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ISR-BOM-ES/PJB/GG/GK/afm

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ISR PERFORMANCE REPORT

Run 800 - 18th January 1977 - 26 GeV/c - Rings 1 & 2

Run 810 - 3rd February 1977 - 26 GeV/c - Ring 2

Running-in Tests of the I1 S.C. Solenoid with the Low-β Scheme

1. CONCLUSIONS

The operation of the superconducting solenoid with the low-β scheme presented no unexpected problems. The additional coupling excited by the solenoid was close to the theoretical value. Compared to the value measured without the low-β scheme in run 776, the coupling is weaker which is caused by the special configuration of β_v through the solenoid and its end plates.

$\lvert C_{sol} \rvert$	Measured value	Theoretical value
Low-β On (run 800)	2.4×10^{-3}	2.11×10^{-3}
Low-β Off (run 776)	3.6×10^{-3}	3.33×10^{-3}

As expected the tune values were not disturbed within the measuring precision of ±0.001.

The vertical closed orbit was slightly disturbed by a mismatch of the dipole compensators. This was expected from the findings in run 776 but on this occasion the effect was much smaller. The optimised settings for the compensators found in this run and in run 776 are given below.

Optimised Compensator Settings

Condition	LBC1	LBC3	LBC2	LBC4
Low-β On, 26 GeV/c (run 800)	48.20 %	60.65 %	48.26 %	60.60 %
Low-β Off, 26 GeV/c (run 776)	57.53 %	72.19 %	57.61 %	72.15 %

Notes : - For low-β off, compensator settings are independent of working line, as solenoid and compensators are outside lattice, and to a high degree of accuracy independent of energy (uniformity of solenoid field). They depend only on the solenoid field level.

- For low-β on, the compensator settings will be affected if any change is made in the innermost quadrupoles of the low-β scheme. Due to these quadrupoles the matching of the dipoles is dependent on momentum as well as solenoid field level. Compensator settings for other energies and/or field levels can be supplied.

Concerning the mismatch of the dipole compensators the evidence is still somewhat confusing. However, it was established that hysteresis effects are small and will only change the orbit by approximately ±0.1 mm at the top of ELSA. The present status of knowledge concerning the compensator mismatch is summarised below.

Run	Condition	Magnet	Error % of <u>set</u>	Comments
776	ELSA 26 GeV/c	LBC2 LBC4	+1.8 % +1.8 %	Pickup measurements with solenoid
800	Low-β 26 GeV/c	LBC1 LBC3	+0.8 % +0.8 %	Pickup measurements with solenoid
810	8C 26 GeV/c	LBC2 LBC4	+1.9 % ∿ 0 %	Individual magnet calibrations using magnetic, beam-position monitor
831	Low-β 26 GeV/c	LBC1 LBC3	-3.0 % -3.0 %	Pickup measurements of luminosity bumps by J.P. Gourber

<u>Notes</u> : - It is tacitly assumed that ring 1 and 2 are subject to the same error and are therefore indistinguishable.

- A positive error indicates a field in the magnet higher than would be expected.

On balance, it appears that the compensators are slightly stronger than would expected. The calibration with the magnetic, beam-position monitor indicates that only one magnet is at fault. This is not inconsistent with the other results since it is not easy to distinguish the two compensators.

The luminosity-bump measurements by J.P. Gourber in run 831 are in total disagreement with the other results. They are based on measurements without the solenoid in run 776 which indicated that a -3 % error in the compensators correlated well with the observed residual distortion. However, the "modified" bump measured in run 831 has an error of 5 % in PU 165 inside the bump and still has some residual distortion.

PU inside I1 Bump	Central Orbit Shift for ±5 mm Bump* mm	Theoretical Shift** mm	Error
105	16.7 ± 0.1	15.87	+5.2
857	5.4 ± 0.1	5.50	-1.8
865	17.1 ± 0.1	16.93	+1.8

* Measure J.P. Gourber run 831

** Calculated by K. Brand.

It may be worth while re-checking the luminosity bumps in both rings with and without the solenoid.

The compensation of the solenoid can now be done within the precision of orbit measurements, but if accurate luminosity bumps are needed i.e. ∿1 % some more work is needed.

