EXPERIMENT : Determine η and γ_{tr}.

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1. Introduction

It is of quite some interest to determine experimentally two important lattice parameters: η and γ_{tr}. Of course, if one shows the one, the other is easily calculated, γ being known quite accurately:

$$\eta = \frac{1}{\gamma^2} - \frac{1}{\gamma_{tr}^2} \tag{1}$$

Two methods were used. Both have as starting point the differential relationship between magnetic field B, momentum p and revolution frequency f (C. Bovet et al., CERN/MPS-SI/Int.DL/70-4):

$$\frac{dB}{B} = \gamma_{tr}^2 \frac{df}{f} + \frac{\gamma^2 - \gamma_{tr}^2}{\gamma^2} \frac{dp}{p} \tag{2}$$

2. B = const.

Without changing the magnetic fields, one changes the beam momentum by a known amount and measures the resulting change in revolution frequency. With B = const, dB/B = 0, and using equ. (1), equ. (2) reduces to (now in differences rather than in differentials):

$$\frac{\Delta f}{f} = \eta \frac{\Delta p}{p} \rightarrow \boxed{\eta = \frac{\Delta f/f}{\Delta p/p}} \tag{3}$$

Procedure : The momentum of the p-test beam from the PS was changed by amounts within the acceptance of the loop. The revolution frequency of the beam injected into and coasting in the AA was measured by Schottky scan around the 100th harmonic. This method is restricted to the injection orbit.

Data

Orbit	10^3 Δp/p at PS	100 f (MHz) in AA	10^4 Δf/f	γ
Injection	0	184.5938	-	3.9395
	+2.357	184.5503	-2.357	
	-2.357	184.6429	+2.660	

$\eta = -0.1064$ derived: $\gamma_{tr} = 2.419$

Comments

The frequency 100 f was measured several times and averaged. For details, see log book.

- PS momentum was changed, but the PS orbit radius was kept constant:

B_0 = 1694 G
ΔB = ± 4 G
Δf/f = $\pm 1.52 \times 10^{-4}$
γ = 3.939
γ_{tr} = 6.124

Δp/p = $\pm 2.357 \times 10^{-4}$
ΔR = ∓0.01 mm

- In calculating Δp/p, one relies on the knowledge of γ_{tr} or η in the PS. In other words, one measures η_{AA} using η_{PS} as yard stick. Since transition is an important fact of life in the PS, its parameters are known quite precisely.

3. p = const.

Without changing the beam's momentum, one changes the magnetic fields and measures the resulting change in revolution frequency. With p = const, dp/p = 0, equ. (2) reduces to:

$$\frac{\Delta B}{B} = \gamma_{tr}^2 \frac{\Delta f}{f} \rightarrow \boxed{\gamma_{tr} = \frac{\Delta B/B}{\Delta f/f}} \tag{4}$$

Procedure. After injection and RF capture, the beam was brought to the desired orbit and debunched. To change B, the currents in all magnetic components (bends, trim, quads, F4, skew quad and octupole) were changed by the same factor. Revolution frequency was measured before and after by Schottky scan around the 100th harmonic. This method can be used on any orbit.

Data.

Orbit	$10^3\ \Delta B/B$	100f (MHz)	$10^4\ \Delta f/f$	γ
Injection	0	184.5930	-	3.9395
	+2.00	184.6397	+2.530	
	-2.00	184.5517	-2.237	
	γ_{tr} = 2.897	derived: η = -0.05475		
Central	0	185.0369	-	3.8619
	+2.00	185.0786	+2.254	
	-2.00	184.9966	-2.178	
	γ_{tr} = 3.004	derived: η = -0.04374		
Stack core	0	185.5010	-	3.7722
	+2.00	185.5395	+2.075	
	-2.00	185.4627	-2.065	
	γ_{tr} = 3.108	derived: η = -0.03323		

Comments

The width in f of an adiabatically debunched beam is very narrow, the central f can be determined with great accuracy. Only one measurement on each orbit was therefore made.

4. Conclusions

The experimental results, together with the theoretical values, are shown in Figs 1 and 2.

The measurements at B = const are in good agreement with the theoretical values.

From the measurements at p = const one obtains results far from the theoretical values, in a systematic way. Either, one has to assume that both the theoretical values and the measurement at B = const are wrong, or, that the measurements at p = const contain a systematic error. I opt for the second assumption and will discuss three possible sources of error:

1) When one changes the magnetic field, the momentum does not stay perfectly constant, it will be affected by betatron acceleration. S. van der Meer, who drew my attention to this effect, also calculated it to be negligibly small. Further, there is a qualitative argument against this explanation: with a window-frame magnet, the betatron acceleration is zero on central orbit and of different sign on the two sides.

