1.1    4.1    7.0   38.0    -24.5  0.9
 5   9   2.07    4.75   1.58   0.89   0.43    0.8    3.1     1.2    4.5    6.7   38.0    -23.6  1.1
 57.19   1.89   10.78   0.65   0.51   0.65    1.2    4.4     1.0    3.9    7.0  100.0    -33.9  0.8
 58.47   5.07   14.29   0.12   0.64   0.75    1.0    3.6     0.9    3.3    5.9   38.0    -23.1  0.6
 61.96  14.67    3.31   0.00   1.08   0.36    0.7    2.7     1.3    4.7    6.3  100.0    -31.8  1.2
 66.57   8.75   11.66   0.00   0.84   0.67    0.8    3.0     0.9    3.3    5.5   38.0    -22.3  0.6
 68.47   1.89   10.78   0.65   0.51   0.65    1.2    4.4     1.0    3.9    7.0  100.0    -33.9  0.8
 69.55   1.32    8.07   1.10   0.64   0.56    1.0    3.9     1.1    4.1    7.0   38.0    -24.5  0.9
 72.82   2.18    4.67   1.58   0.89   0.43    0.8    3.1     1.2    4.5    6.7   38.0    -23.6  1.1
 75.80   4.83   14.18   0.12   0.62   0.74    1.0    3.7     0.9    3.3    5.9   38.0    -23.3  0.6
 78.70  13.80    3.80   0.00   1.05   0.39    0.7    2.7     1.2    4.5    6.2  100.0    -31.9  1.1
 81.76  10.42    4.99   0.00   0.91   0.44    0.8    3.0     1.2    4.4    6.5  100.0    -32.4  1.0
 86.52   5.09   10.20   0.00   0.64   0.63    1.0    3.8     1.0    3.8    6.5  100.0    -33.0  0.8
 97.28  10.13    5.15   0.00   0.90   0.45    0.8    3.1     1.2    4.3    6.5  120.0    -34.2  1.0
101.02   8.36    6.47   0.00   0.82   0.50    0.9    3.2     1.1    4.1    6.5  150.0    -36.5  0.9
105.30   5.09   10.21   0.00   0.64   0.63    1.0    3.7     1.0    3.8    6.5  100.0    -33.0  0.8
112.07   8.26   11.56   0.00   0.81   0.67    0.8    3.1     0.9    3.4    5.6   38.0    -22.5  0.6
115.05   1.42    7.92   1.10   0.64   0.56    1.0    3.8     1.1    4.1    7.0   38.0    -24.5  0.9
118.32   2.07    4.77   1.58   0.89   0.43    0.8    3.1     1.2    4.5    6.7   38.0    -23.6  1.1
120.29   2.31   11.54   0.54   0.51   0.67    1.2    4.4     1.0    3.8    6.9  100.0    -33.7  0.8
121.30   5.07   14.31   0.12   0.64   0.75    1.0    3.6     0.9    3.3    5.9   38.0    -23.1  0.6
123.32  15.00    4.85   0.00   1.10   0.43    0.7    2.6     1.1    4.1    5.8  120.0    -33.0  0.9
MACHINE AVERAGE VALUES.....
