Anlage zum Betrieb eines MHD-Generators mit einem Gaskreislauf und der Einrichtung für Stromdichtemessungen

Device for Operating a Closed-loop M.H.D. Generator with Current Density Measuring Facilities

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ABSTRACT

The description of an experimental segmented electrode generator operating with potassium seeded argon at 100 gr/sec mass flow and permitting the measurement of the current distribution at different electrode geometries is given herein. The purpose of this design is to gain practical experience in the construction of closed cycle generators and to obtain additional information regarding the effect of the surface to volume ratio upon the experimental results. The major components of the system here described are as follows: The plasma jet, the potassium injection system with the corresponding mixing chamber, the M.H.D. generator with measuring facilities, the potassium separator, and the compressor.

The individual components of the system are described in detail. Particular attention is given to the potassium injector which assures a constant seeding ratio at any selected value of the seed mass flow within a range of 0.04 to 2.9 %, and to the potassium separator yielding a continuous separation at a sufficiently low pressure drop. Technical and technological details related to the design of such components as the plasma arc heater, the mixing chamber, the generator and the monitoring facilities are also given.

I. Introduction and measuring programme

In investigations on rare-gas alkali M.H.D. generators it is advisable to use channels with a large volume-to-wall ratio so as to reduce the disturbing influence of the walls. For continuous operation, however, such channels require a closed-loop gas feed because of the high gas flow.

Our present measuring programme called for such an increase in the existing channel cross sections that we had to change over to a closed-loop gas feed. On the basis of our experience and in view of the technical prospects afforded we decided to construct a system with a generator channel cross section of 5 cm^2 and a mass flow of 100 gr argon/sec.

The generator in this device is operated with an argon-potassium mixture in which the potassium concentration can be varied over a range of 0.04 to 2.9 %. In a pressure range of 1.1 - 1.3 atm the working gas has a maximum temperature of 2100 ^oK. Under these conditions a mass flow of 100 gr argon/sec produces a flow velocity of up to 650 m/sec.

The first measurements made with this system will be the current density distribution in the generator. For this purpose the light of the potassium resonance lines emitted in the direction of the applied magnetic field is measured with high spatial resolution in the region of two pairs of electrodes. The light intensity is an indication of the electron temperature, which, in turn, is an indication of the current density in the corresponding region. This method has already been used by F. Fischer to measure the current density distribution in a simulated M.H.D. generator with segmented electrodes [1].

In order to determine the spatial current density distribution, we must find first the connection between the light intensity of the potassium resonance line and the electron temperature by the line reversal method. The spatial intensity enables us to derive the electron temperature distribution. The detailed energy balance of the electrons gives the relationship between the electron temperature and the electric current density [2].

$$j^2/\sigma = \sum_i n_e \nu_{ei}\, \delta \frac{m_e}{m_i} \frac{3}{2} k (T_e - T_0) + R(T_e)$$

The term $R(T_e)$ gives the mean radiation loss per unit volume. Only the radiation losses of the resonance lines are taken into account here. Estimates showed that the residual radiation is so small that it can be ignored. Since the plasma in the vicinity of the line centre is optically thick it is possible to approximate $R(T_e)$ as follows:

$$R(T_e) = \frac{F}{V} \pi B_\lambda (T_e) \Delta\lambda$$

Here, $B_\lambda (T_e)$ is the radiation intensity of the black body at the temperature T_e. In order to determine the value of $\Delta\lambda$ the integral of the intensity over the line region has to be replaced by a rectangle of height B_λ and width $\Delta\lambda$ so that the areas are equal. For the electron temperature range of interest here the value of $\Delta\lambda$ was measured to be 20 Å for both lines of the resonance doublet [2]. The value $\frac{F}{V}$ is the surface-to-volume ratio of the plasma.

