# APPLICATIONS AND TECHNOLOGY

# ELECTROMAGNETIC FILTER FOR H$^-$ SEPARATION FROM PIG WITH METAL HYDRIDE CATHODE

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The paper proposes a design and method for calculating an electromagnetic filter for separation of negative hydrogen ions extracted in the longitudinal direction from the Penning discharge with a metal hydride cathode. The design of the filter was calculated on the basis of preliminary experimental data and analysis of the trajectory of charged particles, which were obtained by the numerical solution of motion equation. It has been built a model that allows to choose the optimal external parameters for effective separation of H$^-$ ions and the interpretation of subsequent experiments. An experimental test of the model has been performed.

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## INTRODUCTION

The application of a metal hydride cathode as a solid hydrogen generator in Penning discharge led to a number of unexpected phenomena [1 - 5]. In particular, the desorption of hydrogen from the metal hydride cathode in the vibrationally / rotationally excited state has significantly changed the discharge conditions [1 - 3]. This was appeared in the fact that in the longitudinal direction along with positively charged particles a negative current was registered [1 - 3]. The authors showed that the main part of this current consists of electrons ($\varepsilon \approx 100$ eV), which overcome the potential barrier near the cathode due to the development of instability in the anode layer. In addition to electrons energy collection, a reduction in potential barrier near the cathodes was also observed [1]. Moreover, the potential barrier near the metal hydride cathode did not decrease as much as from opposite side, which makes negative particles yielding precisely from the side of the cathode-reflector.

On the other hand, the hydrogen $H_2^*$ desorbed from the metal hydride cathode is already in vibrationally excited state and is injected directly to the region, which contains the greatest number of thermal electrons: to the cathode region [2]. Thus, the efficiency of the formation of H$^-$ ions by the mechanism of dissociative attachment substantially increases. Traditionally, the extraction of negative ions is made perpendicular to an external magnetic field through the aperture in an anode. However, due to a change in the discharge properties when a metal hydride cathode is using, it is opens the possibility for longitudinal extraction of negative ions [6, 7]. The problem that arises in this case is the need to separate H$^-$ ions from the total flux of particles yielded along the external magnetic field. Taking into account the large difference in the mass of hydrogen ion and electron, it is convenient to make their separation by an inhomogeneous magnetic field in the region behind the cathode-reflector. And the diverting of positive ions $H_2^+$ is to make by electric field. Taking into account the results of the previous calculations [6] and experiments [7, 8], the goal of this work was to improve the design of the developed filter for efficient separation of charged particles extracted from the Penning discharge with a metal hydride cathode.

## RESULTS AND DISCUSSION

A cathode unit (Fig. 1) consists a copper cathode-reflector and a magnetic filter which includes a grid 1, electrons current collector 2, a coil of magnetic field (4) and a collector of negative ions 5. The copper cathode-reflector 3 has got an aperture in the center 0.5 cm in diameter for charged particles extraction.

The magnetic filter was set on the axis of the discharge behind the aperture in the copper cathode-reflector so, that all reverse magnetic field of the coil 4 was concentrated outside the discharge cell. For convenience the distance between the cathode 3, the grid 1 and the electron collectors 2 were the same and were 0.4 cm. The ion collector 5 were at the distance of 1.8 cm from the copper cathode-reflector 3.

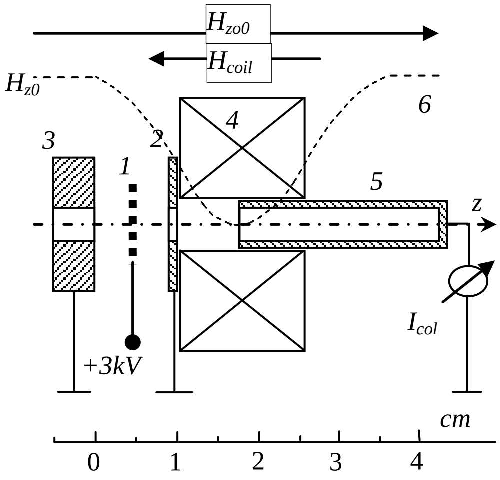

*Fig. 1. The cathode unit with electromagnetic filter 1 – retarding grid; 2 – electrons collector; 3 –copper cathode-reflector with an aperture; 4 – coil of the filter magnetic field; 5 – H$^-$ ion collector*

The cathodes and collectors were under ground potential. The grid (1) was supplied with +3 kV for positive particles removing. The whole electrodes system was placed in external uniform longitudinal magnetic field $H_{zo0}$ with intensity that could be changed in the range of $H_{zo0} = 0 \ldots 0.1$ T.