  0.00  6.23  7.90  0.28  0.73  0.53     0.9     3.2     1.0     3.8     6.1     0.0   -28.1    0.8
```

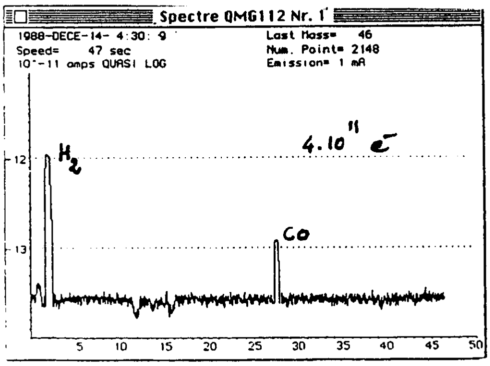
e) <u>For the record : Machine Vacuum Performance</u>

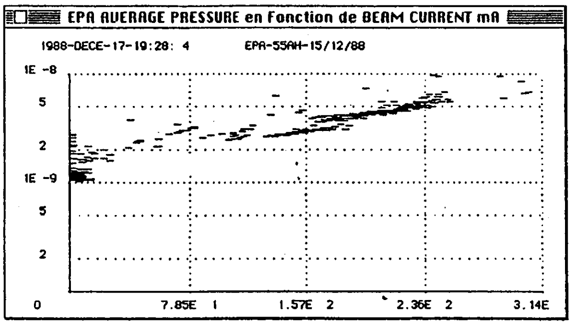
During the experiment, the machine specific pressure rise, residual gas composition, lifetimes were measured and are given here for the record. The machine lifetime, illustrated by the product :

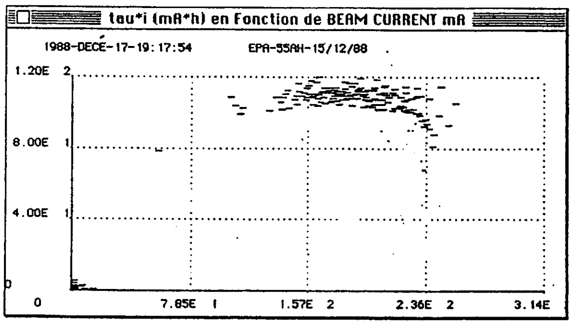
$$\tau \cdot I = 120 \text{ mAh}$$

shows an improvement by 50 to 100 percent with respect to last year measurements (Reference 1).

However, the experiment which delivered ∽ 2 Ah of dose, revealed again that the gas pressure and/or the gas composition are (everything being equal) significantly different at the end of the experiment than at the beginning (long range "activitation" of thermal outgassing).







B. SECOND EXPERIMENT ON 22-12-1988

For this experiment, we intended to :

1) scan more precisely the shaking frequency around the n=0 vertical mode,

2) measure the machine tunes shaking ON/OFF,

3) measure more precisely the emittances with the transverse array camera.

A synthesizer was used to feed the RF amplifier, while the spectrum analyser could be used to observe the machine tunes on UMA 62 (V).

The tunes (without shaking) were found at :

$$Q_v = 4.3857$$

$$Q_h = 4.5765$$

As in the first experiment, the beam was shaken vertically, but with 600 W maximum power, and clearing electrodes were ON. The machine energy was 600 MeV, in 8 electron bunches.

a) Tune Shifts Due to Ions

As an initial test, the beam was shaken at 940 kHz, 600 W, and we found that we could obtain a much larger emittance and coupling reduction than for the first experiment. We also found that we could suppress the excitation, while the beam would remain apparently undisturbed for almost 30 minutes, before the beam would suddenly recapture ions.

This allowed to precisely measure the machine tunes with and without ion capture, with NO disturbing external excitation (see fig.1 in annex)

With $n = 4.5 \times 10^{11}$ e^- :

Tunes, emittances, coupling with ions :

$Q_v = 4.3857$; $\sigma_v = 1.1$ mm ; $\beta_v = 12.3$ m ; $\varepsilon_v = 9.8 \times 10^{-8}$ pi·m·rad

$Q_h = 4.5765$; $\sigma_h = 1.1$ mm ; $\beta_h = 7.6$ m ; $\varepsilon_h = 1.6 \times 10^{-7}$ pi·m·rad

$E_0 = 2.6 \times 10^{-7}$ pi·m·rad

$C_g = 0.61$ (61 % coupling)

Tunes, emittances, coupling without ions :

$Q_v = 4.3611$; $\sigma_v = .75$ mm ; $\varepsilon_v = 4.6 \times 10^{-8}$; $E_0 = 1.2 \times 10^{-7}$

$Q_h = 4.5891$; $\sigma_h = 1.05$ mm ; $\varepsilon_h = 7.4 \times 10^{-8}$; $C_g = 0.61$

Corresponding tune shifts :

$$\Delta Q_v = 0.0246$$

$$\Delta Q_h = 0.0126$$

$$\Delta Q_{vh} = \frac{N_{e^-}\, r_e\, \overline{\beta}_{h,v}}{4\pi\, \gamma\, \sigma_{h,v}(\sigma_h + \sigma_v)}\, \eta \quad ; \quad \eta = \frac{N_{ions}}{Ne^-}$$

With ions, the numbers give the machine average beam sizes :

$$H, \ \bar{\beta}_h = 6.23 \text{ m} \qquad \sigma_h = \sqrt{1.6 \times 10^{-7} \times 6.23} = 1 \text{ mm}$$

$$V, \ \bar{\beta}_v = 7.9 \text{ m} \qquad \sigma_v = \sqrt{9.8 \times 10^{-8} \times 7.9} = .8 \text{ mm}$$

and, assuming NO ions in the corresponding case, the machine average neutralisation in the other one is :

from ΔQ_h ; $\eta = 4.3$ %

from ΔQ_v ; $\eta = 5.3$ %

Therefore, with our present clearing system, the EPA average residual neutralisation should be around 5 % in the absence of shaking.

