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MEASUREMENTS WITH SECONDARY EMISSION QUANTAMETERS BETWEEN 1 AND 5 GEV

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Abstract

A brief description of a secondary emission quantameter[1] is given. Measurements for finding useful construction data are described and an explanation of some unexpected effects due to the gold-plating of the quantameter plates is given. Design features for a SEQ combined with a calorimeter are outlined.

Introduction

In an earlier work[2] on calibration measurements at DESY a quantameter constant for gas-filled quantameters was found which was about 32 % lower than the calculated constant according to Wilson's paper[3]. A lower quantameter constant means an increased efficiency. This effect is due to the gold-plating of the copper plates, which was done in order to yield surfaces with stable secondary emission when the instruments are evacuated for use as nonsaturable secondary emission quantameters.

An explanation for this "gold effect" is difficult to find, since in a quantameter many interactions such as pair-production, bremsstrahlung, photoeffect, and the Compton effect are involved. A rough argument for the "gold effect" can be found in the Z-dependence of the photoeffect. Since this effect goes as Z^4, a thin layer of gold (about 3μ on each side of the plates) may account for the increased efficiency: there will be more ionizing electrons in the gaps between the plates with gold surfaces than with copper surfaces. Also, an increased secondary emission of the gold-plated plates may account for this effect, since a difference of about 19 % between gold and copper has been measured[4].

The "gold effect" may also be responsible for the deviation of up to 10 % of measured quantameter constants[5] from calculated values, since the conditions of the normally used copper surfaces of the quantameter plates can depend on the previous history: different handling and cleaning procedures of the plates may give rise to different oxides and hydroxides on the copper surfaces. Therefore a stable surface like gold seems to be valuable.

All the 7 gas-filled DESY-quantameters with gold surfaces show, within the calibration errors of ± 3 %, the same quantameter constant of $K = 3{,}35 \cdot 10^{18}$ MeV/Coul., while the quantameter with copper surface has $K = 4{,}38 \cdot 10^{18}$ MeV/Coul. The calculated value is $4{,}95 \cdot 10^{18}$ MeV/Coul. The difference between the measured constants is thus 24 %, while 32 % is found between the calculated value and the value for the gold-plated quantameter.

However, the attempt to use the DESY-quantameter as a secondary emission quantameter (SEQ) produced an unexpected difficulty. Within a certain diameter such an instrument should have a stable response, but the measurements with a small beam[2] gave the curve shown in fig. 1: in the center of the SEQ there is a "hole" in the efficiency of about 8 % compared with the edges. Theoretically the response should drop by some percent, depending on the size of the instrument, when the beam strikes the SEQ outside the center, since the electromagnetic cascade is not so well absorbed.

Two explanations for this "hole effect" were discussed:

1) The correction volumes, which are necessary for the gasfilled quantameter, are constructed in such a way that the collector plates - thin gold-plated copper foils mounted on a ring - inside the correction volumes are thicker than between the center parts of the plates (see Fig. 2). Therefore an increased secondary emission at the edges of the SEQ seems possible due to the glancing incidence of parts of the incoming beam.

2) The gold-plating of the copper plates and foils is not uniform in thickness over their diameter. This possibility is very strong, since the plating has been done electrolytically and edge effects are well known in this process: more gold will be deposited at the edges than in the center part of the plates. Therefore an increased efficiency at the edges seems possible according to the photoeffect, as previously mentioned. The increased secondary emission of the gold, however, cannot be responsible for the "hole effect", since the saturation thickness should only be about 100 Å[6], which is much smaller than the thickness of the gold-plating of 3000 Å. Also, measurements of Blankenburg et al.[4] showed that the secondary emission is independent of the thickness of the foils in a secondary emission monitor.

In order to obtain better construction data, a SEQ for test measurements was built.

A SEQ for Test Measurements

This instrument is shown in fig. 3. There are 26 lead plates, each 5 mm thick, and 20 x 20 cm in area. Between the plates are 25 foils of stainless steel, 0.1 mm thick, which are stretched by two screws on each side. The screws and foils are mounted on two strips of stainless steel. The lead plates are held between a bottom and a top plate.

The mounting strips for the foils are outside the lead plates, to minimize the above mentioned edge effects due to glancing beam incidence. Stainless steel foils were chosen in order to get a clean surface for the secondary emission. These foils can be replaced by gold-plated copper foils for testing the "hole effect". The SEQ has such a size that 99 % of the beam energy at 5 GeV is absorbed for a small incident beam. No surface effects from the lead plates are expected, because, by using positive voltage on the plates, the collected electrons come only from the stainless steel foils.