2) We really changed the electric currents in the magnetic elements and in using equ. (4) simply assumed $\Delta B/B = \Delta I/I$. We can calculate the slope of the magnetization curve:

$$\kappa = \frac{\Delta B/B}{\Delta I/I} < 1 \qquad (5)$$

that would explain the observed systematic discrepancy between experimental and theoretical values:

Orbit	γ_{tr} measured	γ_{tr} theor.	$\left(\frac{\text{meas}}{\text{theor}}\right)^2$
Injection	2.897	2.391	1.468
Central	3.004	2.406	1.559
Stack core	3.108	2.541	1.496
			1.508 average

We notice that the ratio $\gamma_{tr,meas}/\gamma_{tr,theor}$ is nearly the same for all orbits and that a value of:

$$\kappa = \frac{\Delta B/B}{\Delta I/I} = 0.66$$

would explain the systematic error.

For the quadrupoles, old measurement data show $\kappa = 1 \pm 0.02$, for the bending magnets no measured data are available. It seems unlikely, however, that κ could be as low as 0.66.

3) W. Hardt pointed out that if κ is different for the quadrupoles, the short bending magnets and the long bending magnets, then also the shape and therefore the length of the orbit changes when all currents are changed by the same factor. This produces an additional contribution to $\Delta f/f$ and a κ not quite as low as 0.66 may suffice as an explanation.

Without digging much deeper into the details, the question cannot be settled. We may pursue it further if we find it to be relevant to other, more important problems.

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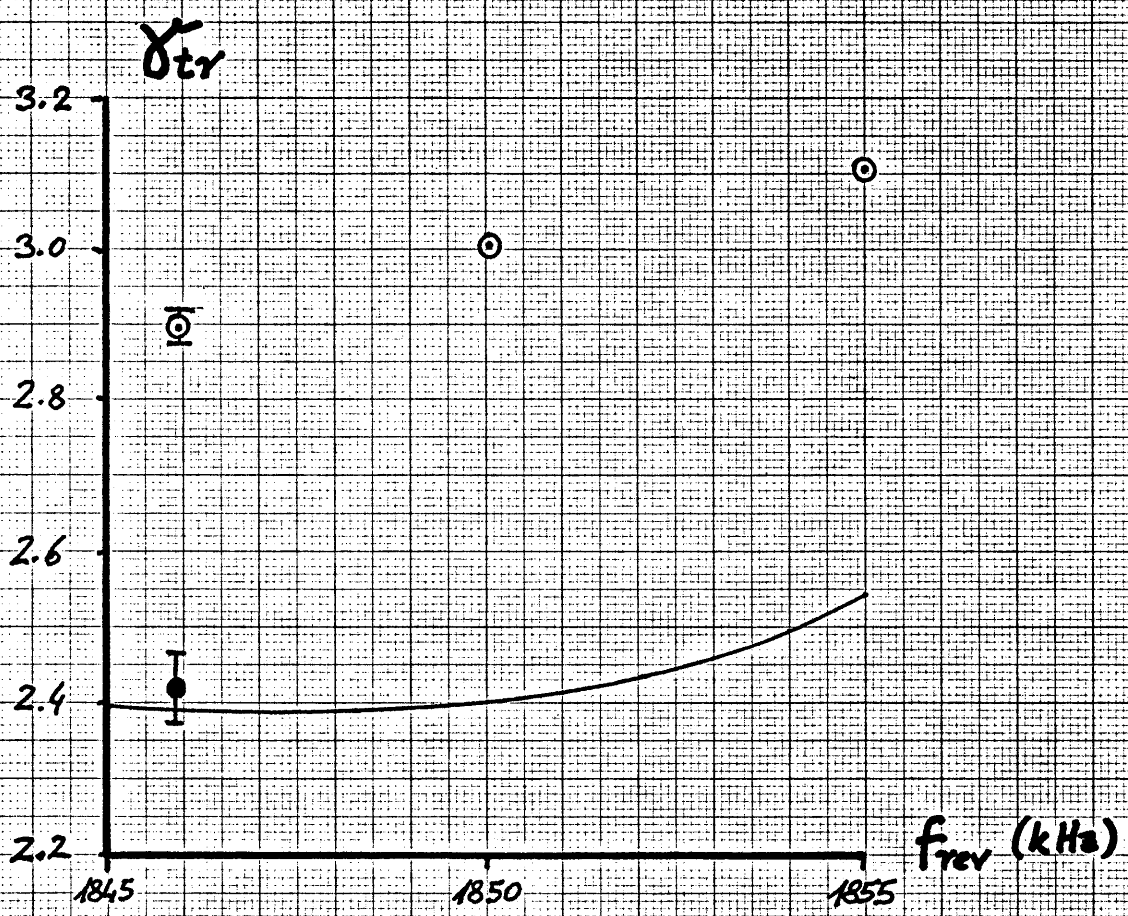