The recording of the event represented on Figure 2 in Annex shows the behaviour of the clearing current.

Initially it is clear that the RF has a stabilizing effect, since on its removal a sizeable beam loss occurs. After 30 minutes of beam being free - or relatively free - of ions, a sudden blow-up corresponding to ion recapture occurs in 2 steps (same ion species captured in 2 different places, or two different species ?). Then it is interesting to note that a re-application of the RF causes an increased initial loss rate.

b) Emittances Versus Excitation Frequency (600 W)

The excitation frequency was varied from 800 to 950 kHz, and the beam size was measured with the transverse camera. The results are shown on Figure 3 where one notes again that shaking works best above the natural beam mode frequency n=0.

The large (∽ conservative) variations of horizontal and vertical beam sizes with RF on between 890 and 950 kHz correspond to natural coherent instabilities of the beam (head tail ?). This is illustrated on Figure 4, where the beam shape shows strong horizontal oscillations. It was noted - unfortunately at the end of the experiment - that the machine was lacking some vertical and horizontal chromaticity, on which one had played during the previous MD session.

Between 850 and 890 kHz RF excitation frequency, strong vertical oscillations and beam loss rendered the measurements impossible.

In this frequency range, the external excitation is more or less on resonance with the ion free beam mode n=0.

Finally, it has to be noted that the emittances recorded on Figure 4 were measured with RF on, as upon removal of the excitation the beam quiet time (i.e. before ion recapture) had progressively decreased to one or two minutes (from the initial 30 minutes).

As already said earlier, this is probably due to the fact that the machine pressure conditions had deteriorated following the strong dose exposure.

This is interesting, as it probably shows that the EPA vacuum is just at the edge of being sufficiently performant ion-wise (together with the clearing system).

C. CONCLUSIONS (PRELIMINARY)

Ion shaking has been seen to work on EPA, with the following qualitative findings :

a) Beam emittances and coupling are strongly reduced.

b) Lifetime is not improved, unlike the AA (but EPA and AA lifetime limitations are of different nature).

c) The best shaking frequency lies just above the n=0 beam transverse mode, and corresponds more or less to the CO+ ion bounce frequency, as for the AA (and may be the UVSOR Japanese Storage Ring, (Reference 2) to be further studied, though).

d) Shaking works only (or best) vertically, as for the AA (to be confirmed).

e) For the first time, shaking has permitted to pass a strong ion trapping threshold at high intensity, allowing the RF knock-out to be removed without ion re-capture. This is remarkable on a small machine like EPA running in 8 bunches mode, and is promising for further understanding of the ion trapping physics.

REFERENCES

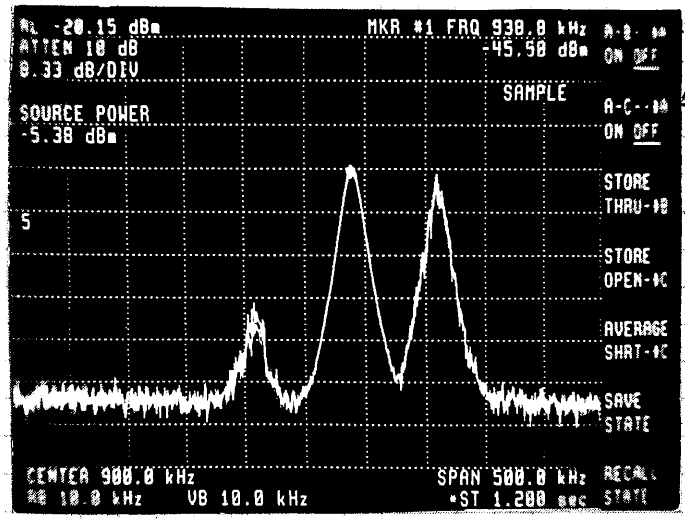
1. *EPA BEAM VACUUM Interaction and Ion Clearing System.*
F. Caspers, et al., EPAC, Rome, 1988.

2. *Ion Trapping Efect in UVSOR Storage Ring.*
T. Kasuga et al., JJAP, Vol. 24, no. 9, 1985, pp. 1212-1217.

ANNEX :

FIRST EVIDENCE OF EPA BEAM FREE OF IONS !

