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HIGH VOLTAGE TECHNOLOGY COURSE - MAY 1966

HIGH VOLTAGE ELECTROSTATIC SEPARATORS

ADDENDUM

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INTRODUCTION

Since the time when the paper on High Voltage Electrostatic Separators was presented (May 1965) some new interesting observations have been made at CERN. These mainly come from the study of the behaviour of the large model, described previously, assembled with a stainless steel anode in conjunction with an alumina coated cathode.

ASYMMETRY EFFECTS

1) Definition

After the usual low-pressure conditioning of a three metres set of stainless steel anode-alumina coated cathode it was noticed that the breakdown voltage U_d obtained for a given helium pressure was strongly dependent on the voltage applied to the cathode or to the anode. In other words :

If U_{d+} = positive voltage applied to the anode

U_{d-} = negative " " " " cathode (absolute value)

and $U_d = U_{d+} + U_{d-}$

then the curve U_{d+} as a function of U_{d-} at the breakdown threshold for a given helium pressure is not such that $U_{d+} + U_{d-} = U_d$ = constant. The curve U_{d-} as a function of U_{d+} at the breakdown threshold for the same helium pressure is not also such that $U_{d+} + U_{d-} = U_d$ = constant and is moreover quite different from the $U_{d+} = f(U_{d-})$ characteristic. On a same plot U_{d+}, U_{d-} it is possible to draw the two characteristics (Fig. 1). They then define in the U_{d+}, U_{d-} plane an area in which the voltage can be sustained by the electrodes. This area is limited by four different curves :

i) a straight line parallel to the U_{d-} axis which is the threshold breakdown voltage of the positive electrode in respect to the grounded walls of the tank. This limitation is an increasing function of the pressure and is generally caused by a spark occuring along the insulators of the anode supports or the bushing.

ii) a straight line parallel to the U_{d+} axis which is the same limit as the limit for the positive side but for the negative polarity.

iii) a -45° angle straight line with respect to the U_{d-} axis. This is the constant breakdown threshold voltage $U_d = U_{d+} + U_{d-}$ which is the gap limit. This limitation is, as shown previously, a function of the gas pressure and electrode spacing.

iv) A well defined but complicated curve made of the two branches of the $U_{d+} = f(U_{d-})$ and $U_{d-} = f(Ud_{+})$ characteristics. This limitation is caused by a breakdown occuring always from behind the negative electrode and is called the asymmetry effect.

2) Influence of the gas

The following observations have been made :

- In low pressure ($\sim 10^{-6}$ Torr) the asymmetry effect does not occur. Then, in that case, the characteristic U_{d+}, U_{d-} is made of the three straight lines $U_{d+} = U_{d+max}$, $U_{d+} + U_{d-}$ = constant and $U_{d-} = U_{d-max}$.
- When the pressure is increased the asymmetry effect occurs at a pressure depending on the kind of gas which is used. For helium this effect appears around an equivalent air pressure of 10^{-4} Torr (fig. 1) for nitrogen and for argon the asymmetry effect is not observable because it would occur if so at a pressure higher than

the critical pressure p_c which is around 10^{-3} Torr in the large model.

- The asymmetry effect is independent of the conditioning state of the electrodes, i.e. does not depend on the value of the conditioning voltage U_f.
- Using a mixed gas (30 o/o He - 70 o/o Ne) the asymmetry effect is cancelled for the characteristic $U_{d+} = f(U_{d-})$ but is stronger for the curve $U_{d-} = f(U_{d+})$.
- If an ionisation gauge is used for measuring the tank pressure, it is important to shield electrically the gauge in respect of the negative electrode otherwise sparks occur at voltages much lower than the U_{d-} limit.

These different observations seem to show that the asymmetry effect is due to an ionic bombardment of the cathode side opposite the gap. The kind of gas and the pressure are determinant factors in this effect. However, the ionisation cross section of the gas is not the fundamental factor for the asymmetry effect as it is for the pressure effect previously reported. Then the results obtained show that another parameter depending on the kind of the gas is involved in the asymmetry effect and it will be seen that this parameter could be the total electron yield γ_i due to high energy ions [1].

