EXPERIMENT : Transverse emittance of high intensity proton stack.

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1. Introduction

With the AA in reversed polarity, a proton stack was obtained with a record intensity of 1.872×10^{12} p. In the 11 hours following the completion of the stack, emittance measurements were made repeatedly, between other observations and actions on the beam. When finally the beam had to be killed, this was done in a way as to obtain further information on the density distribution.

This note summarizes (better late than never) the result of the emittance measurements.

2. Method

The scrapers SHV 1302 in the zero-α_p region were used.

This is a good occasion to have a closer look at the proper way to determine the emittance for a given fraction F of the beam intensity I_o as measured before scraping.

In general, the beam is not centred in the scraper tank and the offset can only be determined with the scrapers themselves. For a precise measurement one must therefore use both opposing blades, i.e. for a horizontal measurement : external and internal; for a vertical measurement : top and bottom.

Ideally one would move in first, say, the external blade until the the intensity drops to FI_o . Then one moves in the internal blade until it just touches the beam, without causing any further beam loss. The emittance for the fraction F of the beam is then (attention : display gives all scraper position as positive) :

$$\varepsilon_H = \frac{1}{\beta_H} \left[\frac{X_{ext} + X_{int}}{2} \right]^2 \tag{1}$$

and the centre of the beam is at

$$X_o = \frac{X_{ext} - X_{int}}{2} \quad (X_o \text{ counted positive on external side}) \tag{2}$$

The X_o thus determined may be used for further measurements using one blade only.

In practice it is not possible to find the other edge of the beam with the second blade without causing further beam loss. If $F_1 I_o$ is the intensity of the beam remaining after scraping with the first blade, the intensity will drop to $F_2 I_o$ after sensing the other edge with the opposite blade. One should now take care that the second loss it small compared to the first one :

$$F_1 - F_2 \ll 1 - F_1 \tag{3}$$

Even though F is a highly non-linear function of X, one may then ascribe the emittance determined as in (1) to the fraction

$$F = \frac{1}{2} (F_1 + F_2) \tag{4}$$

E.g., to determine the horizontal 95% emittance :

- move in external blade until 4.5% are lost, F_1 = 95.5%, read X_{ext};
- retract external blade to avoid loss rate;
- move in internal blade until another 1% is lost, F_2 = 94.5%, read X_{int}.

In the case of machine acceptance measurements, $1 - F_1$ should be as small as possible, say 1 o/oo. Condition (3) is then difficult to fulfil and one will accept $F_1 - F_2 \approx 1 - F_1$, i.e. one gives as machine acceptance the emittance of 99.85% of the beam that was made (by blow-up) to fill the acceptance.

Emittances given in the next chapter were determined according to (4).

3. Emittance measurements (see Figs 1 and 2)

a) In the first 3 hours after completion of the stack, loss rates were investigated with various combinations of HF cooling systems ON and OFF. As a consequence, when emittances for F = 99.85% were first measured at t = 3 h, they were not much smaller than the machine acceptances at that time :

$\varepsilon_H = 62\pi \quad (A_H = 75\pi)$ mm mrad

$\varepsilon_V = 48\pi \quad (A_V = 70\pi)$

b) Some adjustments were then made to the vertical HF cooling and all 3 systems left ON. Within 2.3 h the emittances, again for F = 99.85%, dropped significantly :

$\varepsilon_H = 28.3\pi$, factor 2.2

$\varepsilon_V = 14.4\pi$, factor 3.3

c) The vertical cooling systems had been designed for the nominal $Q_V = 2.276$, whereas the value measured was 2.262. To check the significance of this difference, Q_V was now raised to the nominal value, at constant $Q_H = 2.264$. In that process, the 11th order resonance $3\,Q_H + 8\,Q_V = 25$ was crossed, without any loss of beam.

The emittances measured thereafter (1.1 h after b), again F = 99.85%) showed a slower decrease :

$\varepsilon_H = 20.6$, factor 1.37

$\varepsilon_V = 11.5$, factor 1.25

It may of course be that the 11th order resonance, although not causing any loss, had still blown up the emittances.