22/12/88



Shaking 600 W at 940 kHz

5 x 10''

Shaking removed

4.5 x 10''

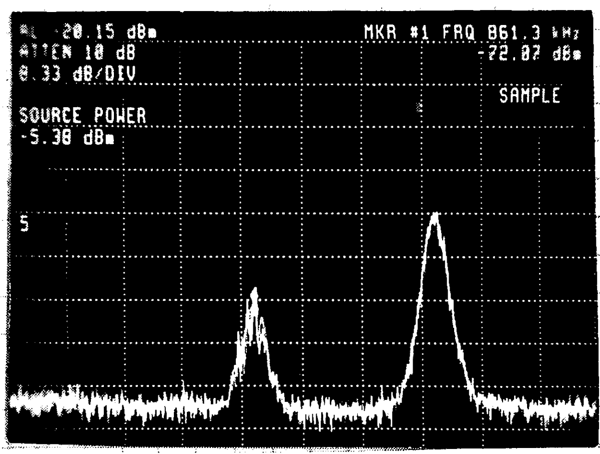
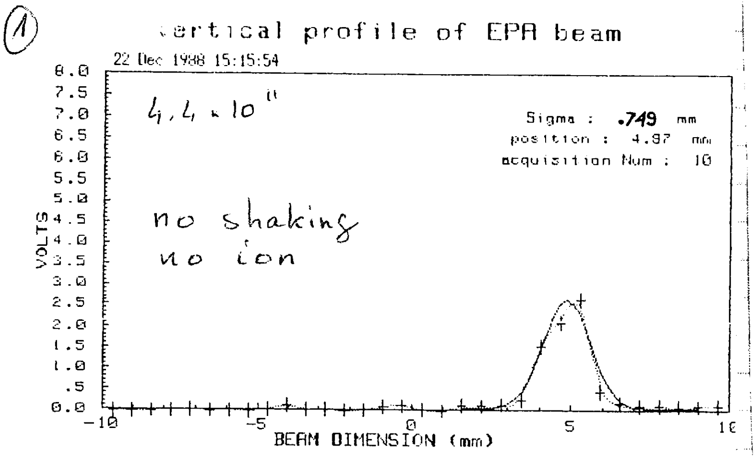
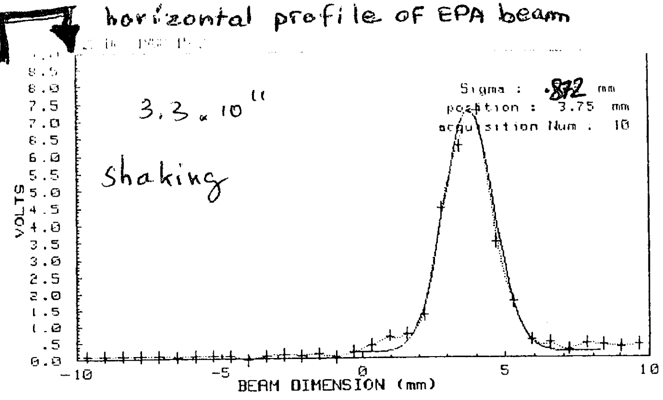
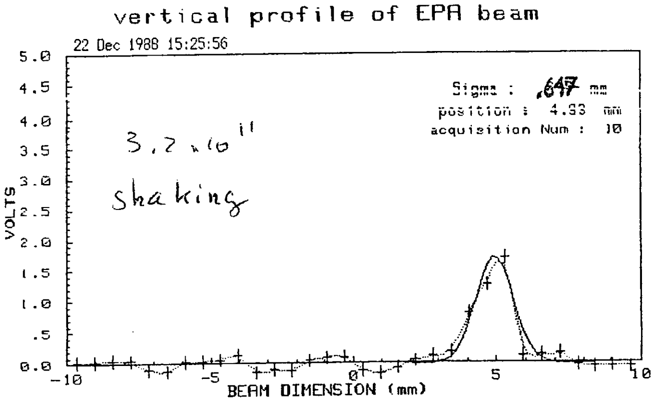
