EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
ORGANIZATION EUROPEENNE POUR LA RECHERCHE NUCLAIRE

CERN-PS DIVISION

PS/BD NOTE 2002-140 (Tech)
Updated the 17/09/2002

REPORT ON ELECTRON COOLER NEUTRALIZATION STUDIES MADE 15 JULY 2002

J. Bosser, E-B. Holzer, V. Prieto, G. Tranquille

Geneva, Switzerland
14 August 2002

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Participants: J. Bosser, E-B. Holzer, V. Prieto, G. Tranquille

1) Experimental set-up

Two sets of neutralization electrodes are installed on the AD electron cooler (Figure 1). The first set, located between the gun and the first toroid is powered by two bipolar power supplies V_{n1} and V_{n2}

The second set, located between the second toroid and the collector is fed by two bipolar power supplies V_{n3} and V_{n4}

Depending on the voltage applied on the electrodes, either the low energy electrons or the low energy ions can be extracted from the vacuum chamber.

2) Aim of Experiment

The aim was to investigate the influence of the neutralization electrode polarization on the space charge potential (Usp [V]) of the electron beam.

It is known that the electron kinetic energy T is such that

$$\frac{\partial f_{rev}}{f_{rev}} = \frac{\partial ß}{ß} = \frac{1}{\gamma(\gamma+1)}\frac{\partial T}{T}$$

with $ß = \frac{v}{c}, \gamma = \frac{1}{\sqrt{1-ß^2}} \approx 1$ and $\gamma(\gamma+1) \approx 2$

The kinetic energy is related to the nominal acceleration voltage U_0 and to the space change potential by

$T = q[U_0 - U_{sp}]$

with $U_{sp} = \frac{3q\,a^2}{4\varepsilon_0}[n_0 + n_e - n_i] = \alpha[n_0 + n_e - n_i]$, $\alpha = \frac{3q\,a^2}{4\varepsilon_0}$

where : $n_0[m^{-3}]$ is the nominal electron density related to the nominal current by

$I_e = q\, n_0\, \pi a^2\, ßc$ (a = 25mm = electron beam radius)

: n_e [m^{-3}] is the low energy electron density

: n_i [m^{-3}] is the low energy ion density

Both n_e and n_i are much lower than n_0.

Therefore,

$$\frac{dT}{T} \approx \frac{-\alpha(dn_e - dn_i)}{U_0 - \alpha(n_0 + n_e - n_i)} = 2 \cdot \frac{df_{rev}}{f_{rev}}$$

Considering $n_i \leq n_0$ and $n_e \leq n_0$, we approximately have

$$\frac{-(dn_e - dn_i)}{n_0} \approx 2 \cdot \frac{df_{rev}}{f_{rev}} \cdot \left[\frac{U_0}{\alpha \cdot n_0} - 1\right] \qquad \text{Equation (1)}$$

As a result:

- a positively polarised electrode will collect low energy electrons. This induces a reduction of n_e, and using Equation (1) with $dn_i = 0$ implies:

$$\frac{dn_e}{n_0} < 0 \Rightarrow \frac{df_{rev}}{f_{rev}} = \frac{dß}{ß} > 0$$

- a negatively polarised electrode will collect low energy ions. This induces a reduction of n_i, and using Equation (1) with $n_e = 0$ implies:

$$\frac{dn_i}{n_0} < 0 \Rightarrow \frac{df_{rev}}{f_{rev}} = \frac{dß}{ß} < 0$$

3) Data

We operate at 300MeV/c where the revolution frequency $frev \approx 0.5$MHz. During our measurements we operate on the second harmonic

Electron cooler nominal parameter

$U_0 \approx V_{cathode} = V_{grid} = 26$kV

$I_e = 2.36$[A], $ß = 0.3$

$V_{rep} = 0.8\text{kV}, V_{col} = 3.5\text{kV}$

$$\alpha \cdot n_0 = \frac{q_0 I_e}{ß} = 708\text{V}, \frac{U_0}{\alpha \cdot n_0} - 1 = 35.7$$

Vacuum conditions at the cooler

LOCATION	PRESSURE on 10^{-11} torr
2906	2.6
2916	6.2
2919	2.2

4) Electron Cleaning

We polarise the electrodes with a positive voltage versus ground and measure the changes in the revolution frequency offset at the second harmonic. Low energy secondary electrons are extracted from the space charge, thus inducing an increase in the revolution frequency.