In all other respects the solenoid behaved as expected.

2. SET-UP CONDITIONS FOR THE MD RUN 800

The machine was first set-up for a standard low-β run and with the solenoid off. This essentially entails taking precautions against beam losses around I1 by moving the injection orbit to -35 to -36 mm and by applying a horizontal bump of +15 mm in I1 during the injection optimisation. The closed orbits and the working line were measured and corrected before powering the solenoid.

3. EFFECT OF THE SOLENOID ON THE CLOSED ORBITS OF THE LOW-β SCHEME

a) Vertical Closed Orbit

During the first tests with the I1 solenoid on the ELSA working line (run 776) the theoretical settings for the compensators were found to be

∿1 % too high and a residual distortion appeared in the closed orbit. The same mismatch with the theoretical settings was expected and found during the present tests. To determine the mismatch the compensators were varied on the basis that there was a common calibration error. Table 1 summarises these measurements. Compensator LBC1 was varied in steps of 1 % and LBC3 in steps of 1.3 %, i.e. in proportion to their set values. Before starting the compensators were degaussed by the cycle 0 → 100 % → -30 % → +10 % → -3 % → +1 % → 0 % and then they were set on the upward branch of the hysteresis curve to progressively higher values i.e. from left to right in Table 1. In order to check the effect of hysteresis the closed orbit for the last set of values (LBC1 = 50.58 %, LBC3 = 63.74 %) was repeated after cycling the magnets to +100 % and then setting them on the down ward branch of the hysteresis curve. The closed orbits showed little change, i.e. r.m.s. value unchanged, peak-to-peak at $\bar{r}$ = +40 mm changed by 0.1 mm and the PU's 761,721 and 161 which were chosen for their particular sensitivity to the action of the compensators showed changes of only 0.1 mm. Hence hysteresis effects are very small and on the limit of the measurement precision.