II. Construction of the closed gas loop

This part of the system comprises the compressor, plasma jet, mixing chamber with the potassium injection system, M.H.D. generator with the measuring device and the magnetic field coils, and the potassium filtering system (Figs. 1 and 2). The argon comes from the compressor into the plasma jet, where it is heated to a maximum mean temperature of 2500 °K. Potassium is then injected into the mixing chamber at a constant controlled rate. The argon-potassium mixture now enters the M.H.D. generator through a BN channel lined with tungsten pipes. At the input end of the generator the working gas has a maximum temperature of 2100 ^{O}K. After passing through the generator the gas is cooled down to approximately 80 ^{O}C. The greater part of the potassium is then extracted in the filter situated at this point. The gas is cooled further to a temperature of 20^{o} - 30^{o}C and passes through a second filter before returning to the compressor. A two-stage piston compressor capable of producing a maximum pressure of 17 atm is used for compressing the working gas. The compressor is of such a type that the gas cannot be contaminated with vapours given off by the lubricant. The pressure fluctuations occuring at the output end of the compressor are reduced to such an extent by pressure-reducing valves placed between the compressor and plasma jet that the pressure fluctuations in the generator are smaller than 1 %.

The gas is heated by means of a plasma jet of our own design which causes hardly any contamination of the gas. It has an output of 200 kW. In this jet the chamber walls and the cathode are cooled by the argon being heated. It was thus possible to attain an efficiency of 75 %. Only the anode is water-cooled (Fig. 3).

The question arises as to whether the charged particles produced in the plasma jet are carried by the gas flow into the generator channel and there give a higher carrier density than is compatible with the prevailing temperature. This problem was investigated by means of conductivity measurements in a suitable experiment. For this purpose auxiliary discharges of high current density were operated at various distances between the plasma jet and the measuring chamber. It was discovered that with a gas temperature of 2000 ^{o}C the recombination rate is so high that the electrical conductivity returns to equilibrium within $\sim$ 2 msec. In the device described here the gas takes 3 msec to flow from the plasma jet to the generator.

The mixing chamber next in line after the plasma jet consists of BN tubes lined with tungsten pipe. The thermal insulation is improved by encasing the BN tubes with MgO pipes. All parts of the outer casing are made of stainless steel.

A special arrangement was developed for supplying potassium, so that it is added to the argon as a steady, exactly known, vapour flow. The liquid potassium, which is contained in a cylinder, is pushed into an evaporation chamber by a variable speed piston. This evaporation chamber is made from tungsten cylinder (with one end blocked off) which projects into the mixing chamber. A small hole is drilled in the closed end of the cylinder, so that excess pressure builds up in the cylinder and forces a stream of potassium vapour out into the mixing chamber. The hole may be made so small that the variations in the potassium supply caused by unsteady evaporation or irregular piston motion is compensated.

In order not to damage the Teflon-containing piston rings in the compressor the potassium has to be totally removed from the working gas after it passes through the generator. The argon-potassium mixture is first cooled down to approximately 90° C. Since, however, condensation centres are absent in this extremely pure gas a supersaturated potassium vapour component is left over in the argon after it emerges from the cooler. Most of the potassium is extracted in the filter placed at this point. The potassium is mostly extracted at the surface of the glass wool filter and runs off to be collected. Continuous operation is thus possible, since the filter does not "block up". The pressure fall is only 0.05 atm. After leaving the filter, the argon is cooled down to a temperature of 20° - 30° C and then undergoes final purification in a second filter (also filled with glass wool).

Chemical analyses of the working gas was performed on a small device corresponding to the high temperature component of the closed loop. These showed that after one pass the gas picks up less than 0.01 % impurity. Because the increase of impurities was so small we decided to do without a gas-purifying system and instead to replace part of the working gas continuously with fresh gas. Argon is released by means of a diaphragm-controlled device which keeps the gas pressure at the compressor input constant at a set value. This also ensures that steady pressure conditions prevail throughout the system.

III. Monitoring facilities

In order to maintain safe and reliable operation of the equipment, the gas loop has to be monitored with automatic control facilities. The entire unit is switched off if the following conditions arise: insufficient supply of cooling water, overheating of sections particularly vulnerable to thermal influences, penetration of water inside the plasma jet (due to a leak in the anode cooling system), and insufficient gas flow through the cathode of the plasma jet.