In fig. 4 the measurements of the useful diameter of the SEQ with stainless steel foils are shown. As theoretically expected, the response drops from the center of the SEQ to the edges of the lead plates by about 3 %, but rises by nearly 10 % when the beam strikes the mounting strips of the foils. There is no "hole effect". This suggests that the nonuniformity of the gold-plating might be responsible for the "hole effect".

In fig. 5 the calibration constant of the SEQ is shown at several energies and different times. Within ± 0.5% the response is stable. This behaviour shows that the surfaces of the lead plates are not critical, as mentioned above.

The stainless steel foils and the construction therefore seem reliable for the basic design of a SEQ, which is described in the last chapter.

For testing the "hole effect" the stainless steel foils were replaced by gold-plated copper foils. In fig. 6 the response curve is shown. The efficiency does not drop from the center of the SEQ to the edges as in the case of the stainless steel foils, but increases steadily. For example at a distance of 8 cm from the center, the efficiency is about 2 % higher, while in the case of stainless steel foils the efficiency is 3 % lower than in the center. The total effect of the gold is therefore about 5 %.

Although the "hole effect" is not so large as in the case of fig. 1, it can be seen clearly from these measurements. The effect is caused by the nonuniform thickness of the gold-plating. This has been checked by measuring the thickness of the gold at the center and at the edges of two foils. Variations of up to 50 % have been found for both the SEQ foil and the foil of the DESY-quantameter. Therefore it is necessary to take special precautions during the gold-plating to avoid these effects. But since the stainless steel foils are as stable as the gold, there is no need for gold-plated foils.

One might think of using the "hole effect" to build a small SEQ, which shows stable response over the whole diameter. This possibility was not investigated further, since the SEQ will also be used as a calorimeter for calibration tests. Total energy absorption is necessary for a calorimeter, which forbids a smaller diameter.

Another result of the measurements is the value of the calibration constant of the SEQ. As in the case of the gas-filled quantameter, there is again a drop of the calibration constant, when the gold-plated copper foils are used instead of the stainless steel foils. The calibration constantsfor the test SEQ and the gas-filled quantameter are given in table 1. The "goldeffect" is of the same order as in the case of the gas-filled quantameter. For the SEQ we have about 36 %, while for the gas-filled quantameter 24 % was found. The difference of 12 % may be due to the different thicknesses of the gold-plating which are 4μ for the SEQ and 3μ for the gas-filled quantameter at the center of the foils. Furthermore, there should be a difference

due to the different materials: copper and stainless steel.

Since the thickness of the gold for only one foil of each quantameter was measured at the center and at the edges, it is not possible to give exact values for the "hole effect" versus the thickness of the gold. But the order of the effect can be seen from table 1: the response changes by about 8 % for 1μ of gold.

For the gas-filled quantameter no "hole effect" is observed. This may be due to the correction volumes. There would be a 12 % energy loss at 6 GeV in the absence of the correction volumes[7]. Since the beam spreads out over the whole diameter near the end of the quantameter a compensation for the "hole effect" seems possible.

Proposal for a Secondary Emission Quantameter Combined with a Calorimeter for DESY

According to the above measured data, stainless steel as a secondary emission foil seems reliable. One may ask, why we use thin foils instead of thick plates as in the case of the Wilson quantameter[3]. There are two reasons:

1) Thick emitter plates will absorb one half of the total beam energy of several KW's. Cooling of the electrically insulated emitter plates becomes necessary, which may give rise to leakage currents of untolerable order.

2) We have to calibrate the secondary emission quantameters on the external electron beam with a Faraday cup. If we take thick plates of the same material for the emitter as well as for the collector, nearly one half of the charge of the electron beam is deposited on the electron emitting plates, while in a photon beam this effect vanishes. The measured quantameter constant for an electron beam therefore has to be corrected for use in a photon beam. The size of this effect can be calculated from the value of the calibration

constant of the SEQ,

$$K_{SEQ} = 1.5 \cdot 10^{21} \frac{MeV}{Coul.}$$

and from the formula

$$K_{SEQ} = \frac{E}{e} \cdot \frac{Q_{FC}}{Q_{SEQ}} ,$$

where E is the energy of the electron beam, e is the charge of the electron, Q_{FC} is the charge measured by the Faraday cup and Q_{SEQ} is the charge measured by the SEQ. Taking a beam energy of 3 GeV, one finds

$$\frac{Q_{FC}}{Q_{SEQ}} = 8 \cdot 10^{-2}.$$

The correction therefore would be about 4 % for quantameter plates of same thickness and material. However, for thin foils of 0,1 mm stainless steel as emitter plates this correction becomes negligible. Furthermore, the efficiency of the SEQ is increased, since there are more emitting surfaces near the maximum of the electromagnetic cascade.