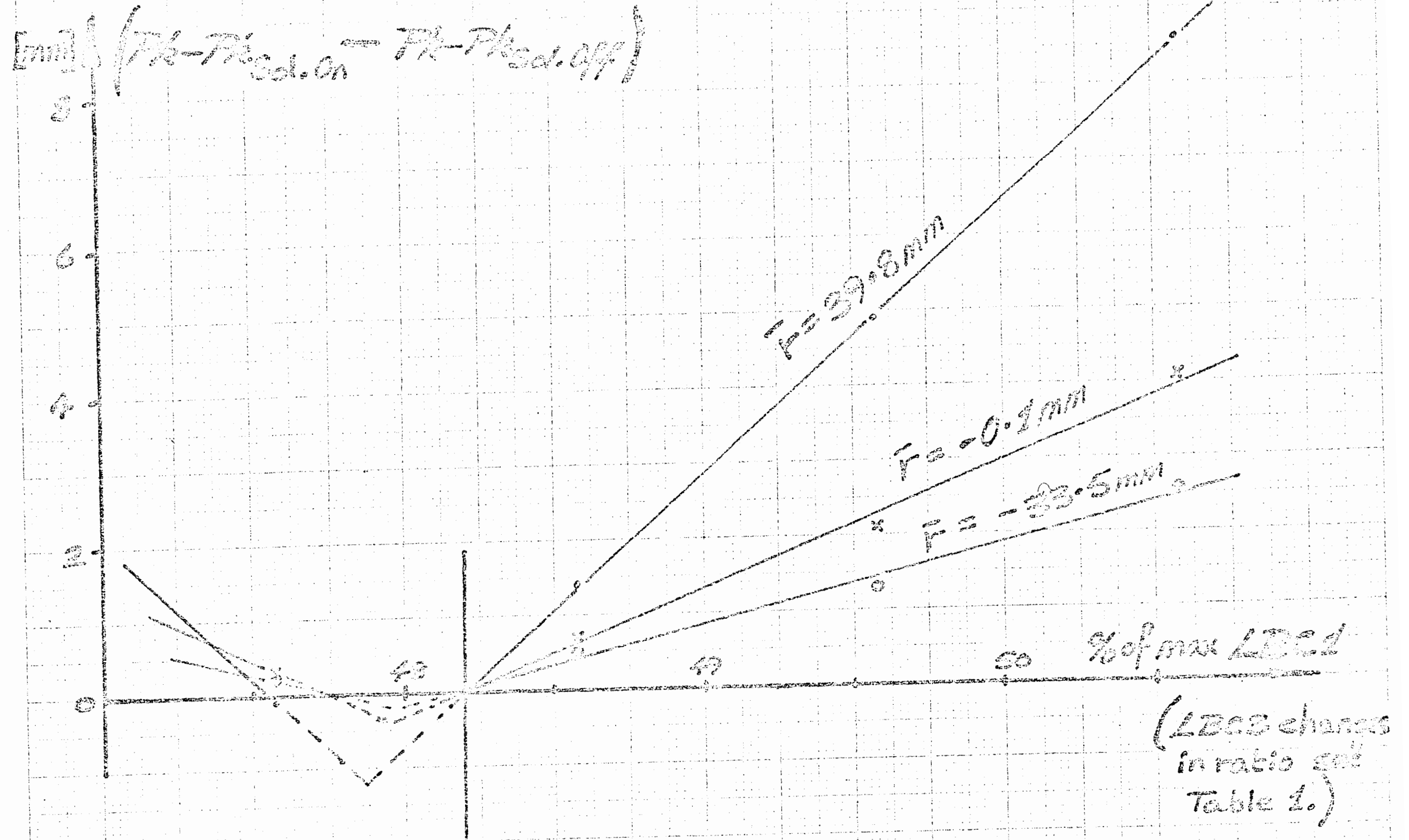
Figure 1 shows the results of Table 1 graphically. The upper graph shows how the peak-to-peak values of the closed orbit converge towards the values with the solenoid off as LBC1 and C3 are reduced in strength. The points at LBC1 = 47.58 % indicate that for values just below the optimum ones the compensators partially compensate the closed orbit distortion from the rest of the machine but as the values decrease further the distortion will again increase (there are insufficient points to draw this accurately in Figure 1). The lower graph shows how the readings of three of the most sensitive pickups differ from their values with the solenoid off. Unlike the upper graph this gives an unambiguous zero point. Since the orbit at $\bar{r}$ = 39.8 mm will be the most sensitive this has been chosen. The optimum settings are LBC1 = 48.20 % and LBC3 = 60.65 % which are much closer to the theoretical values of LBC1 = 48.58 % and LBC3 = 59.85 % than would have been expected from the tests without low-β in run 776.

Table 1 - Vertical Orbit Measurements for Optimisation of Compensators with Low-β Scheme (ELSA working line, Ring 1).

Status / $\bar{r}$ (mm)	Solenoid	Off	100 %	100 %	100 %	100 %	100 %
	Comp. C1	Off	47.58 %	48.58 %*	49.58 %	50.58 %	50.58 %**
	Comp. C2	Off	59.84 %	61.14 %	62.44 %	63.74 %	63.74 %
39.8	pk.-pk.	7.7 mm	7.6	9.1	12.6	16.3	16.4
	r.m.s.	1.8 mm	1.8	2.1	3.0	4.0	4.0
-0.1	pk.-pk.	6.4	6.7	7.1	8.5	10.5	10.7
	r.m.s.	1.6	1.6	1.8	2.1	2.5	2.5
-33.5	pk.-pk.	7.3	7.5	7.8	8.6	9.9	9.8
	r.m.s.	1.8	1.8	1.9	2.1	2.4	2.4
39.8	PU761	-1.0	-2.3	-0.2	2.0	4.2	4.3
	PU721	-1.6	-0.4	-2.0	-3.8	-5.6	-5.7
	PU161	1.9	3.3	1.3	-0.8	-2.8	-2.9

* Theoretical compensator settings.

** Hysteresis check - Compensators cycled 0 → 100 % → set values. For all other columns in table compensators were initially degaussed by 0 → +100 % → -30 % → +10 % → -3 % → +1 % → 0 and then set on the upward branch of the hysteresis curve.



