Ions Formation Density Distribution in SPT ATON Channel

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Abstract: Using data of spectral and probe measurements ions formation mean density distribution in the channel of second generation SPT-II of ATON type (model A-3) for two propellants (xenon and krypton) under operation in different modes have been obtained. The features of ions formation in the source channel for its optimal operation modes have been revealed.

Nomenclature

U_d	=	discharge voltage
I_d	=	discharge current
$\dot{m}_{anode}$	=	anode mass flow rate
$\dot{m}_{cathode}$	=	cathode mass flow rate
n_e	=	electrons concentration
T_e	=	electron temperature

I. Introduction

THE wide using of the computer simulation for the forecasting of SPT characteristics in the broad range of the work parameters is typical for the last decade. The use of the computer simulation under the consideration of the processes inside SPT channel is especially complex problem because it is necessary to take into account a large number of different physical processes. In this connection the value of the experimental database for the plasma local parameters inside the source discharge chamber which will allow to carry out the verification of the correspondence between the used models and real physical processes, taking place in the discharge, increases.

Under similarity criteria[1] for the source of definite dimensions the optimal operation mode exists in which the most high integral characteristics are achieved. Therefore it is important to determine the features of the plasma parameters distribution in the source channel just for this mode.

This work has been aimed to the reconstruction of the ions formation pattern in the channel of the A-3 source of SPT ATON[2] type in the different modes of its operation on xenon and krypton, and also to the determination of the ions formation processes features which are the characteristic ones for its optimal modes.

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II. Experiment statement and Main Assumptions

The experiments have been carried out in the vacuum chamber of the circular section with the diameter 0,8m and with the length 2,5m. The evacuating pump provides ~$3\cdot10^{-5}$mmHg of static vacuum (by air) and ~$2\cdot10^{-4}$mmHg of dynamic vacuum (by air) under the total mass flow rate of xenon 2,4mg/s or of krypton – 2,5mg/s.

The spectral and probe measurements have been carried out on the model A-3 of SPT ATON[2] type with the external insulator 60mm in diameter and internal insulator 36 mm in diameter.

In order to register spectra from the source channel a longitudinal slit with the width 1,5mm, parallel to the accelerator axis, has been cut in its external insulator. Under the carrying out of measurements in the model nominal operation modes the slit was ended at the distance 4mm from the anode, and under the measurements at high discharge voltages it was ended at the distance ~12mm from the anode in order to avoid break-downs.

Spectral measurements have been carried out by a standard procedure using a quartz optics for providing of UV band registration. There has been used photoelectric registration system (on the base of photomultipliers FEU-100 and FEU-62 and monochromator MDR-23 with a scan of spectrum) with the following signal transform into a digital one by A to D converter in one experimental set. In another experimental set registration of spectra has been carried out by a photo-electronic cassette on nine linear CCD, placed in the focal plane of the diffraction spectrograph DFS-452. The resolution of spectral lines was not worse than 0,1nm in these conditions. The strip tungsten lamp SIRSH-8,5-200-1 with uviol input window has been used as a reference source for a signal calibration.

The values of electron temperature and density of the source channel plasma which are necessary for the calculations have been carried out by near-wall electrostatic probes, located along the model A-3 channel[2].

Under the model A-3 operation on xenon the measurements have been carried out at the xenon anode mass flow rates 1,3mg/s and 2mg/s and at the discharge voltages 300V, 350V, 600V, 900V. The cathode mass flow rate has been equal to $\dot{m}_{cathode} = 0.4mg/s$. For the model A-3 under its operation on xenon the optimal mode is realized under the anode mass flow rate 2mg/s (the cathode mass flow rate is $\dot{m}_{cathode} = 0.4mg/s$) and under the discharge voltage 350V (the discharge current is I_d=2,07A).

Under the model A-3 operation on krypton the measurements have been carried out in one of its optimal operation mode, which is realized at the anode mass flow rate 2mg/s (the cathode mass flow rate is equal to 0,5mg/s) and under the discharge voltage 300V (the discharge current is equal to I_d=3A).