4.1) The polarization with V_{n1} and V_{n2} (with $V_{n3} = V_{n4} = 0$ [V]) did not give significant frequency shifts. **Note:** V_{n1} does not seem to work.

4.2) Polarising V_{n3} and / or V_{n4} results in significant frequency shifts as shown in Figure 2.

From Figure 2 we see that taking a total frequency shift $\Delta frev = 250 + 150 = 400\text{Hz}$ the corresponding change in the space charge density $-\frac{dn_e}{n_0} = \frac{2 \cdot 400}{2 \cdot 0.5\text{MHz}} \cdot 35.7 = 2.8 \cdot 10^{-2}$

5) Ion Cleaning

We now put a negative (versus ground) voltage on the neutralization electrodes and measure the corresponding revolution frequency shifts. A decrease of the ion density will result in a decrease in the revolution frequency.

5.1) Polarisation of V_{n1} gave no results

5.2) Polarisation of V_{n2} gave significant frequency shifts as shown in Figure 3.

From the measurements: $\frac{dn_i}{n_0} = \frac{2\Delta f_{rev}}{f_{rev}} = \frac{-2(750-150)}{2 \cdot 0.5\text{MHz}} \cdot 35.7 = -4.3 \cdot 10^{-2}$

5.3) Polarisation of V_{n3} and / or V_{n4}. The results are shown in Figure 4.

$$\frac{dn_i}{n_0} = \frac{2\Delta f_{rev}}{f_{rev}} = \frac{-2(380-150)}{10^6} \cdot 35.7 = -1.6 \cdot 10^{-2}$$

The number is lower than that attained in 5.2), which is coherent since secondary ions are expected to drift to the cathode.

6) Effects of CBV

Referring to Figure 2 we see that the slopes with V_{n3} alone and with V_{n4} alone are different by about a factor 2. This could be inferred to the mean position of the electron beam when passing by the neutralization electrode. We therefore modified the current of the CBV corrector. When CBV is changed from its nominal current 1.2A to 0 A the frequency shift moves from –150Hz to –230Hz.

We then changed [I (CBV) = 0.A] the voltages are V_{n3} and V_{n4} as in 5.3). The results are reported in Figure 5. The dissymmetry is still maintained.

7) Reduction of the Frequency Drift

During cooling at 300 MeV, a slightly smaller drift is obtained with $V_{n1} = V_{n2} = 0V$, $V_{n3} = V_{n4} = -25V$, I (CBV) =1.2A

8) Spectrum Analyser

We connect the spectrum analyzer on any of the PU installed along the cooler drift tube. A coherent line is present (at the time when the e-beam is ON) at 300.7 kHz. This is due to the shaker.

9) Conclusion

The relative density of the stored ionized electron and / or ions can amount to a few percent at 300 GeV/C. This number is large enough to induce observable energy shifts on the cooled antiproton beam.