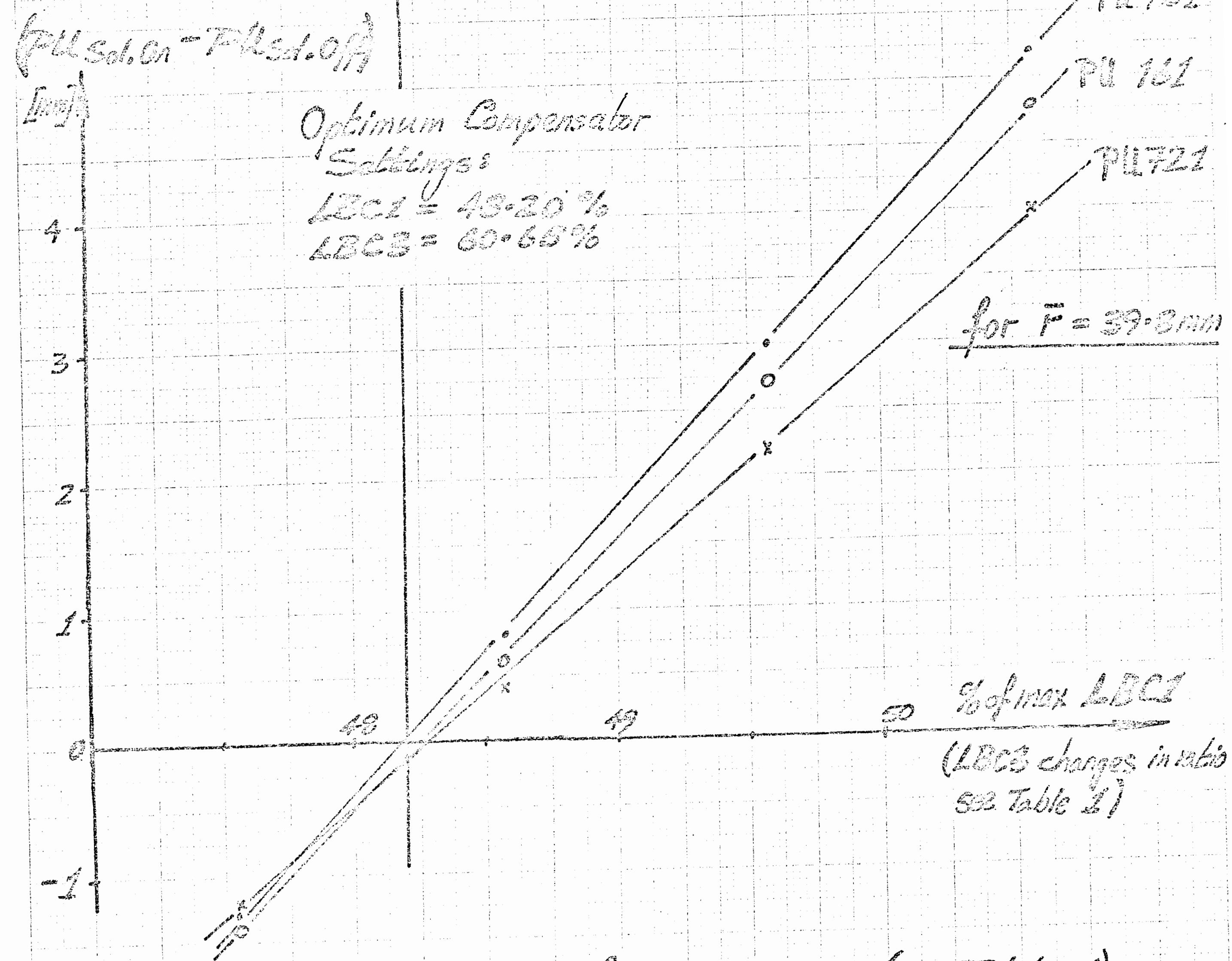


Figure 1. Optimisation of Compensators (see Table 1)
(Ring 1 ELSA working line low-β on)

b) Horizontal Closed Orbit

Associated with the vertical orbit distortion arising in the solenoid there is a much smaller horizontal orbit distortion. Rather than try to correct this locally in an already crowded intersection it was decided to allow this distortion to propagate around the machine and to correct it with standard machine elements. The magnitude of this distortion (uncorrected) is given in Table 2.