3) Influence of a cross magnetic field

When a magnetic field is established in the separator the asymmetry effect disappears completely [2]. This magnetic field is made perpendicular to the electric field in the gap; near the walls of the tank the angle between the electric and magnetic fields varies between 0 and $\frac{\pi}{2}$ along the wall (fig. 2 a).

The asymmetry effect appears only if the maximum value of the magnetic field is decreased below 100 Gauss (fig. 3). The highest value of the magnetic field is always obtained in the corners of the tank where the electric field is at its minimum value.

4) Influence of the geometry

It is possible to cancel the asymmetry effect observed with helium by changing the geometry inside the tank. If a metallic shield, connected to wall ground potential, is put in the median plane of the tank on each side of the gap region (fig. 2 b), then the asymmetry effect disappears completely.

The asymmetry effect seems mainly dependent on the cross section geometry of the separator but could also be dependent on its total length [3].

CONCLUSION

From these different results and observations it is possible to postulate a mechanism responsible for the asymmetry effect (fig. 2 c).

- Ions are created in the gas by electrons in the positive side of the separator. Some of these ions, which are accelerated by the electrical field are crossing the zero potential line on each side of the negative and positive electrodes. The position of this zero potential line depends on the relative value of the positive and negative voltages.
- When these ions have crossed this zero potential line, the electrical field being reversed, they are curved towards the cathode and slowed down when approaching the tank walls. If their energy when crossing the zero potential line is enough they will bombard the wall of the negative side; the bombarded region will strongly depend on the relative value of the positive and negative voltage.
- This bombardment will eject secondary electrons from the wall. The electron yield γ_i is a function of ion energy and of the kind of the ion. For inert gas ions of a few Kev this yield is generally larger than one. The highest value of the yield is always obtained for helium (at 100 kev, γ_i (He^+) $\cong$ 13 and γ_i (H^+) $\sim$ 3 on Mo target, at 1 Kev, γ_i (He^+) $\cong$ 0.85 and γ_i (A^+) $\simeq$ 0.15 on Ni target). The kinetic energy distribution of these secondary electrons is concentrated in a low energy band the width of which weakly depends on the energy of the incident ion [1].

- These low energy electrons will ionize the gas before falling back to the emitting side. The production of ions will be higher in the low electric field region (corners) where the electron trajectories are the longest.
- The ions produced will then bombard the cathode causing a spark on the cathode side opposite the wall as it is observed.

This model is enough to explain qualitatively the results obtained. As an example, the magnetic field effect is due to the fact that the ionization trajectories of the secondary electrons are shorter when the magnetic field is applied and so the ions causing the spark are produced at a much lower rate. A calculation shows very well this fact whatever the angle between the electric and magnetic fields may be. In fact, this is true only for electrons of sufficient initial velocity v_0; for a crossed magnetic field this limit is:

$$v_0 \geqslant \sqrt{\frac{3\pi}{2}} \frac{E}{B}$$

if $\vec{v}_0$ is parallel to $\vec{E}$

path length with $\vec{E} = \frac{mv_0^2}{eE}$

path length with $\vec{E}, \vec{B}$ ($\vec{B} \,//\, \vec{E}$) $= \frac{mv_0^2}{eE}$

path length with $\vec{E}, \vec{B}$ ($\vec{B} \perp \vec{E}$) $= \frac{3\pi}{2} \frac{mE}{eB^2}$

with e = electron charge

m = " mass

This condition is fulfilled in the low electric field region where the magnetic field has the highest value (corners). As another example the effect of the shield is to stop the ionic bombardment and then to stop the ionization causing the spark.

This asymmetry effect is a very important effect and must be cancelled for the operation of separators because it limits the working voltage since the system must work with asymmetric voltage which is not favourable for the insulators and bushing. The use of another gas which does not produce the asymmetry effect is not a solution as helium has to be used for other considerations, previously reported (essentially the fact that helium gives the longest T_x time). Up to now the best solution seems to be to install a shield which screens the corner regions from bombarding ions.