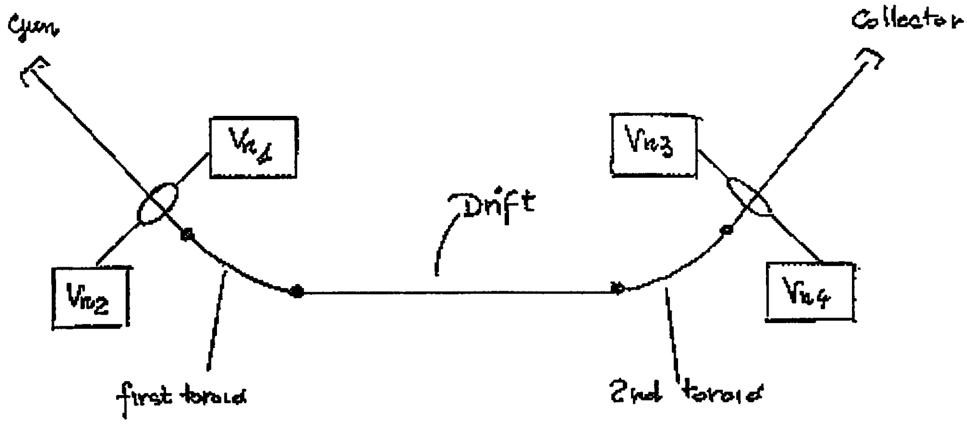

Figure 1 Experimental set up

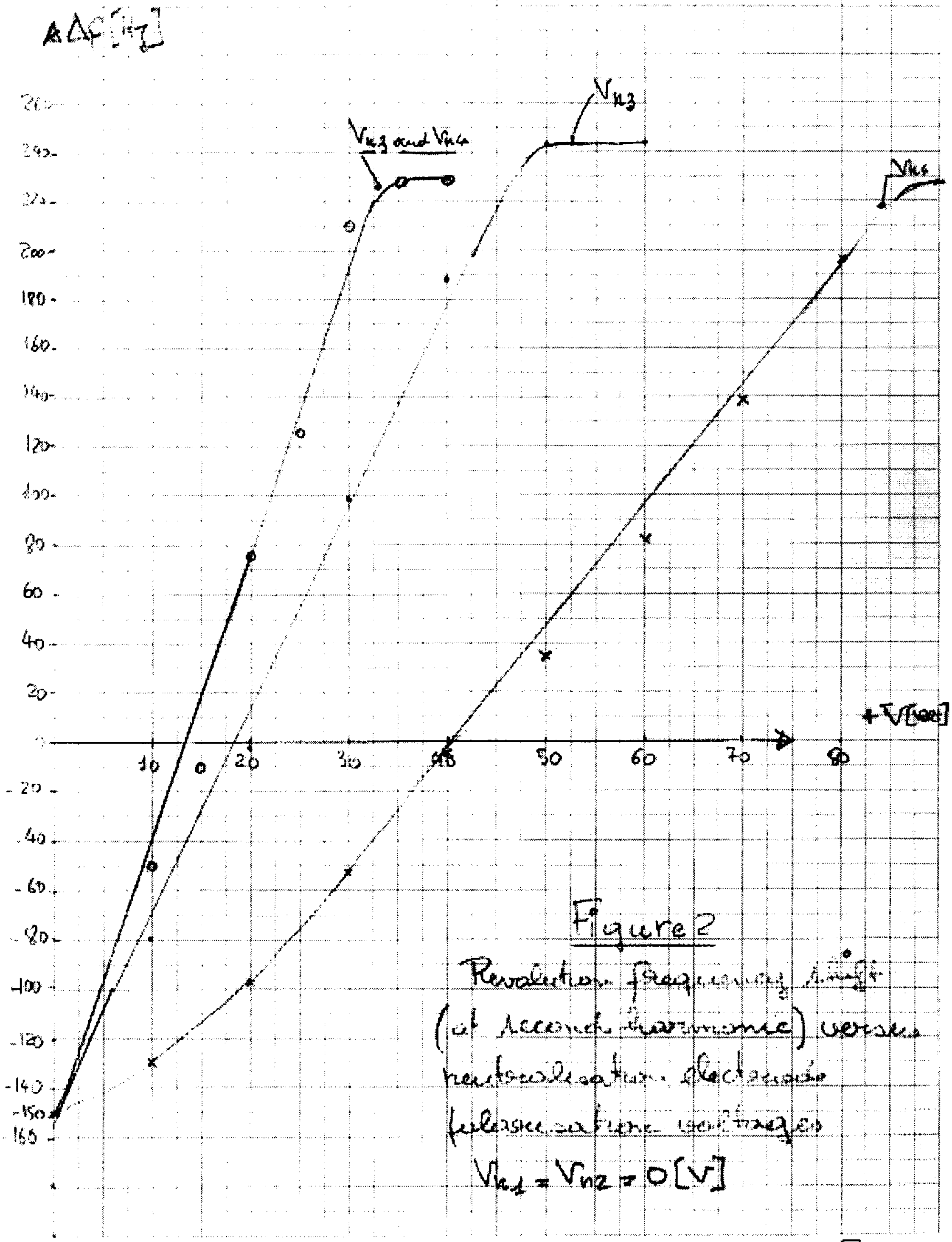

Figure 2

Revolution frequency Δf (of second harmonic) versus neutralisation electrode polarisation voltages