Since the SEQ will be used in high intensity photon beams at DESY, beam powers of several KW's will be dissipated in the SEQ. Lead plates as for the test instrument cannot be used, because the melting point of lead is very low and the heat transfer coefficient is small. A high Z material is necessary, since otherwise the size of the foils becomes so large that mechanical complications will arise. The best material is tungsten and since the plates are of a simple shape, the costs are reasonable.

The construction of the proposed SEQ is similar to that shown in fig. 3. 26 tungsten plates, each 3.2 mm in thickness (= one radiation length) and 300 x 300 mm in area constitute the absorber of the SEQ. According to the Monte-Carlo calculation of Völkel[7] more than 99 % of the energy of a 6 GeV electron or photon beam should be absorbed. The beam diameter may be as big as 15 cm. The 25 secondary emitting plates are made of stainless steel foils of 50 µ thickness. The ground

plate and top plate, which carry the tungsten plates, are made from copper and are water-cooled. An electrical heater (about 500 Watts) and a platinum wire thermometer are also built in. The whole assembly is mounted on standoff insulators in a vacuum tank, which has an entrance window of 10^{-2} radiation length. The instrument will be evacuated by a 200 l/sec ion pump with special shields to reduce the zero current of the SEQ down to 10^{-13} Amps.

The electrical heater and the thermometer are introduced for calibrating the SEQ as a calorimeter. Thus, there exists a simple method for checking the SEQ in a photon beam periodically, without moving the instrument into an electron beam. The power requirements for the photon beam are 50 Watts minimum, for about 1 % accuracy, one hour beam input and nearly 10°C temperature rise. Clearly, the first calibration of the SEQ should be made in an electron beam, to have another check of the calibration constant. For very high intensity electron beams the SEQ may be used instead of a Faraday cup, since the water cooling of the SEQ introduces no zero currents, while for a Faraday cup the cooling may give rise to leakage currents.

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Quantameter	emitter foils	thickness of gilding in center	calibration constant [MeV/coul]	gold effect relative [%]	gold effect per μ of gold [%]	hole effect
DESY-Quantameter gasfilled 90% A + 10% CO_2	copper 0.1 mm thick	——	$4{,}38 \cdot 10^{18}$	24	8	no
	goldplated copper 0.1 mm	3 μ	$3{,}35 \cdot 10^{18}$			no
DESY-Quantameter evacuated	copper 0.1 mm thick	——	not measured, no pump provided	——	——	—
	goldplated copper 0.1 mm	3 μ	$13.4 \cdot 10^{20}$	——	——	yes ≈ 8%
Secondary emission test quantameter	stainless steel 0.1 mm thick	——	$14.55 \cdot 10^{20}$	36	9	no
	goldplated copper 0.1 mm	4 μ	$9.35 \cdot 10^{20}$			yes ≈ 5%