For the current density measurements in the generator it is important that the electron temperature at a given current density should always be reproducible. The electron temperature increase depends, however, on the degree of purity of the argon-potassium mixture and on the percentage of potassium in the argon.

In order to ensure constant conditions of operation and gas purity, the electron temperature increase at constant current density can be continuously monitored by measuring the light emission at the K resonance lines wavelength of a constant current density discharge located between the generator and the first cooler. This light emission is a sensitive function of the electron temperature and affords a simple method of checking the degree of purity of the gas and potassium concentration.

Once the argon emerges from the potassium filtering system, its potassium content has to be checked. For this purpose light in the wavelength range of the potassium resonance lines is passed through the gas. If radiation is absorbed there is still potassium in the argon. This is shown by a signal. The monitoring facilities make it possible to detect potassium concentrations of less than 10 PPM. With 0.1 % potassium in the generator, we estimate that ≈ 10 PPM go into the compressor.

IV. MHD generator with measuring facilities

The MHD generator is so constructed as to allow generator channels of various cross sections to be readily incorporated and the electrode geometries to be altered with no great effort. The channel walls are made of BN and the electrodes of tantalum. Thermal insulation is provided by MgO. It is possible to measure the gas temperature at four points in the channel with thermocouples and also to measure the gas pressure. In addition, electric probe measurements can be made at any point. The channel at present in use has a cross section of 25 x 20 mm^2 and is 205 mm long. It contains 15 pairs of electrodes.

The magnetic field is produced by water-cooled coils without iron cores. With these coils it is possible to attain a maximum magnetic flux density of 3 tesla for a short time at currents of 4.1 kA.

In order to measure the radiation intensity and electron temperature in the region of two pairs of electrodes with sufficiently high spatial resolution, the light emission of a plasma column with axis in the direction of the magnetic field and a cross section of 1 mm^2 had to be measured. For this purpose the relevant electrode region has sliding side walls each of which has a viewing aperture aligned in such a way that the connecting line of the apertures in each plate always points in the direction of the magnetic field (Fig. 5). The side walls with the viewing apertures are rigidly connected with the bank supporting the optical system. The optical bank can be shifted horizontally and vertically in a region of 25 x 30 mm^2. The position is changed by means of servo motors. The position of the bank is indicated with an accuracy of ± 0.05 mm. The viewing apertures have a maximum diameter of 1 mm.

Since the plasma is optically thick to radiation of the wavelength of the potassium resonance lines and only the emission of plasma from inner regions of the channel is to be investigated, the potassium in the colder boundary layer has to be displaced. This is done by blowing pure argon through the viewing apertures into the channel. The light emission is measured with a monochromator and a cooled RCA 7102 photomultiplier. The optical connection between the moving optical bank and the fixed detecting device is provided by a light pipe. The light signal is recorded by an x-y plotter. When the viewing aperture moves rectilinearly this recorder plots either space coordinate on the x-axis. The light intensity is written as the ordinate.

The electron temperature measurements were made on one of the potassium resonance lines by the line reversal method. The suitability of this measuring method was investigated by Riedmüller and Salvat [2,3]. They found that for our conditions the reversal temperature is equal to the electron temperature if the plasma is optically thick to most of the potassium resonance radiation. This condition is satisfied here because the plasma is transparent to the radiation only in the line wings.

Measurements were started by recording the intensity of the light emitted from a black body - in this case a tungsten strip lamp - as a function of the temperature of the black body with an x-y recorder. It was then possible to record the light intensities in the line range of interest emitted from the plasma plus that transmitted from the black body as a function of the black body temperature T_S. The temperature where the two curves intersect corresponds to the electron temperature. This method enables the electron temperature (for any wavelength range of the potassium resonance line) to be measured within 1 sec.

In these measurements deviations in the electron temperatures are obtained if the electron temperature is measured as a function of the wavelength. In the region of the line centre, where plasma is optically thick, the electron temperature of the colder layers next to the wall is measured. In the line wings, where plasma is transparent, an electron temperature averaged over the channel cross section is measured.