REFERENCES

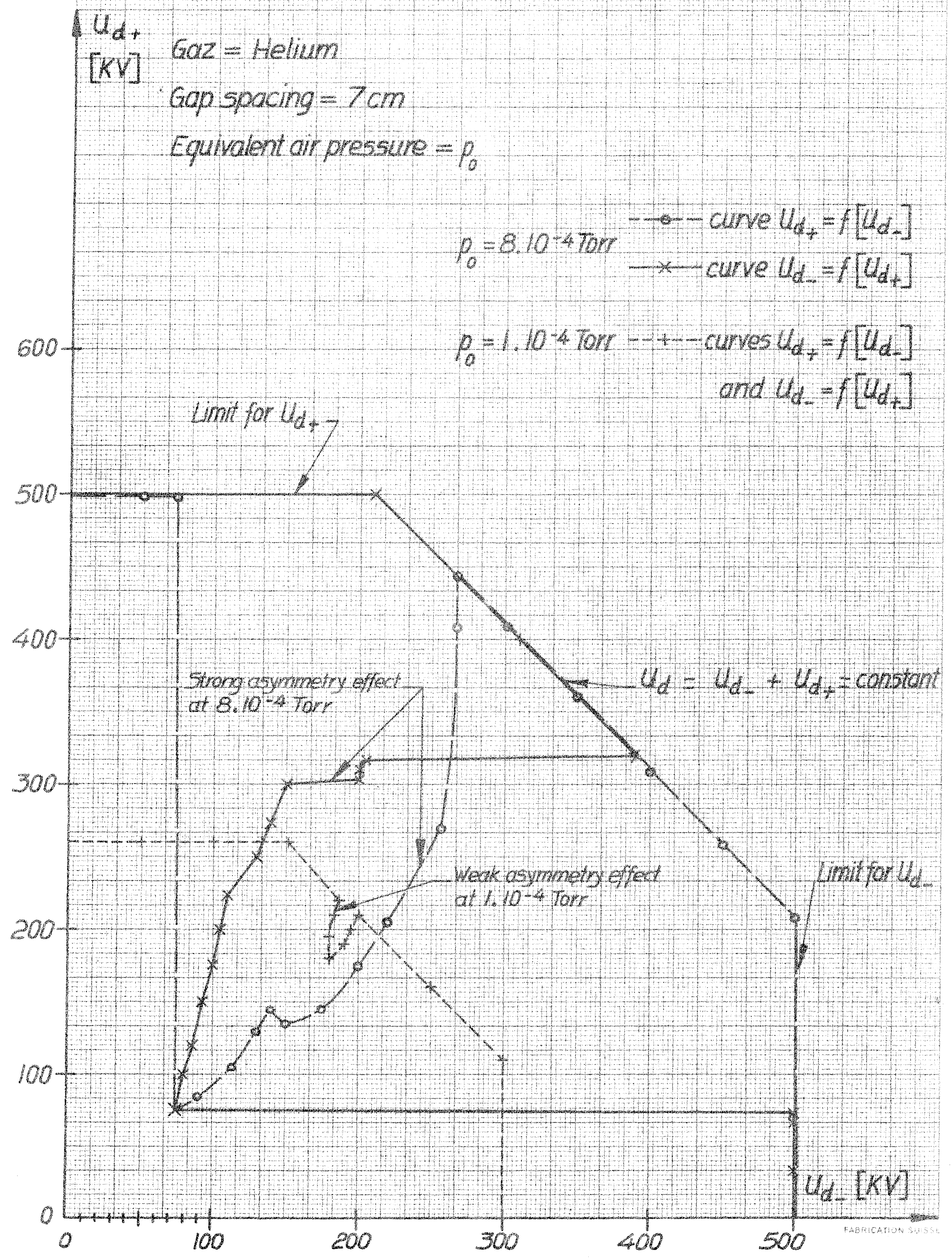
1) S. Flügge - Handbuch der Physik - XXI - p. 638 (956)

2) R. Michelier et D. Simon - Cross magnetic field in separators - to be published

3) P. Coet - Les performances haute tension des séparateurs électrostatiques - CERN-MPS/Int. 66-1.