Table 2 - Horizontal Closed Orbit Distortion with Low-β Scheme (ELSA Working Line, Ring 1)

	Solenoid Off		Solenoid On	
	Peak-Peak	r.m.s.	Peak-Peak	r.m.s.
$\bar{r}$ = 39.8 mm	10.5 mm	2.1 mm	14.6 mm	3.8 mm
$\bar{r}$ = -0.1 mm	13.4 mm	3.0 mm	14.1 mm	3.6 mm
$\bar{r}$ = -33.5 mm	9.1 mm	1.9 mm	9.0 mm	2.0 mm

(compensators set to theoretical values).

This distortion is exceedingly small at injection rising to 0.7 mm additional distortion on the peak-peak value on the centre line and 4.1 mm at $\bar{r}$ = +40 mm. This distortion although appreciable can be accounted for in the basic orbit correction using the CR's.

c) The Calibration of the Solenoid Compensators in Run 810 (Ring 2) with the Solenoid Off

In this run, the compensators were individually powered and the resultant orbit distortion was measured in I5 with the magnetic beam position monitor. Fortunately, the phase shift between either compensator and the detector is such as to give close to maximum distortion in the beam detector. The distortion caused by a single short dipole is given by :

$$y(\phi) = \frac{1}{2\sin(\pi Q)} \sqrt{\beta_\phi \beta_\psi}\ \delta \cos Q(\pi - |\phi - \psi|)$$

where ϕ is the normalised phase at observation point,

ψ is the normalised phase at dipole,

δ is kick given by dipole.

Other symbols have their usual meanings.

Units are (m) and (radians).

Using the parameters in Table 3 we find the following,

$$y(\text{beam detector}) = 7.718\ \delta(\text{LBC2})$$

$$y(\text{beam detector}) = 7.891\ \delta(\text{LBC4}).$$

The kicks were determined using ISR-BOM/SP/rh "Magnetic Measurements of the Compensator Magnets" by S. Pichler. In the region considered, i.e. up to 30 % of I_{max}, the magnets have linear responses.

Table 3 - Beam Parameters at Compensators and Beam Detector. (Ring 2, 8C Working Line)

	Beam Detector	LBC2	LBC4
β_v	14.40	15.22	17.19
$\mu_v/2\pi$	4.22926	8.49863	8.60257
		$Q_v = 8.6245$	

The distortions for various compensator settings were measured on the 8C working line using a 1.088 A stack on centre line. This should give an estimated precision of ±0.05 mm with the beam position detector. Table 4 summarises the results obtained.

Table 4 - Calibration of LBC2 and LBC4 on 8C Working Line. (Ring 2, 26 GeV/c)

Magnet	Setting	Beam Det. Reading :		Shifts :		Error =
		Direct	Corrected*			$\left(\frac{\Delta y_{corr} - \Delta y_{calc}}{\Delta y_{calc}}\right) \times 100$
		y_{meas}**	$y_{corr.}$	Δy_{corr}	Δy_{calc}	
	% of I_{max}	mm	mm	mm	mm	%
Set 1st value directly from 0 %						
LBC2 "	+25.0 -24.0	6.20 -5.50	6.22 -5.56	-11.78	-11.56	+1.9***
Set 0 % → 100 % → 1st value						
LBC4	0.0 -20.21	0.22 -4.59	0.22 -4.63	-4.85	-4.89	-0.8
"	-20.21 0.0	-4.59 0.20	-4.63 0.20	4.83	4.89	-1.2***
"	0.0 23.75	0.20 5.91	0.20 5.94	5.74	5.74	0.0
"	23.75 0.0	5.91 0.20	5.94 0.20	-5.74	-5.74	0.0***
"	0.0 -20.21	0.20 -4.67	0.20 -4.71	-4.91	-4.89	+0.%

* Calibration correction for beam detector supplied by K. Brand.

** Average of measurements taken by approaching null setting of detector from each side.

*** Measurements which are expected to be affected by hysteresis as the current change is opposed to the prior direction.

Note : The precision is estimated as ±0.05 mm. For a shift of ∿5 mm the two measurements will contribute ±2 % error.