Conclusions

The foregoing measuring method is used to investigate the spatial current density distribution in the generator for various electrode geometries. The purpose of these investigations is to provide an experimental check on numerically calculated distributions [4] and give an electrode geometry with as small an internal impedance as possible. They are also intended to determine the influence of the gas flow on the current density distribution as a result of relaxation phenomena. The occurrence of instabilities is also investigated by measuring fluctuations in the potential distribution and pressure.

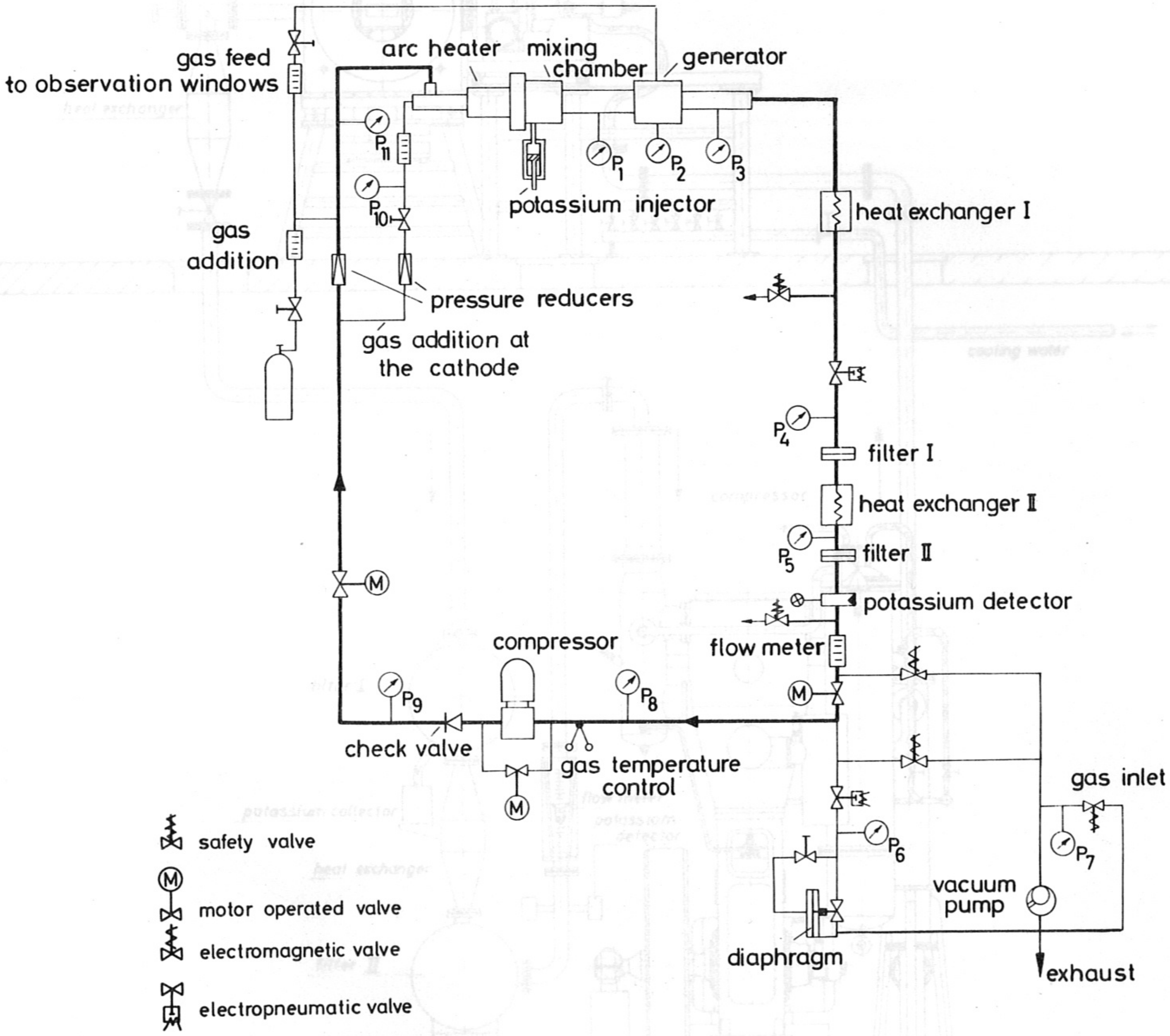

Fig. 1 Scheme of the closed cycle system

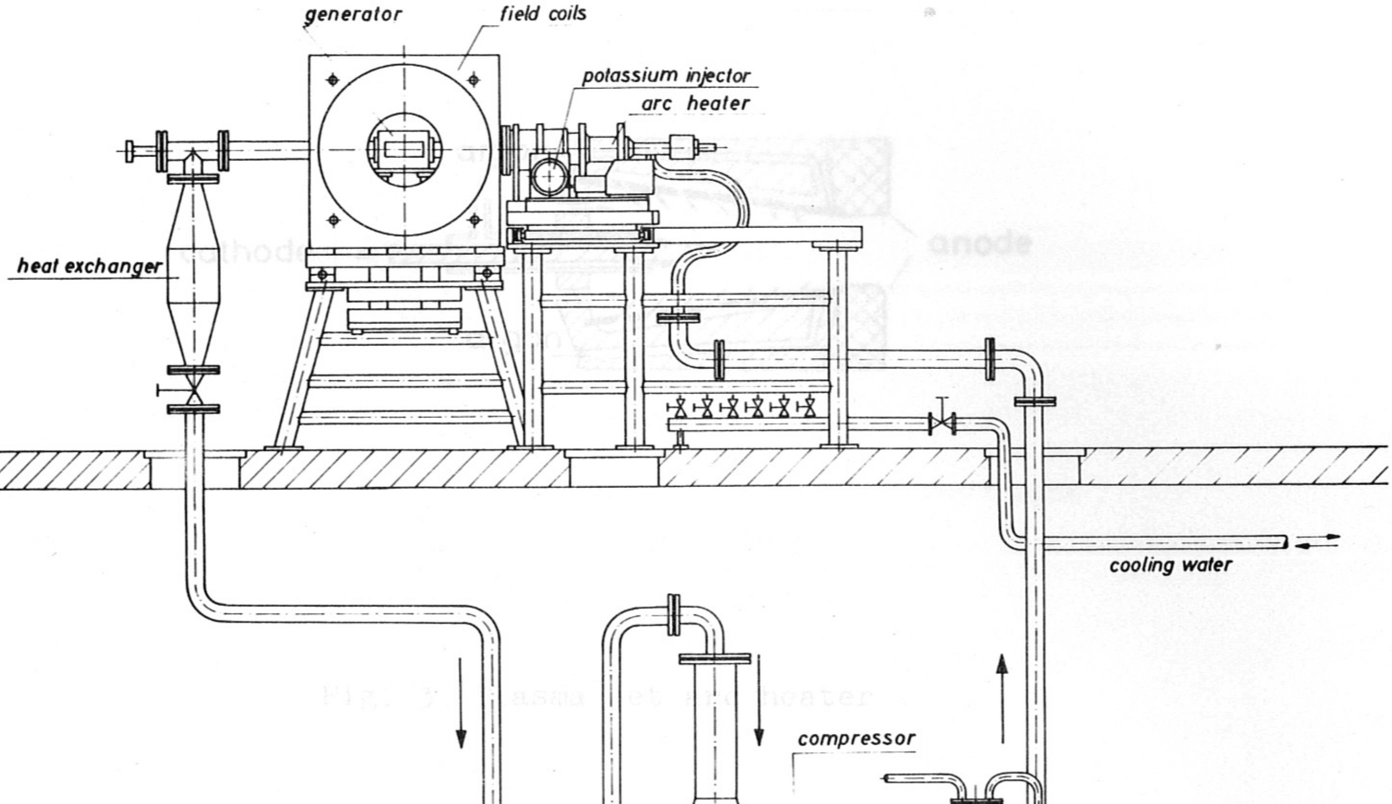