The idea is to create reverse magnetic field in the gap between the cathode 3 and the ion collector 5 to divert electrons on the electron collector 2, but not impact on H$^-$ ions being registered by ion collector 5.

The main differences between the cathode unit and those one considered earlier [6, 7] are primarily the reduction of its longitudinal dimensions. This was done in order to place the ion collector 5 maximally close to the cathode-reflector 3, and set the edge of the ion collector 5 at the zero-point magnetic field $H_{z0}$ (see Fig. 1). The distances between the cathode 3, the grid 1 and the electron collector 2 were 0.4 cm. Apparently, this is the minimum possible distance, since its further decrease leads to an electrical breakdown between the grid and the cathode, when discharge is working in the mode of electron emission in the longitudinal direction. Reducing the distance between the ion collector 5 and the cathode 3 will change the configuration of the coil 4 and increase the transverse dimensions of the cathode unit.

Taking into account the configuration of the electrodes, which ensures the registration of only the paraxial group of particles, the equation of motion can be considerably simplified and the trajectories of the motion of charged particles can be considered only near the axis in axially symmetric fields [9]:

$$\frac{d^2r}{dz^2}+\frac{1}{2}\frac{\varphi_o'}{\varphi_o}\frac{dr}{dz}-\frac{q}{8mc^2}\frac{rH_{z0}^2}{\varphi_o}\left(1-\left(\frac{r_0^2H_{zo0}}{r^2H_{z0}}\right)^2\right)=0,$$

where $\varphi_o=\varphi(0,z)$ – potential on the axis with respect to the potential of particle creation point $\varphi_{o0}=\varphi(0,z_0)$. (In our case the potential of particle creation point is emitter potential $\varphi_{o0}=0$); $H_{z0}=H(0,z)$ – magnetic field on the axis at an arbitrary point; $H_{zo0}=H(0,z_0)$ – magnetic field on the axis at the emitter point $z_0$.

Equation (1) was obtained under the assumption of a homogeneous magnetic field ($H_{zo0}$ and $H_{z0}$ do not depend on $r$) and for the case of slowly varying magnetic and electric fields.

To solve equation, it is necessary to specify a non-homogeneous magnetic and electric field in the gap. The magnetic field profile in equation (1) is determined by two parameters: $H_{zo0}=H(0,z_0)$ and $H_{z0}=H(0,z)$. The firs one is an external magnetic field created on the axis of the Penning cell in the absence of a filter coil. The second one is the profile of inhomogeneous magnetic field on the axis in the cathode-collector gap, which is created by the counter-switching of the coils. The values of the parameter $H_{zo0}$ were fixed and selected at 600 Oe, 800 Oe, and 1000 Oe, basing on the conditions of the device. Profiles $H_{z0}$ and $\varphi_o=\varphi(0,z)$ were calculated in the program femm 4.0 basing on the geometric dimensions of the cathode unit, the potentials of the electrodes and the current flowing through the coil.

The solution of the paraxial equation of trajectories (1) was carried out numerically by the Runge-Kutta method of the fourth order with a fixed step of integration. The result of numerical solution is the dependence of $r(z)$ – particle's position at a certain value of the longitudinal coordinate $z$ in the cathode-collector gap. In our calculations, the coordinate $z$ = 0.0 cm corresponds to the end of the cathode 3, $z$ = 0.4 cm to the grid 1, and $z$ = 1.8 cm to the collector edge 5 in the center of the filter coil 4 (see Fig. 1). These dependences in the form of graphs are presented in Fig. 2. In the figures the profiles of total magnetic field, the filter coil and the ion collector are presented. The position and dimensions of the filter coil and the ion collector correspond to the scale of the picture.

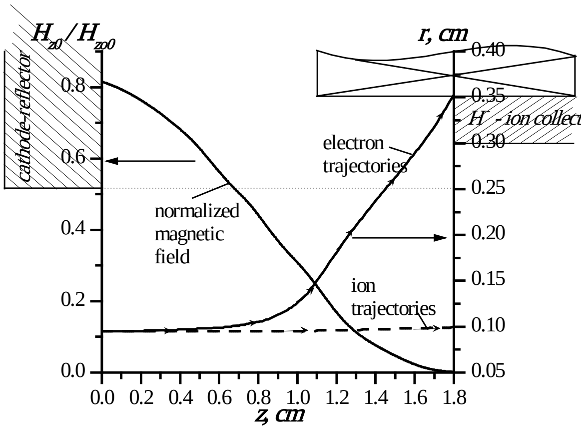

*Fig. 2. The trajectories of electrons and ions as well as the normalized profile of magnetic field in the gap cathode (z = 0 cm)-collector (z = 1.8 cm)*

One can see, that a inhomogeneous magnetic field in the cathode-collector gap has little effect on the trajectory of $H^-$ ions, while the electron trajectories are noticeably curved and do not fall on the collector at a zero value of total magnetic field $H_{z0}$.