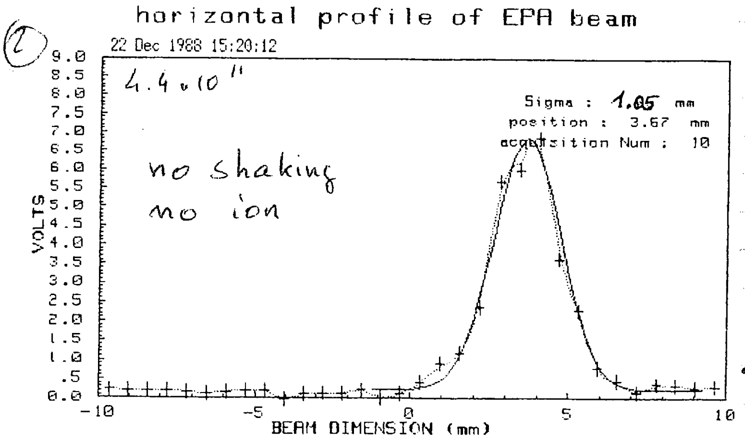


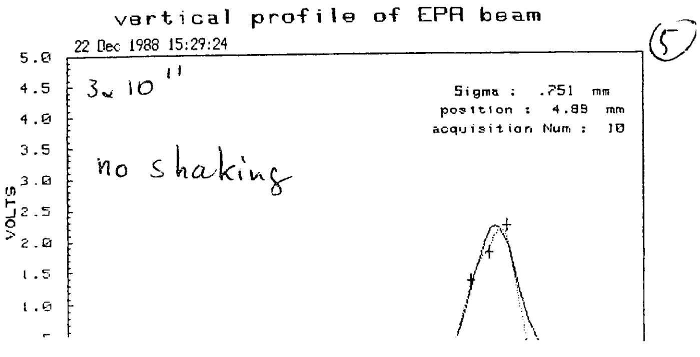
FIG. 1



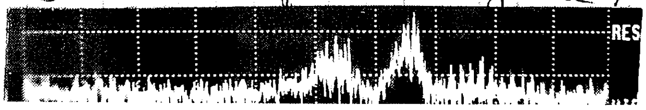


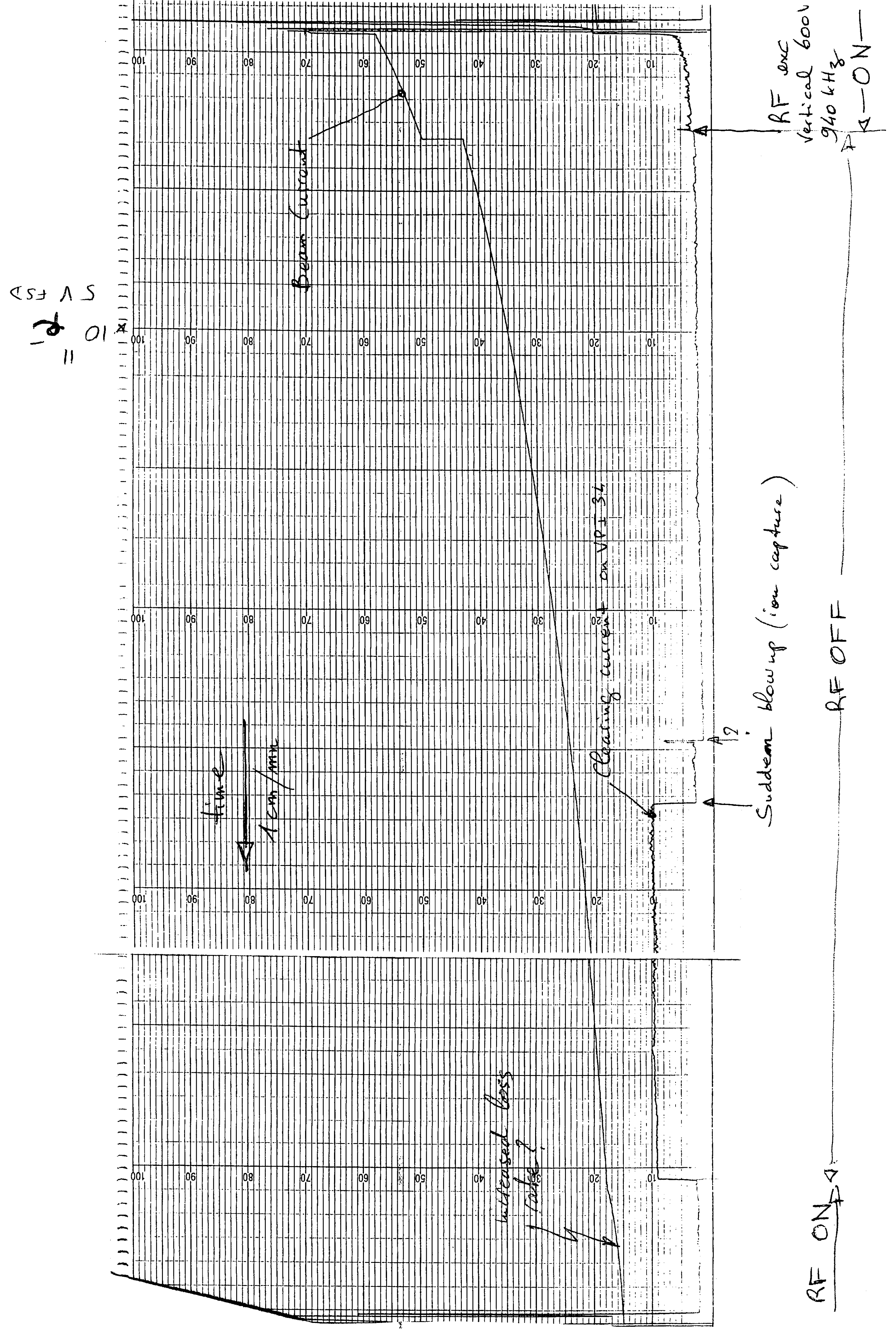






at 3 x 10'', 0.5 hour after, sudden 'capture again'!

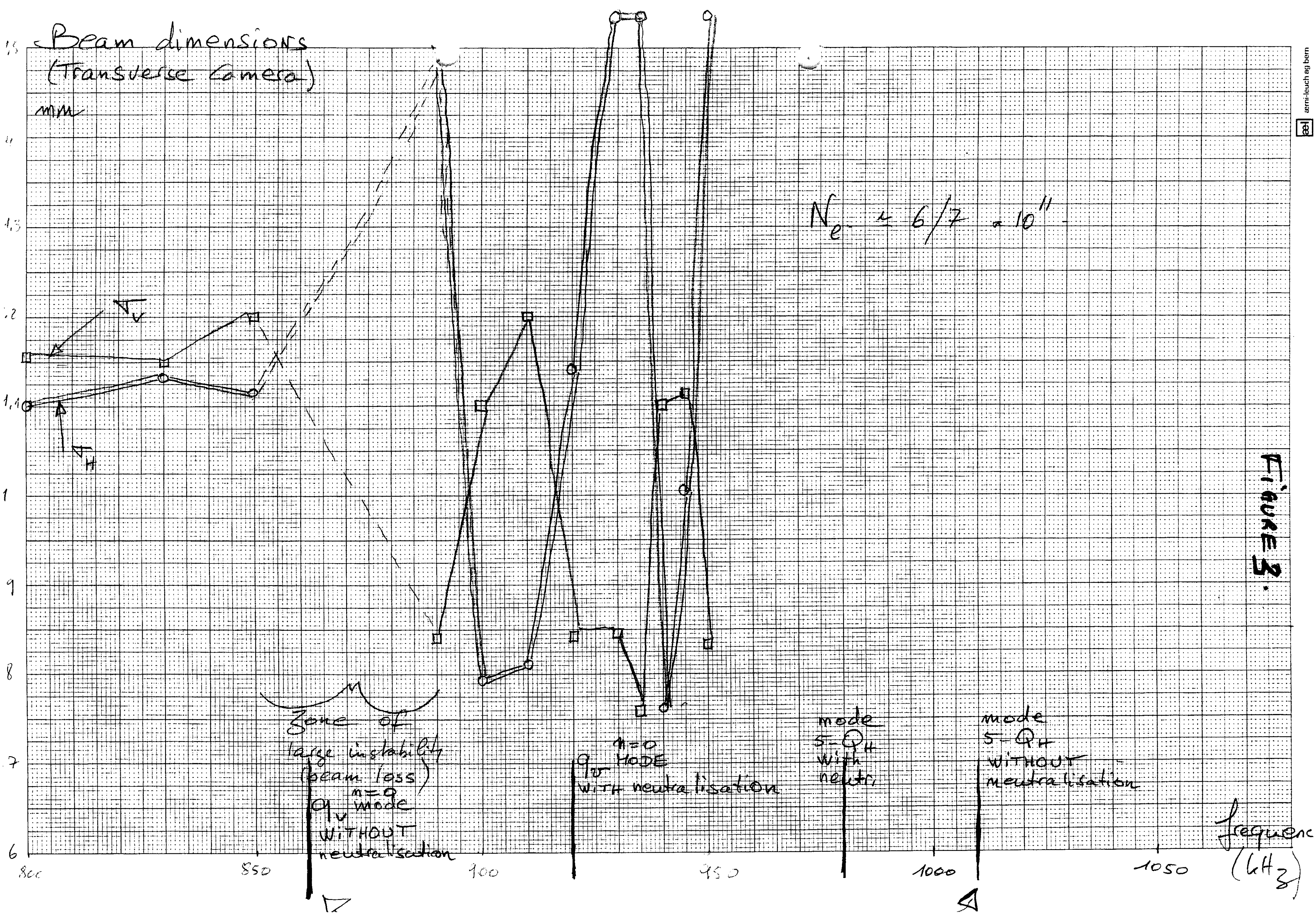