Table 1

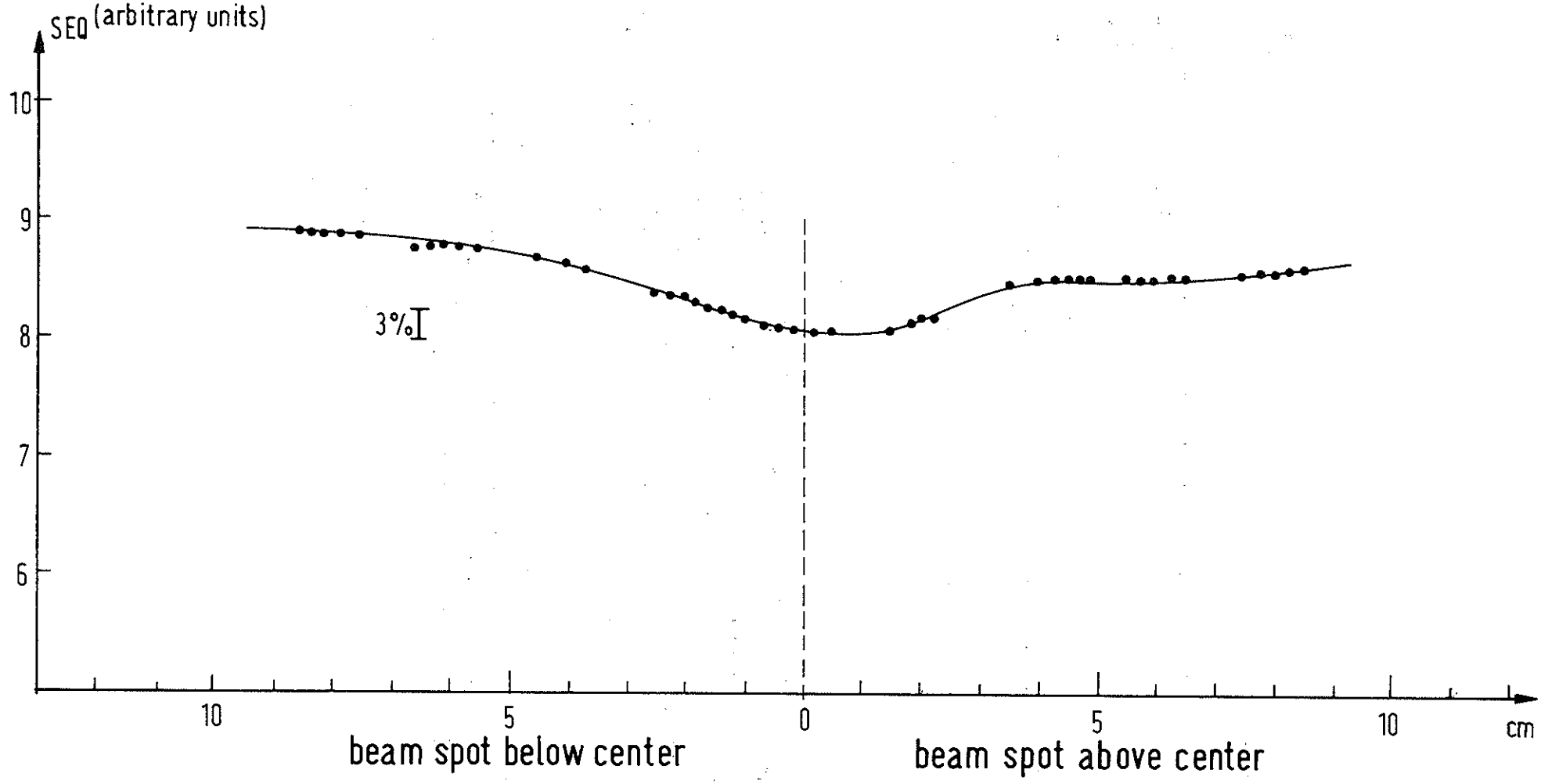

Fig.1 Dependence of the efficiency of the secondary emission quantameter from the position of the entrance surface. This SEQ is the evacuated DESY-quantameter with goldplated copper foils as emitters.