One can see that the main part of electrons diverts to the electrons collector 2 at a resultant zero magnetic field on the collector edge $H_{z0}$ = 0. The rest of electrons have an entrance radius $r_0 \leq 0.08$ cm. The magnetic field in the gap has weak effect on them. Estimates shown, that their current should be an order of magnitude smaller, than the total electron current.

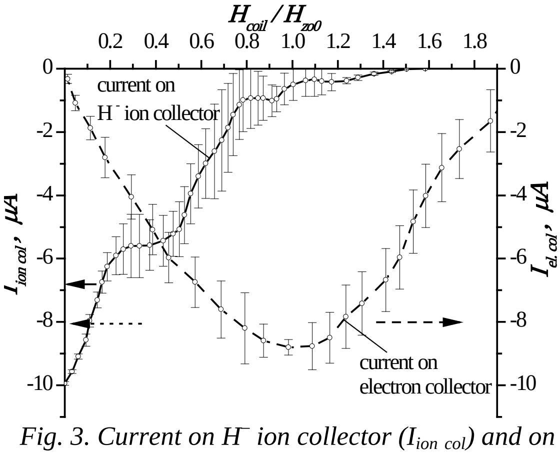

*Fig. 3. Current on $H^-$ ion collector ($I_{ion\ col}$) and on electron collector ($I_{el.\ col}$) depending on $H_{coil}$ / $H_{zo0}$*

An experimental check of the filter operation was carried out using an electron gun, which simulated the electron flow characteristic for the discharge cell [4]. The electron gun was set on the axis of the system instead of the metal hydride cathode. It created a cylindrical electron beam 1.2 cm in diameter with a current 10 mA and energy 100 eV. The experimental results are shown in Fig. 3.

One can see that at $H_{coil}$ / $H_{zo0}$ = 1 the electron beam is diverted almost completely on the electrons collector. Only a small group of paraxial particles passes through with a current by order of magnitude smaller than the total current. Thus, the obtained data are in good agreement with the calculation. Large errors are caused by using a non-stabilized emission power source of the electron gun.

## CONCLUSIONS

So, as a result of numerous calculations, it was built a model that allows to choose the best external parameters for the efficient separation of $H^-$ ions from the axial flow of charged particles. Good coincidence between the experimental and the calculated data shown the possibility to apply the model for the interpretation of following experiments.

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## ЭЛЕКТРОМАГНИТНЫЙ ФИЛЬТР ДЛЯ СЕПАРАЦИИ $H^-$ ИЗ РАЗРЯДА ПЕННИНГА С МЕТАЛЛОГИДРИДНЫМ КАТОДОМ

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Предлагается конструкция и методика расчета электромагнитного фильтра, предназначенного для сепарации отрицательных ионов водорода, извлекаемых в продольном направлении из разряда Пеннинга с металлогидридным катодом. Расчет конструкции фильтра проводился на основании предварительных экспериментальных данных и анализа траектории заряженных частиц, которые были рассчитаны путем численного решения уравнения движения. Построена модель, позволяющая выбирать оптимальные внешние параметры для эффективной сепарации ионов $H^-$ и интерпретации последующих экспериментов. Проведена экспериментальная проверка работоспособности построенной модели.

## ЕЛЕКТРОМАГНІТНИЙ ФІЛЬТР ДЛЯ СЕПАРАЦІЇ $H^-$ З РОЗРЯДУ ПЕННІНГА З МЕТАЛОГІДРИДНИМ КАТОДОМ

***І.М. Середа, О.Ф. Целуйко, Д.Л. Рябчиков, Я.О. Гречко, А. Крупка***

Пропонується конструкція і методика розрахунку електромагнітного фільтра, призначеного для сепарації негативних іонів водню, видобутих у поздовжньому напрямку з розряду Пеннінга з металогідридним катодом. Розрахунок конструкції фільтра проводився на підставі попередніх експериментальних даних та аналізу траєкторії заряджених частинок, які були розраховані шляхом чисельного рішення рівняння руху. Побудована модель, що дозволяє вибирати оптимальні зовнішні параметри для ефективної сепарації іонів $H^-$ і інтерпретації наступних експериментів. Проведена експериментальна перевірка працездатності побудованої моделі.