Also, the emittances at $F = 99.85\%$ are those of the thin halo and need not be representative for the bulk of the beam. The significance of the measurements at $t = 3.0$, 5.3 and 6.4 h is therefore limited.

d) Consequently, the more significant emittances at $F = 94\%$ were measured 0.3 h later :

$$\varepsilon_H = 6.4\pi$$

$$\varepsilon_V = 3.7\pi$$

For a beam with a Gaussian density distribution (projected onto one coordinate) :

$$F = 1 - e^{-\frac{(x-x_o)^2}{2\sigma^2}} \qquad (5)$$

and the ratio of the emittances at $F = 99.85\%$ and at $F = 94\%$ is 2.31. Comparing measurements c) and d) one sees that the beam had a more-than-Gaussian density tail.

4. Scraping to death

After 3 hours of experimenting with the transverse feedback system, it was decided to kill the beam. It was planned to first measure ε_V at $F = 95\%$ and then to scrape horizontally in steps until expiration.

As a consequence of the feedback studies, the emittance was unexpectedly large and the vertical scraper was moved in too far :

$$t = 11.7 \text{ h} : \varepsilon_V = 11.4\pi \text{ for } F = 0.59, \text{ see Fig. 1.}$$

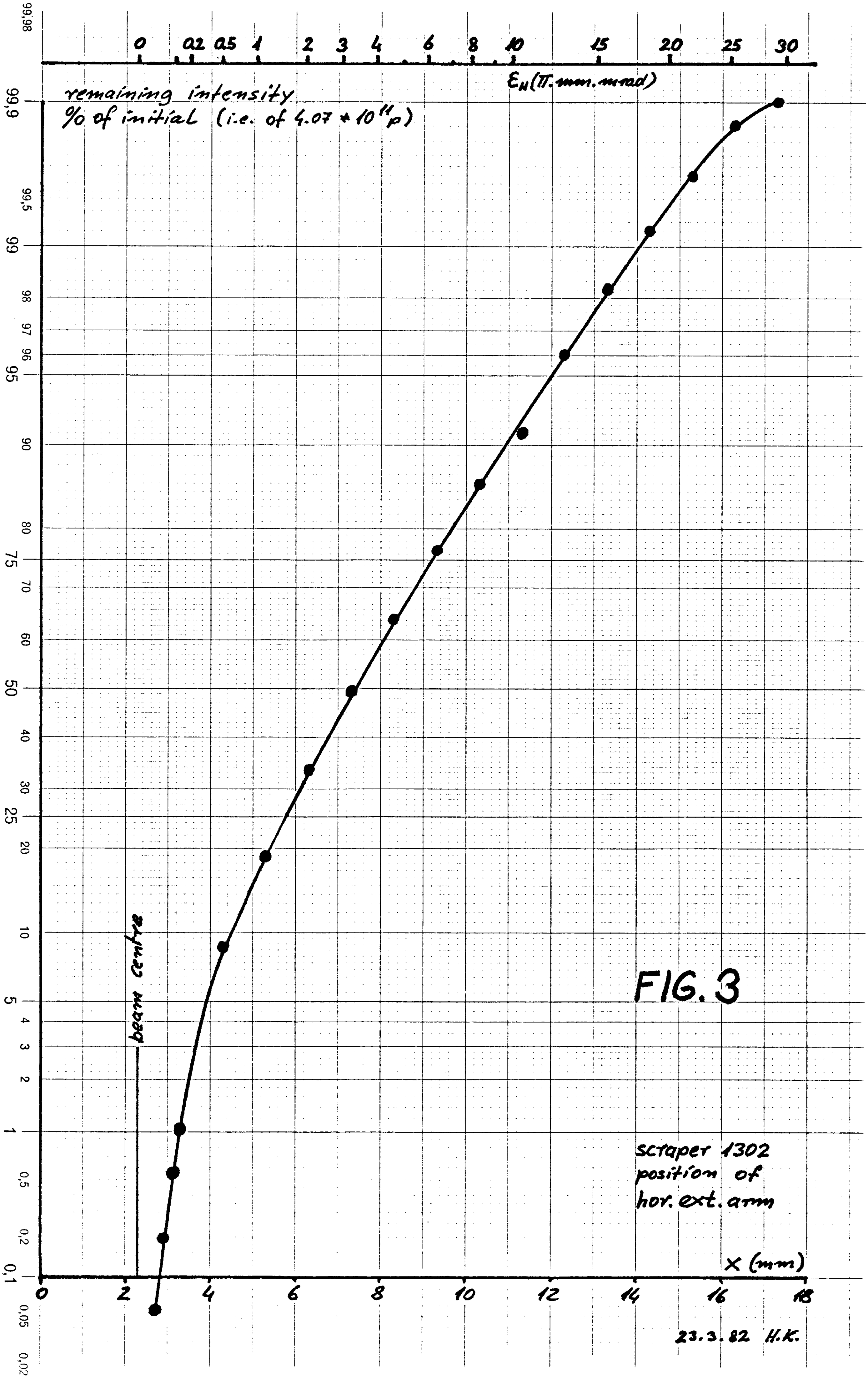
The subsequent horizontal scraping yielded the points at $t = 11$ h. The complete curve is shown in Fig. 3.