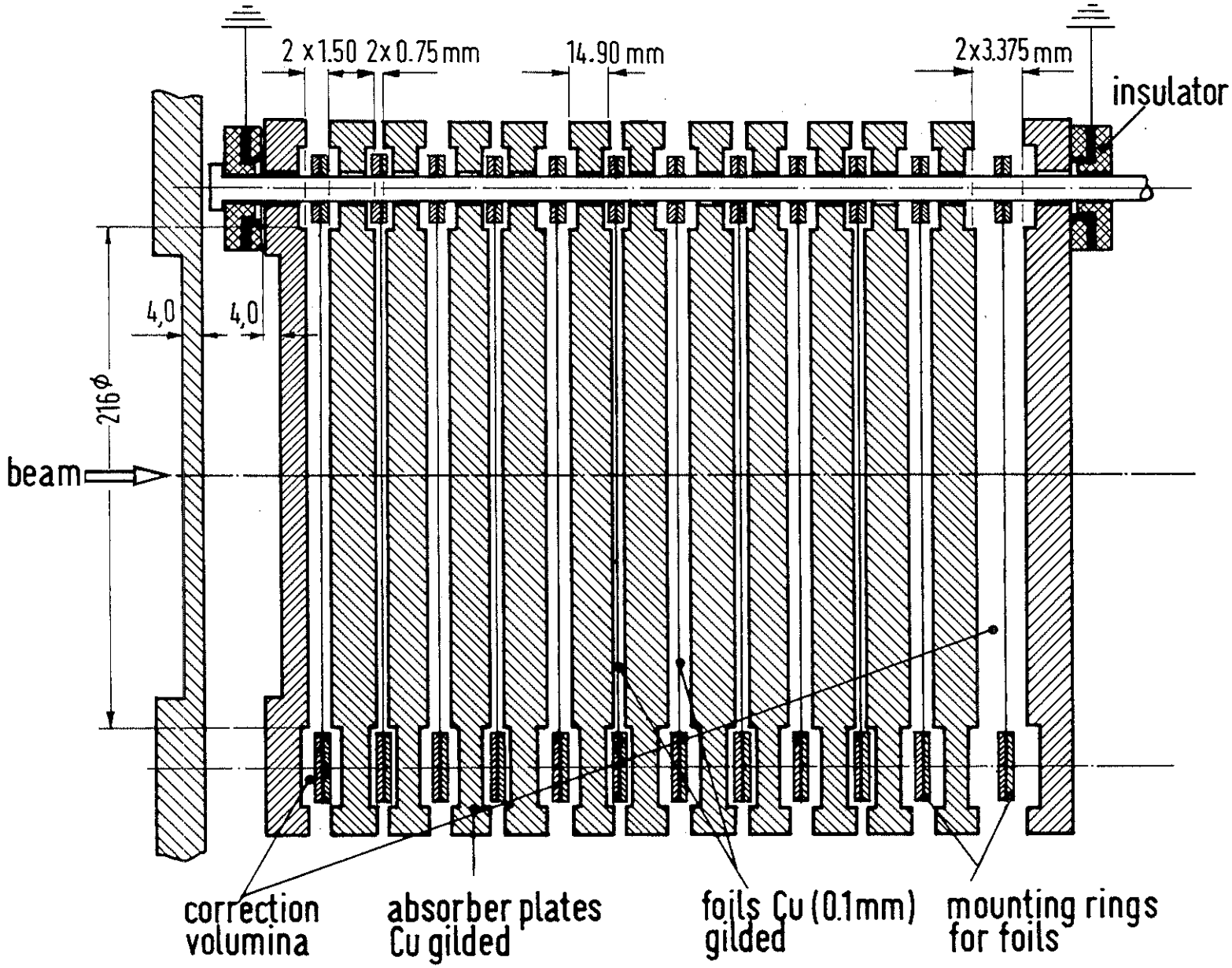

Fig.2 DESY-Quantameter

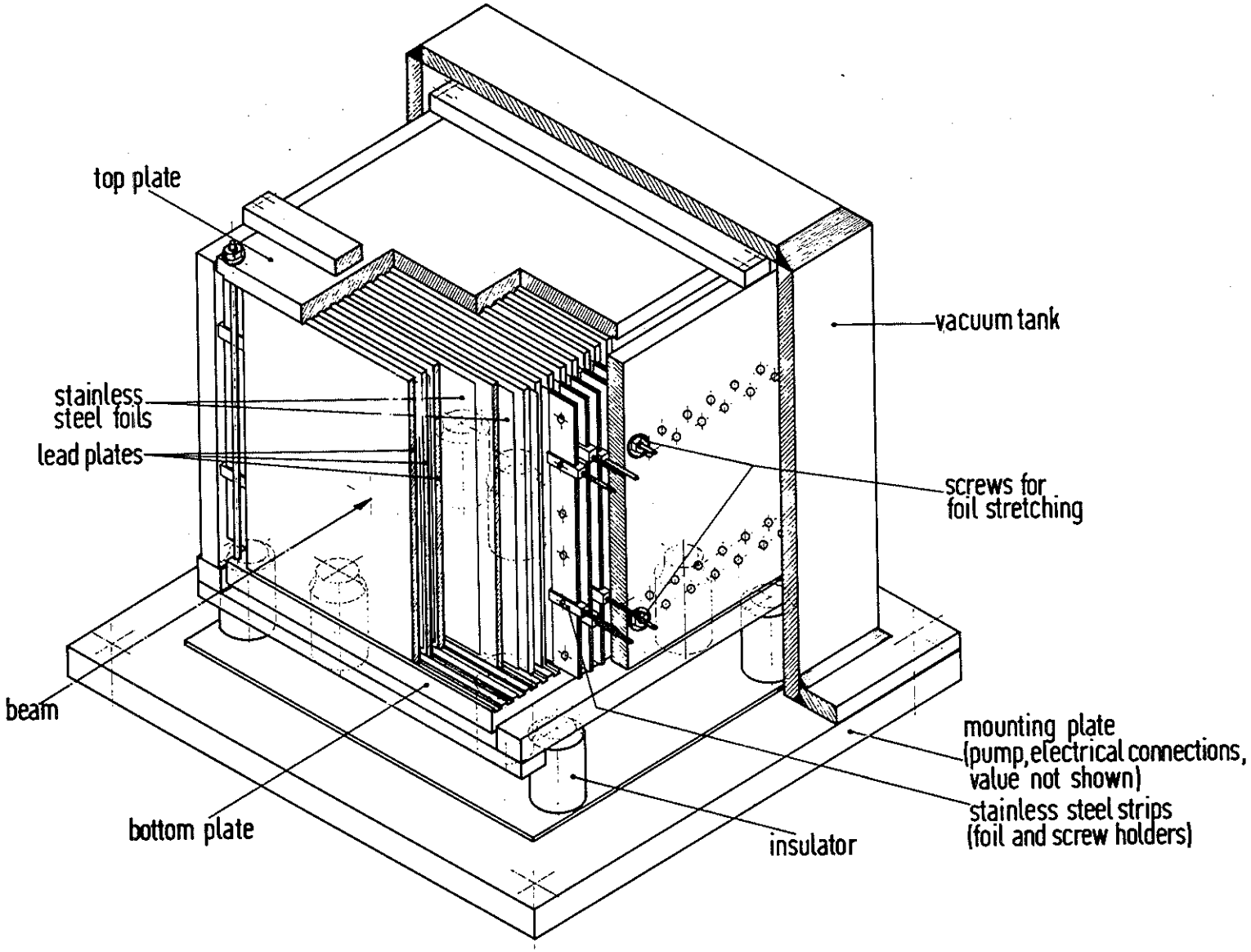

Fig.3 Secondary Emission Quantameter for Testmeasurements