5 V FSD
= 10
100
90
80
70
60
50
40
30
20
10
Beam Current
RF exc
vertical 600V
940 kHz
ON
RF OFF
Sudden blow up (ion capture)
Clearing current on VP ± 34
time
1 cm/min
increased loss
cause ?
RF ON

ANNEX

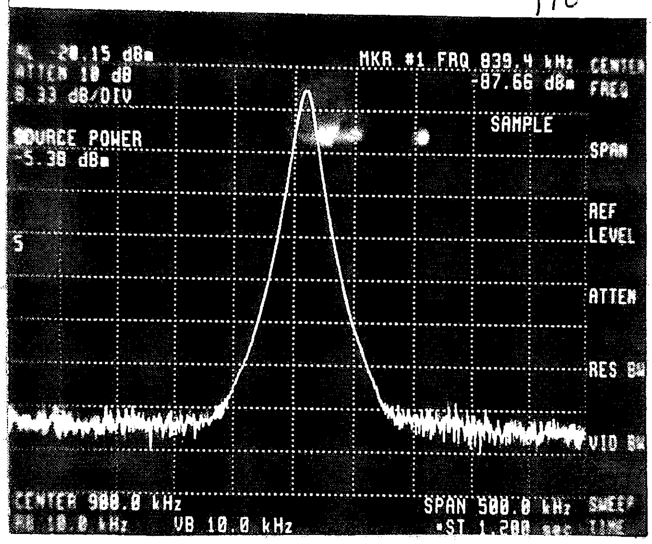
FiG. 2

FIGURE 3.


Beam dimensions
(Transverse camera)
mm
1,3
1,2
1,1
1
.9
.8
.7
.6
σ_v
σ_H
$N_e \simeq 6/7 \times 10^{11}$
Zone of large instability (beam loss)
Q_v $n=0$ mode WITHOUT neutralisation
Q_v $n=0$ MODE WITH neutralisation
mode $5-Q_H$ with neutr.