Plotting on probability graph paper allows a simple test for Gaussianity : a Gaussian density distribution gives a straight line. For the bulk of the beam this is the case with $\sigma_x \doteq 4$ mm. Also apparent is a denser core, 5% of the total intensity are within about 2 mm of the beam centre with a much smaller $\sigma_x \doteq 1$ mm.

Differentiation of the curve, Fig. 3, yields the amplitude distribution, Fig. 4.

As the scraping measurement was made after considerable maltreatement of the beam during the feedback studies, the results shown in Figs 3 and 4 are of little significance but rather serve the purpose of demonstration of method and evaluation.

H. Koziol



remaining intensity
% of initial (i.e. of 4.07 * 10^11 p)
ε_H (π. mm. mrad)
beam centre
scraper 1302
position of
hor. ext. arm
X (mm)
23.3.82 H.K.

FIG. 3

Emittance measurements on high intensity proton stack

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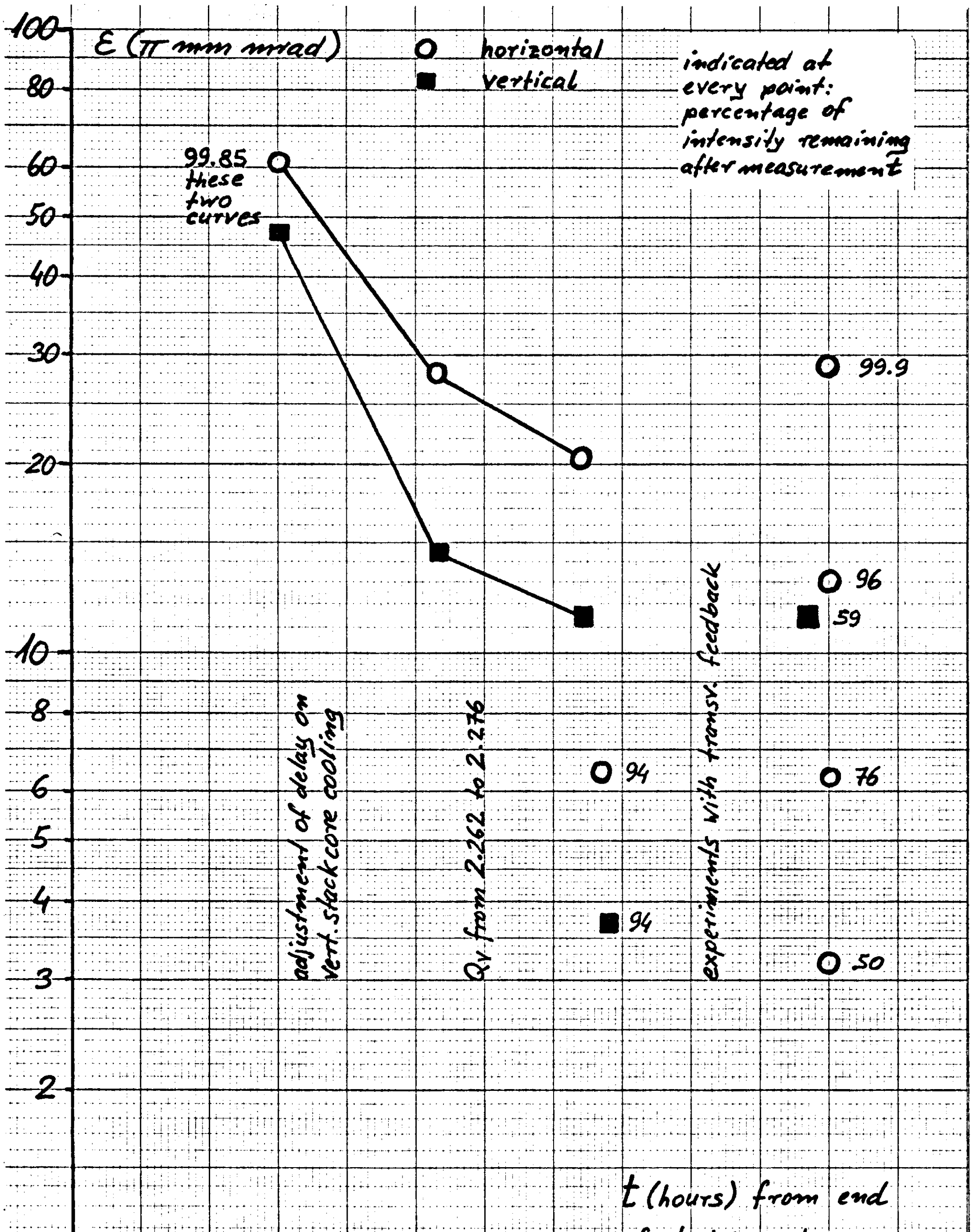