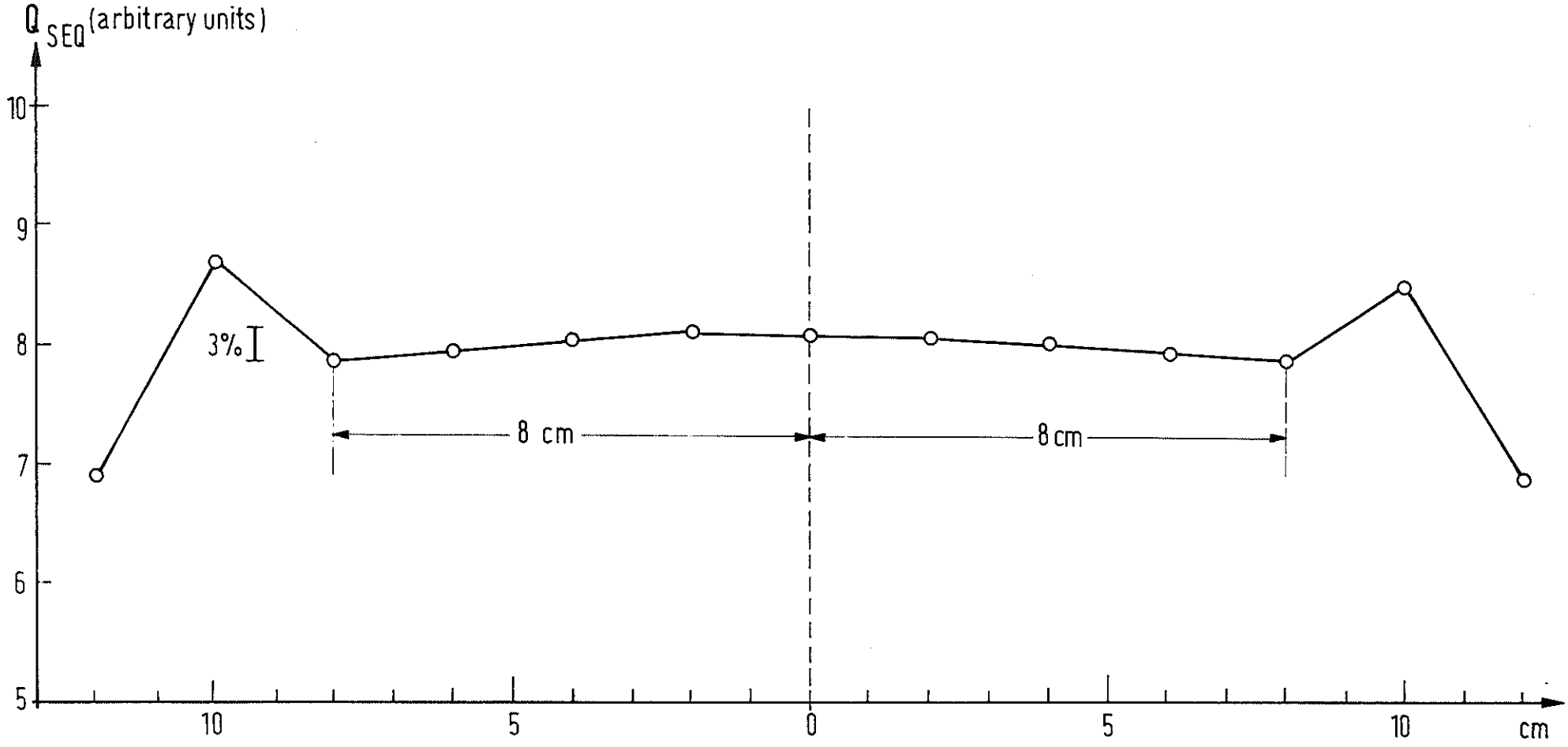

Fig. 4 Dependence of efficiency of the secondary emission quantameter from the position of the beam spot on the entrance surface. Test