$V_{k1} = V_{n2} = 0\,[V]$

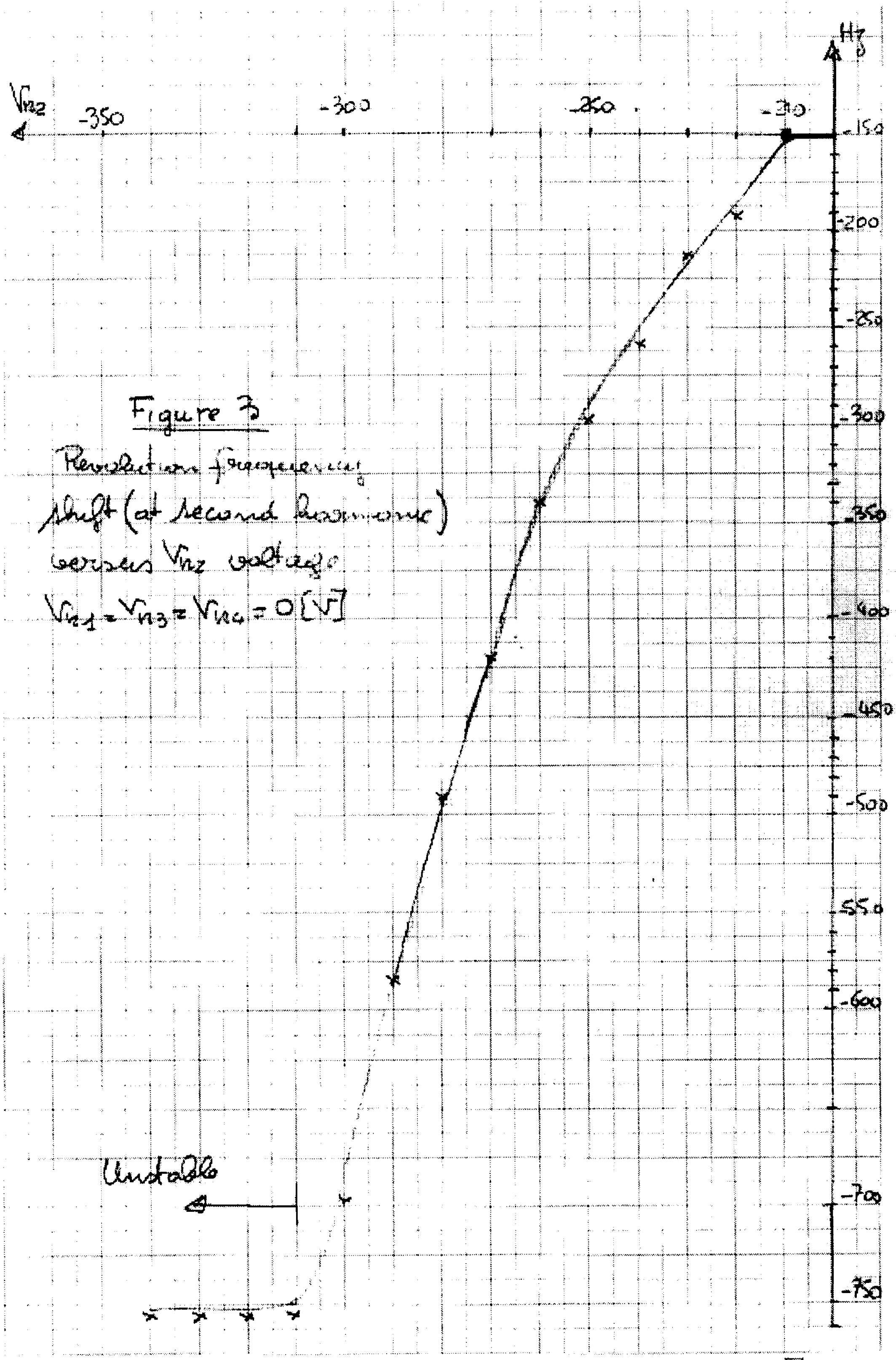

Figure 3
Revolution frequency shift (at second harmonic) versus V_{h2} voltage
$V_{h1} = V_{h3} = V_{h4} = 0$ [V]