FIG. 1

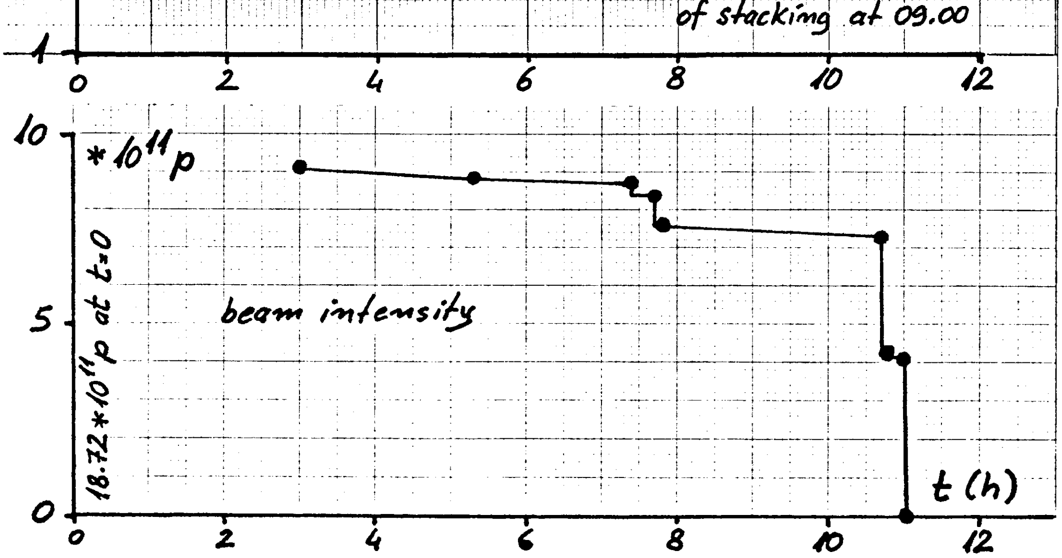

FIG. 2

23.3.82
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