quantameter with stainless steel foils.

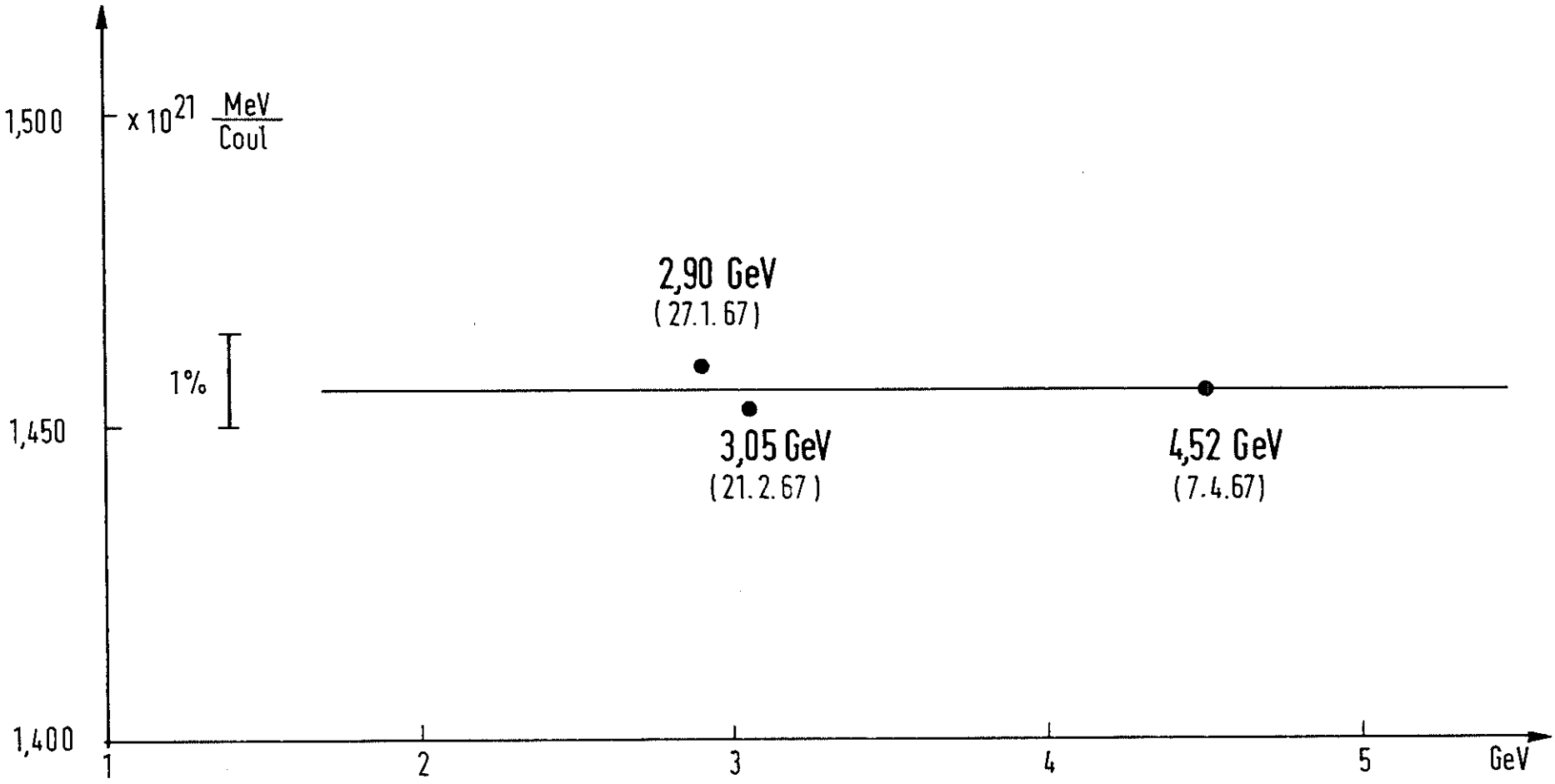

Fig.5 Calibration constant of secondary emission quantameter with stainless steel foils