Asymmetry plot

Fig. 1



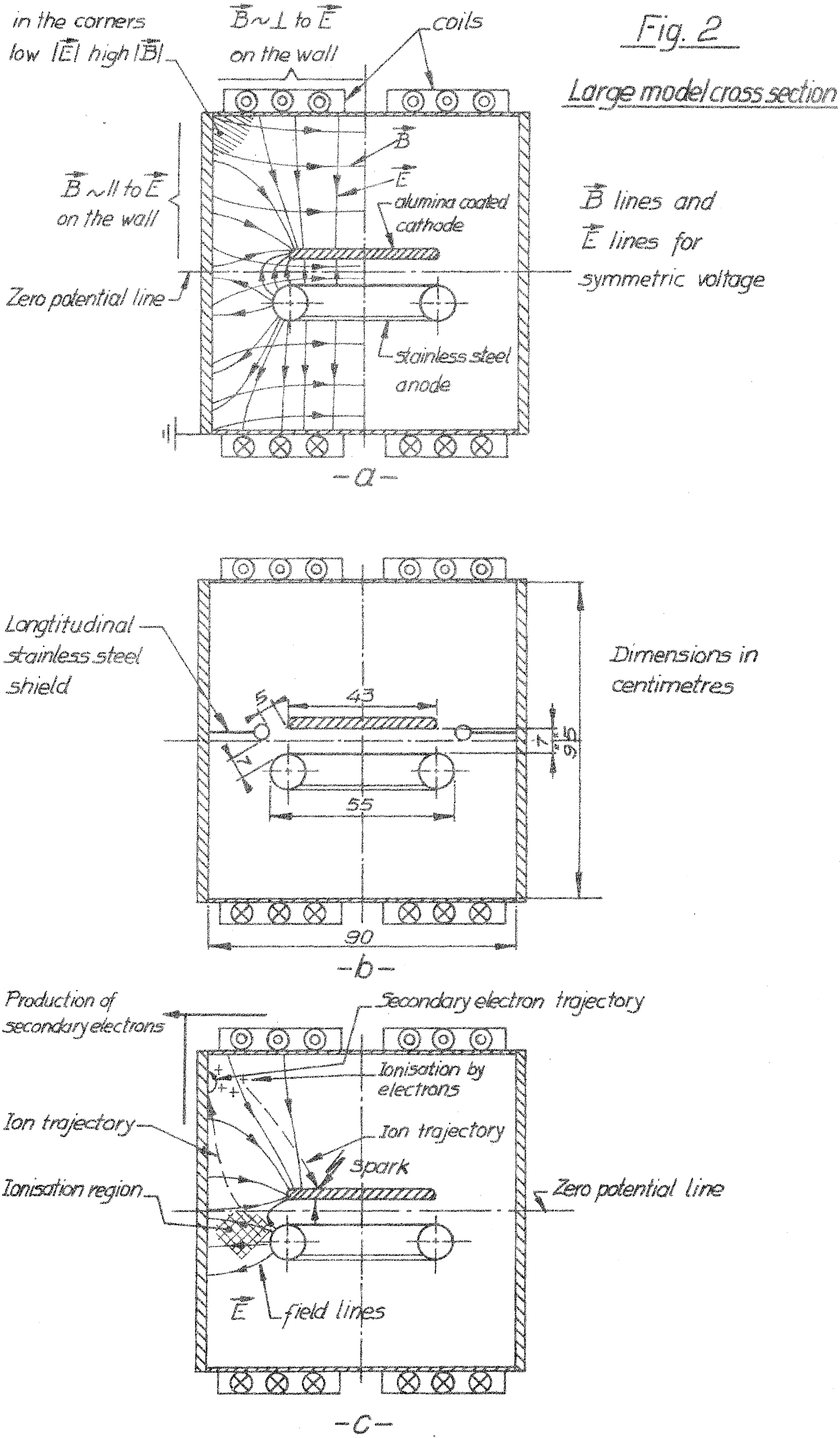


Fig. 2

Large model cross section

Influence of magnetic field   Fig. 3