Although the estimated measuring error is of the same order of magnitude as the effect being looked for, it would appear that LBC2 is ∿2 % too strong and LBC4 is correct or possibly slightly too weak. Since the compensators are close together a small error in LBC2 would be hard to distinguish from a similar error in LBC4 or from half the error appearing in each compensator. This result is therefore not inconsistent with the orbit measurements using pickups.

4. EFFECT OF THE SOLENOID ON THE LOW-β SCHEME WORKING LINE

No systematic effect on the working line could be detected (see Figure 2), as was expected from the first tests without the low-β scheme in run 776 and from theoretical considerations.

5. COUPLING MEASUREMENTS

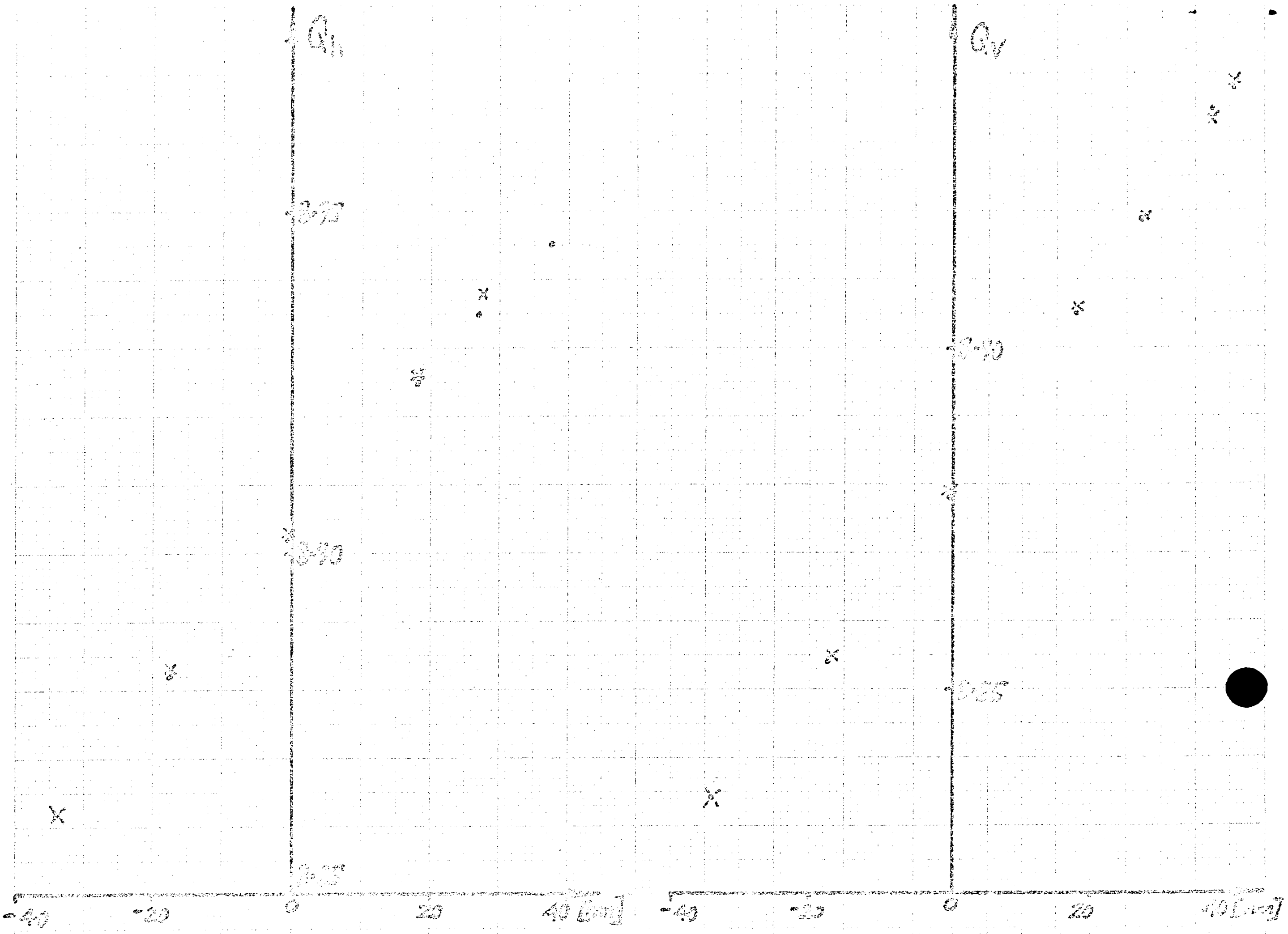
Measurements of the modulus of the coupling coefficient C have been performed in ring 2 with the low-β scheme on the ELSA working line.