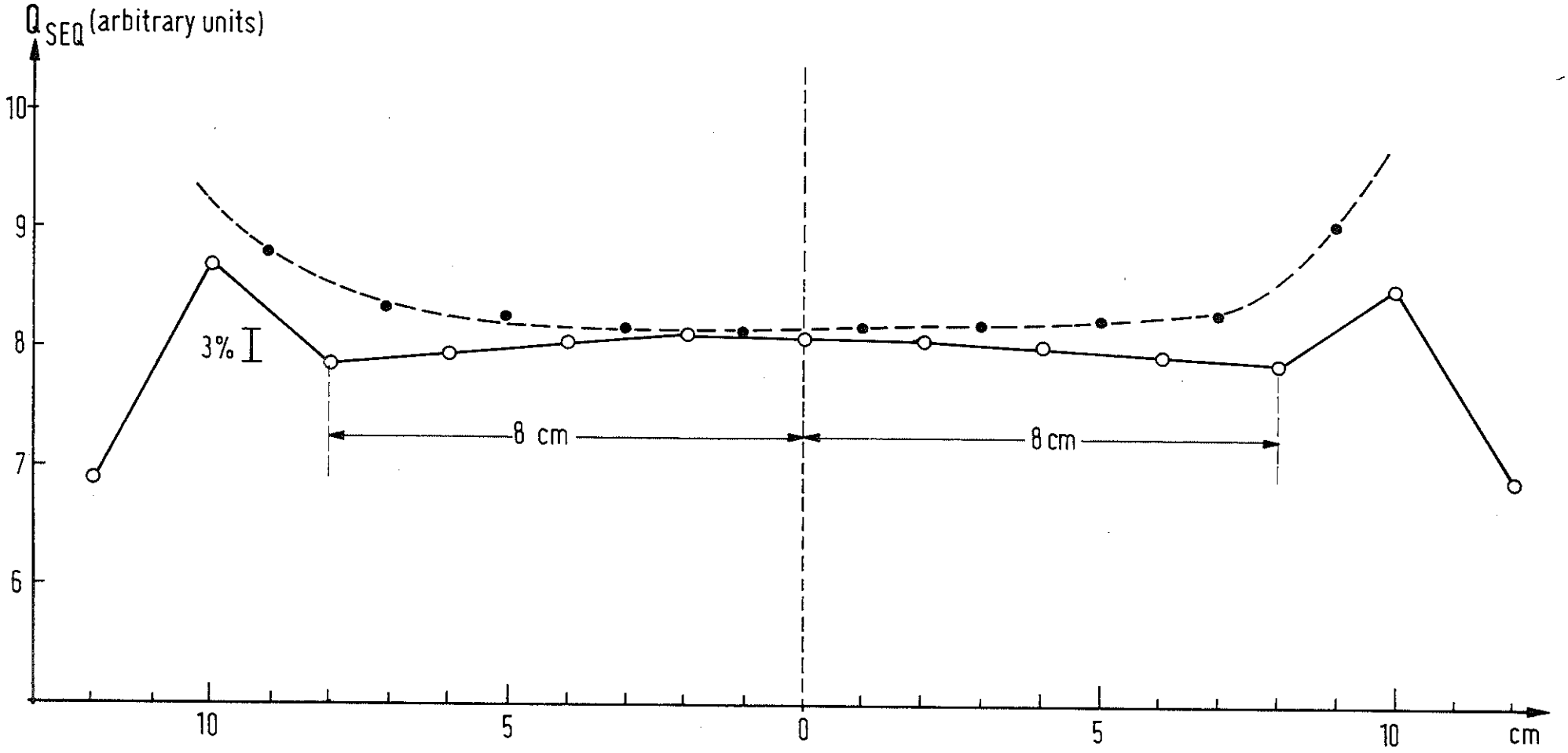

Fig.6 Dependence of efficiency of the secondary emission quantameter from the position of the beam spot on the entrance surface. Test quantameter with goldplated copper foils (----) Test quantameter with stainless steel foils (——)