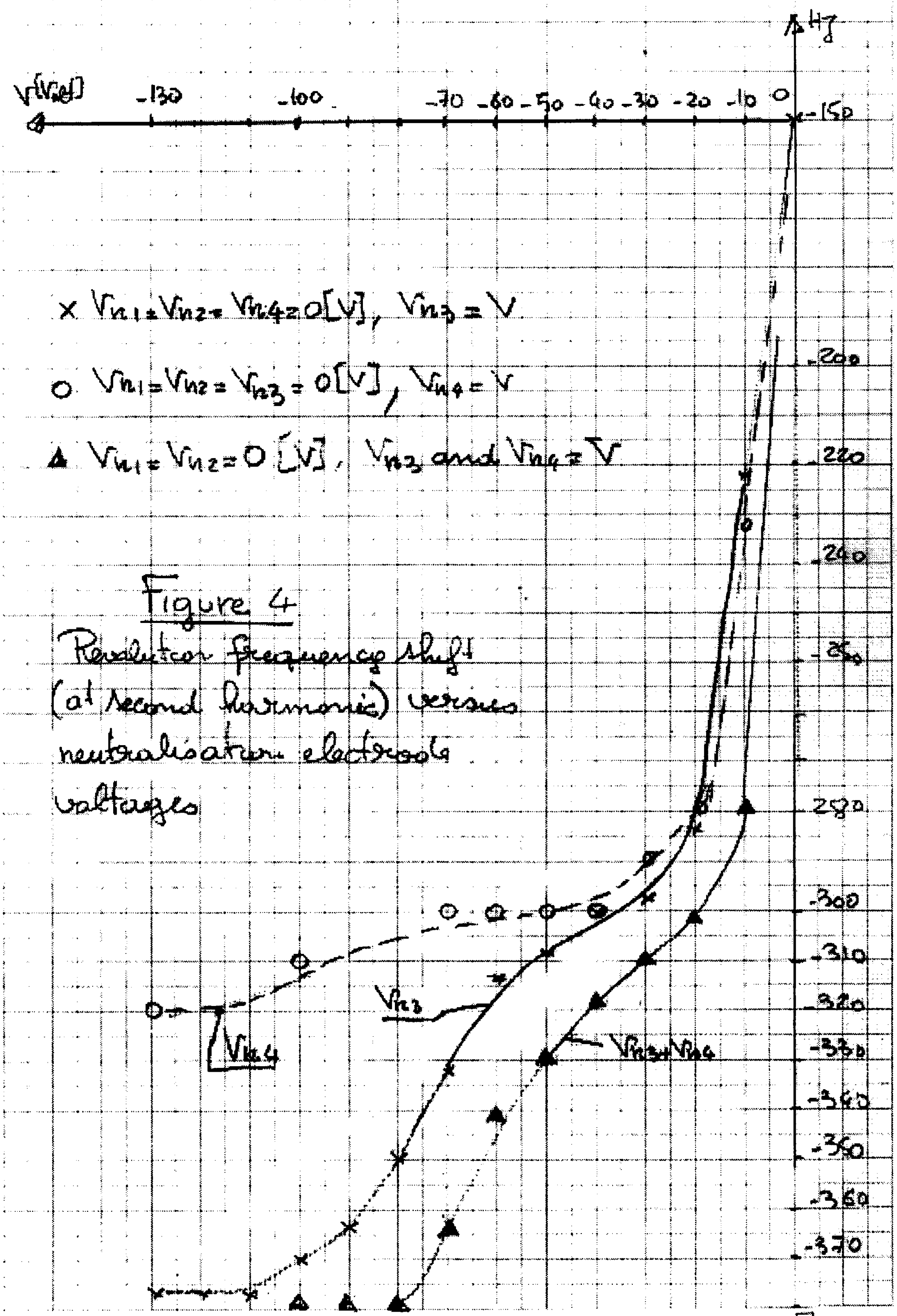

Figure 4
Resolution frequency shift (at second harmonic) versus neutralisation electrode voltages