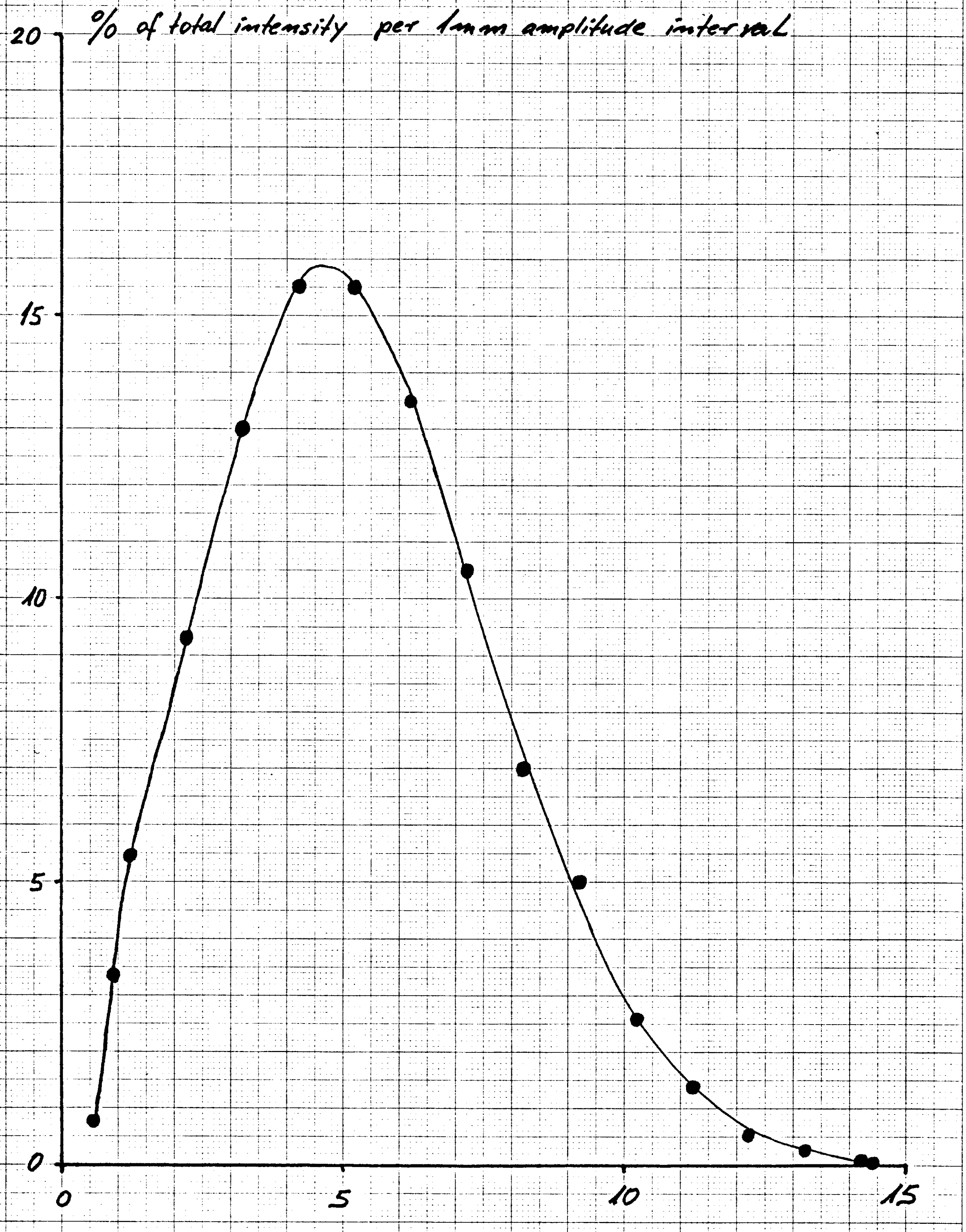

FIG. 4

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