FIG. 1

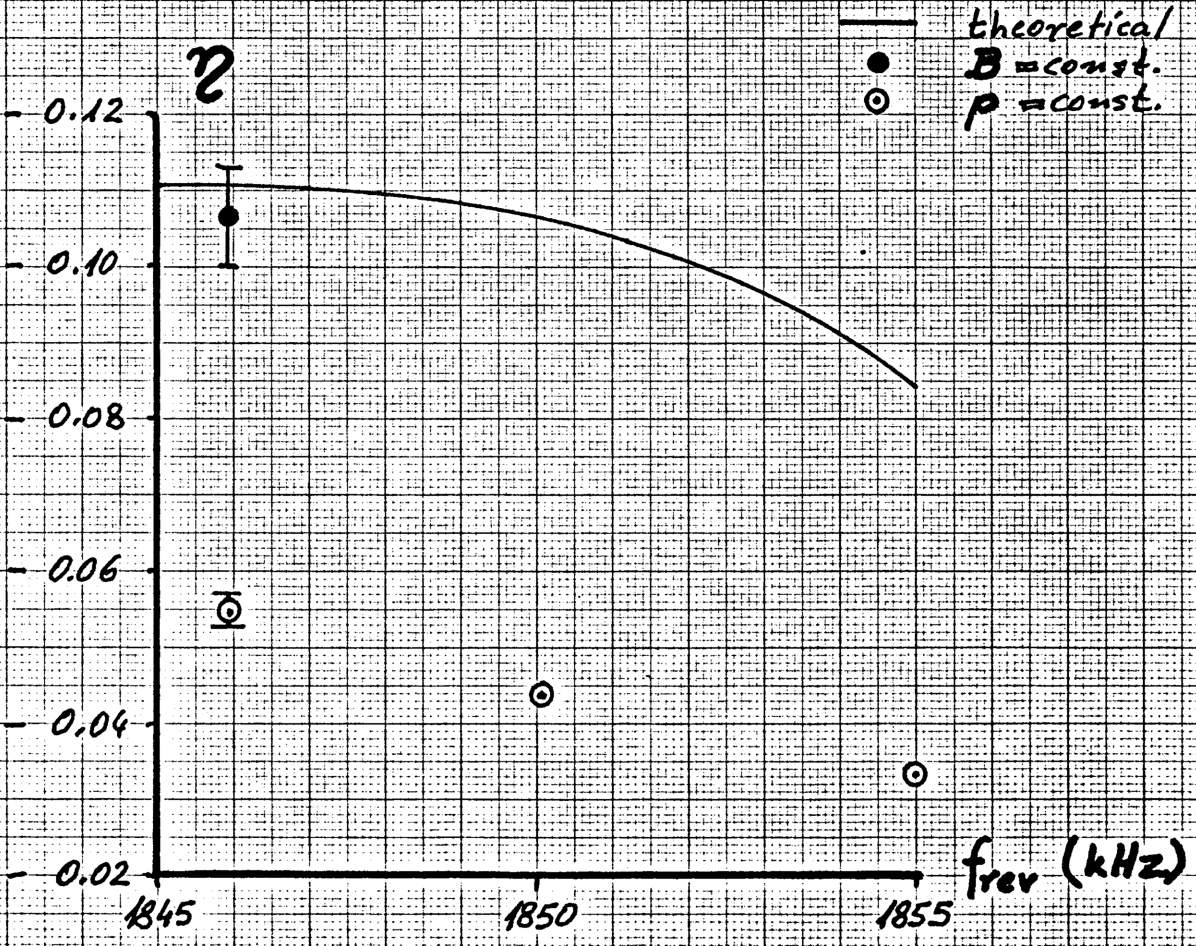

FIG. 2

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