Fig. 2 Closed cycle generator arrangement

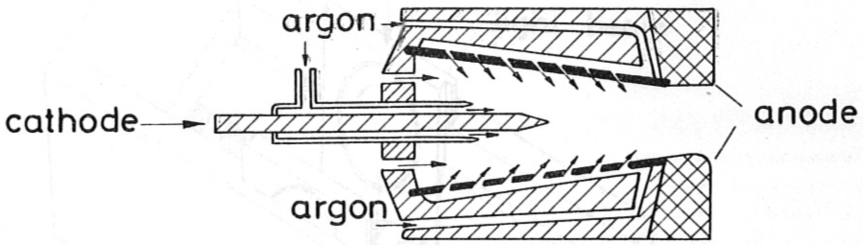

Fig. 3 Plasma jet arc heater

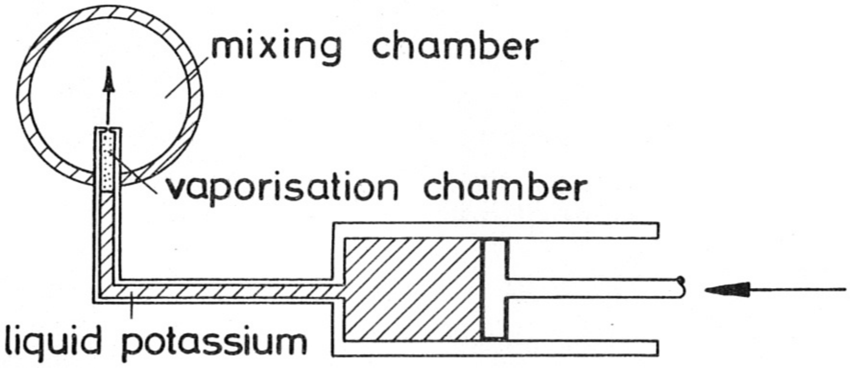

Fig. 4 Potassium injection system

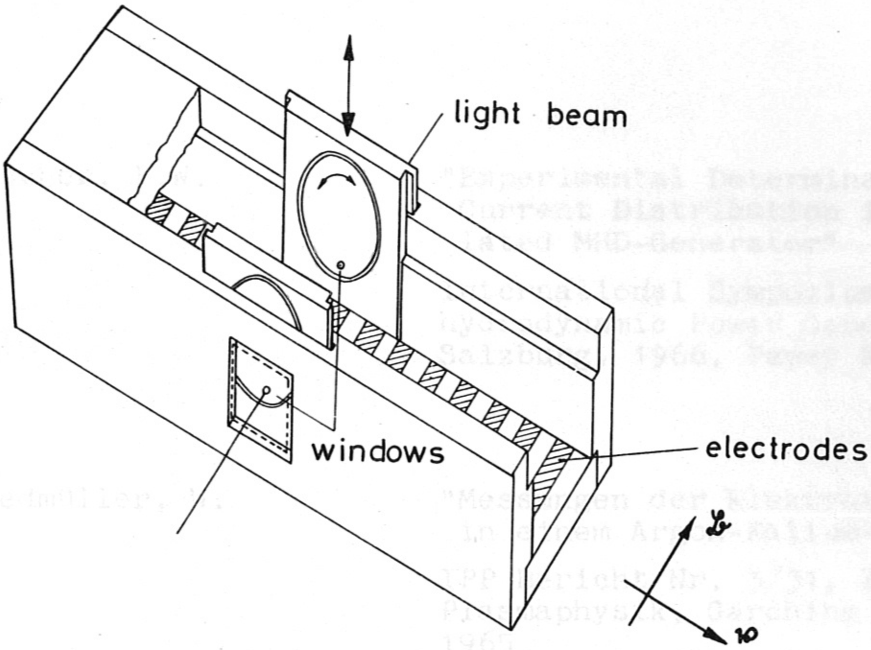

Fig. 5 M.H.D. generator duct with movable side walls, upper electrode wall is removed

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