The first measurements were made with the I1 solenoid off and with the two sets of skew-quadrupoles at zero after having been cycled to +100 % for Q1 and to -100 % for Q2. This cycling was meant to create two equal and opposite C-vectors associated with the remanent fields of the two quadrupole sets Q1 and Q2, in order to minimise their effect. The average value of $|C|$ measured under these conditions was,

$$|C| = 8.9 \quad 10^{-3}$$

with $\Delta = Q_h - Q_v = 4.5 \quad 10^{-3}$.

This value is 10 % smaller than the one obtained in run 779, which is not so surprising since the skew-quadrupoles were not cycled in this previous run.



Solenoid off (points •)			Solenoid on (crosses x)		
F mm	Qh	Qv	F mm	Qh	Qv
-34.2	8.862	8.834	-34.2	8.862	8.834
-17.6	8.882	8.854	-17.8	8.883	8.855
-0.7	8.902	8.878	-0.6	8.903	8.879
18.2	8.925	8.905	18.5	8.926	8.906
27.2	8.935	8.919	27.1	8.933	8.919
37.5	8.946	8.925	37.3	not stable	8.933
40.6	not stable	8.933	40.5	not stable	8.939

Figure 2. Low-β Working Line with I1 Solenoid On and Off. (Ring 1, 26GeV/c)

A current of -4.6 % in Q2 still gave a good compensation of the coupling in the sense that the remaining signal modulation was negligible. Taking into account the calibration factor of Q2 measured in run 779, a current of -4.6 % should create a $|C|$ of 10^{-2}, which means that the coupling of ring 1 was probably overcompensated leaving a residual $|C|$ of $\sim 10^{-3}$.

The I1 solenoid was then switched on and the modulus of C was re-measured with a current of -4.6 % in Q2.

$$|C| = 2.92 \quad 10^{-3},$$

with $\Delta = 0.34 \quad 10^{-3}$.

The theoretical value$^{1)}$ under these conditions is

$$|C_{sol}| = 2.11 \quad 10^{-3}.$$

Keeping in mind that the ring coupling was overcompensated and knowing the angle between the ring vector and the solenoid vector (76.772°), it is possible to calculate from the measurements the contribution of the solenoid,

$$|C_{sol}| = 2.4 \quad 10^{-3} \;.$$

Taking into account the smallness of $|C_{sol}|$, this result appears to be in good agreement with the theoretical value.

The predicted currents for Q1 and Q2 for compensating the solenoid effect, i.e.,

$$\left.\begin{aligned} I_{Q1} &= 15.3\ \% \\ I_{Q2} &= -11.5\ \% \end{aligned}\right\} \text{in ring 2}$$

were then added. By varying the currents of Q1 and Q2, it was verified that this setting really gave a minimum in the signal modulation. In spite of all our efforts, it proved impossible to improve this minimum, which was, however, larger than expected and corresponded to $\sim 5 \times 10^{-4}$. It was independent of the pulse current, the momentum spread and the initial emittances which seems to indicate that this residual signal was parasitic. In any case, the residual modulation was at least 5 times smaller than the one due to the solenoid itself, which still indicates that the predicted currents of Q1 and Q2 compensate $|C_{sol}|$ within a few 10^{-4}.

6. Degree of contamination of the I1 vacuum chamber

The induced radioactivity in the I1 vacuum chamber was monitored using the scintillation counters "A" of experiment R108 (see their description in the ISR Performance Report dated 7.1.77).

The values of the counting rates were :

- before starting the MD period : 1.9 x 10^5/10 s,
- after the low-β test and before switching the solenoid : 2.6 x 10^5/10 s,
- just after the low-β + solenoid period : 9 x 10^5/10 s.

These measurements are consistent with the levels noticed during the MD runs 772 and 776.

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