mode $5-Q_H$ WITHOUT neutralisation
800
850
900
950
1000
1050
frequenc (kHz)

0		ν_V	ν_H	c
910	ON		.812	7.6
		1.2		7.4
910	OFF		1.32	7
		1.2		6.8

7.8×10'' 910

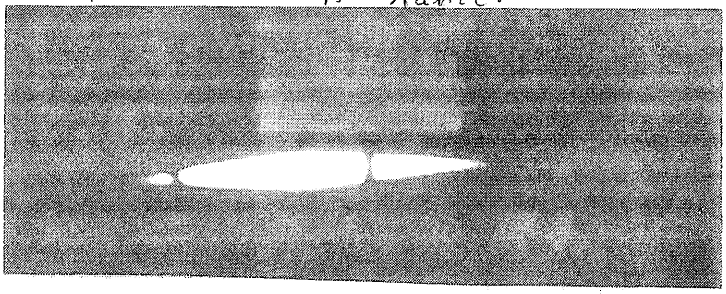


920	ON	.842		7.1
			1.14	7.3
920	OFF	1.11		6.1
			1.22	6.4

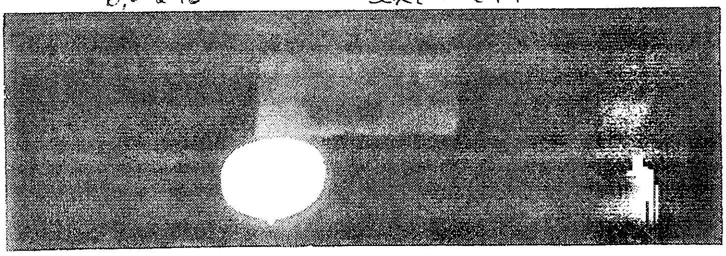
(avec recapture!)

Fig. 4

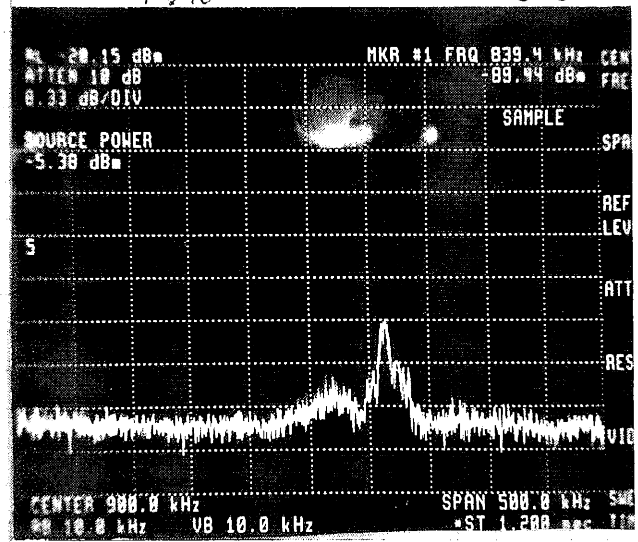
7×10'' H instabil. OFF



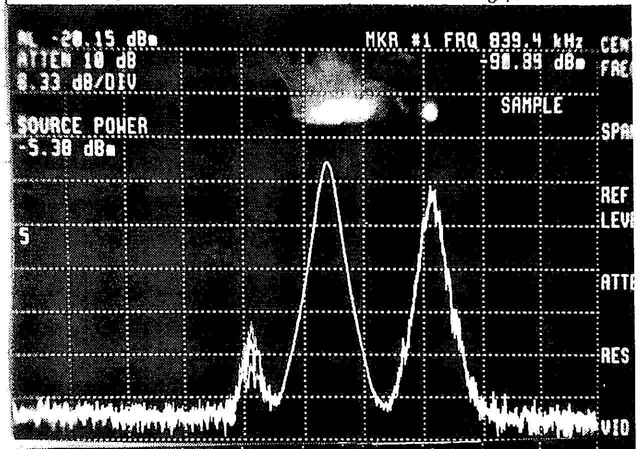
6.6×10'' exc. OFF



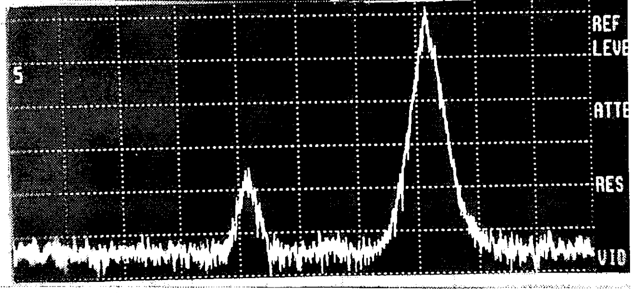
7×10'' 910



7.8×10'' 920 ON



6.7×10'' OFF



recapture après 1' 6.6×10'' OF