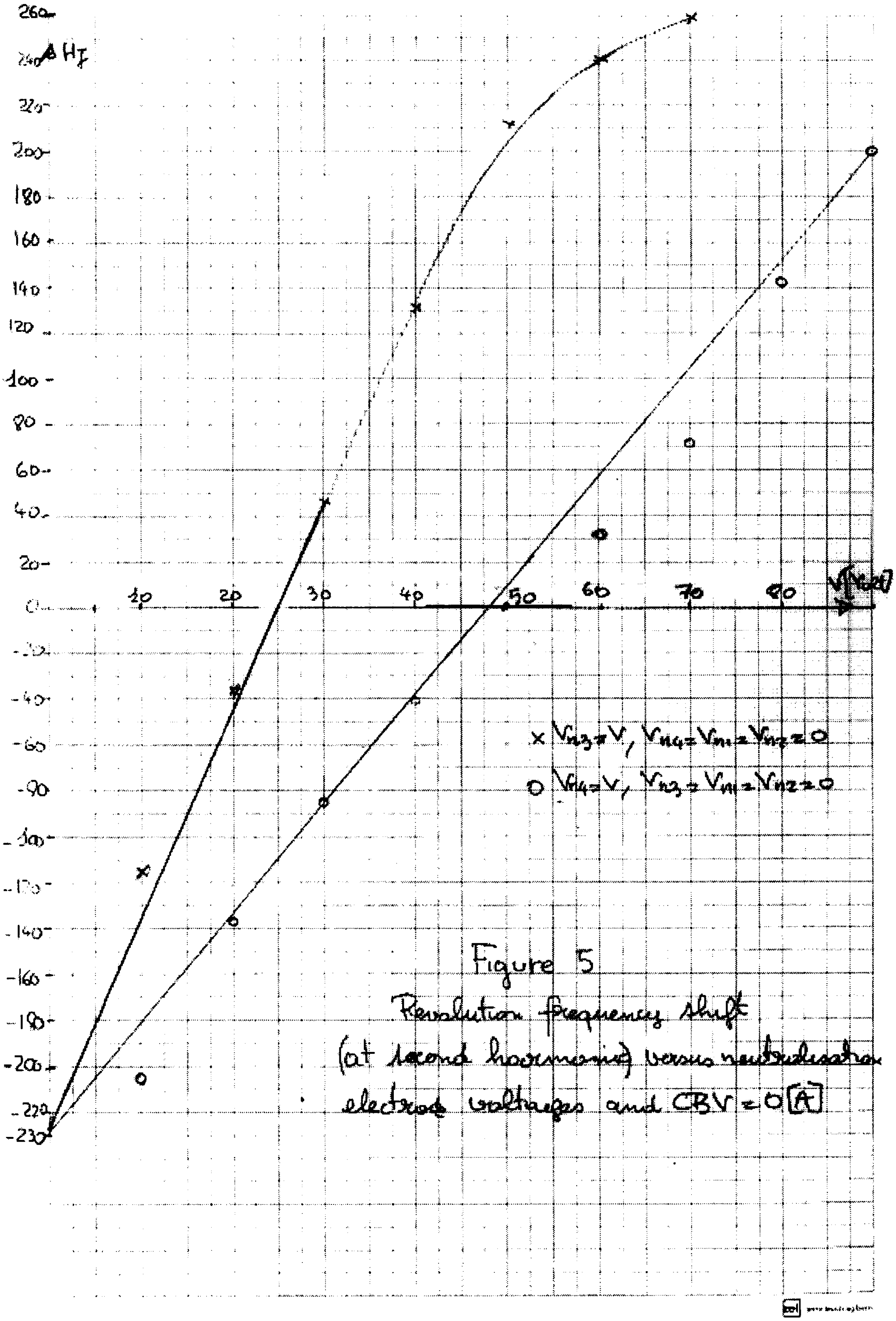

Figure 5

Revolution frequency shift (at second harmonic) versus neutralisation electrode voltages and CBV = 0 [A]

Distribution:

P. Belochitskii
J. Bosser
T. Eriksson
E-B. Holzer
S. Maury
F. Pedersen
J-P. Potier
V. Prieto
G. Tranquille