Under all measurements the currents in the magnetic coils of the source have been corresponded to the minimum of the discharge current.

The analysis of the obtained spectral database has allowed to choose the diagnostic lines of the neutral atoms radiation of the investigated plasma under the calculation of the plasma parameters on the coronal model. These are two lines[3] of IR band with the wavelengths λ_1=882nm and λ_2=828nm for the xenon plasma. These are two lines of visible band with the wavelengths λ_3=437,6nm and λ_4=446,4nm for the krypton plasma. In this case by the known distribution of the intensity of this line one may calculate the distribution of ions birth density of the single q^+ and double q^{++}_{atom} ions from the neutral atoms of the propellant in the accelerator channel[4]:

$$q^+ = A\frac{<\sigma^+ V_e>_{o\infty}}{<\sigma V_e>_{om}} I_{mk} \tag{1}$$

$$q^{++}_{atom} = A\frac{<\sigma^{++}_{atom} V_e>_{o\infty}}{<\sigma V_e>_{om}} I_{mk}\,, \tag{2}$$

where A is the constant for the given line. Here I_{mk} is the intensity of the spectral line emitted through transition from the level m onto the level k , $<\sigma V_e>_{om}$ is the velocity-averaged cross-section of the excitation of the level m by the electron shock from the ground state, $<\sigma^+ V_e>_{o\infty}$ is the velocity-averaged cross-section of the single ionization of an atom by the electron shock from the ground state, $<\sigma^{++}_{atom} V_e>_{0\infty}$ is the velocity-averaged cross-section of the double ionization of an atom by the electron shock from the ground state.

The data on the ionization cross-sections, necessary for the calculation by formulae (1) and (2), have been taken from Ref. 5 and data on the cross-sections of the levels excitation – from Ref.6.

Using data of the probe measurements the distribution of the double ions birth density q^{++}_{ion} in the source channel has been also calculated for the second mechanism of ions formation, i.e. under ionization by the electron shock of the singly charged ions:

$$q_{ion}^{++} = n_e n_i < \sigma_{ion}^{+} V_e >_{o\infty}, \quad (3)$$

where n_i is the ion concentration, $< \sigma_{ion}^{+} V_e >_{0\infty}$ is the velocity-averaged cross-section of the single ionization of an ion by the electron shock from the ground state. In the first approximation it has been assumed that $n_i \approx n_e$ and the calculation has been carried out by formula:

$$q_{ion}^{++} \approx n_e^{\,2} < \sigma_{ion}^{+} V_e >_{o\infty}. \quad (4)$$

The calculations by formulae (1), (2), (4) have been carrying on under the assumption of Maxwellian distribution function for electrons.

III. Experimental Results and Their Discussion

For the model A-3 at its operation on xenon in the optimal mode ($\dot{m}_{anode} = 2mg/s$, U_d=350V) the ions formation mean density distribution for xenon singly charged ions $q^+(z)$ and doubly charged ions $q^{++}(z)$ along A-3 channel has been calculated by the experimentally obtained intensity distribution of the xenon atom lines with λ_1=882nm and λ_2=828nm along A-3 channel, and also by probe measurements data. Two mechanisms of ions formation have been considered under $q^{++}(z)$ calculation: the ionization by the electron shock of the xenon neutral atoms and of the singly charged xenon ions Xe^+. The obtained distributions are represented in the Fig.1. It is seen from the Fig.1, the maxima of the ions formation density of the singly charged $q^+(z)$ and doubly charged $q_{atom}^{++}(z)$ ions from the neutral atoms fall on the same cross-section z=14mm from the source anode. Maximum of the ions formation density of doubly charged xenon ions from the singly charged xenon ions $q_{ion}^{++}(z)$ takes place in the cross-section z=18mm from the source anode. As a result the maximum of the total $q^{++}(z)$ due two ionization mechanisms takes place in the cross-section z=17mm from the anode, i.e. it is shifted to the source exit by 3mm in comparison with the function $q^+(z)$ maximum.

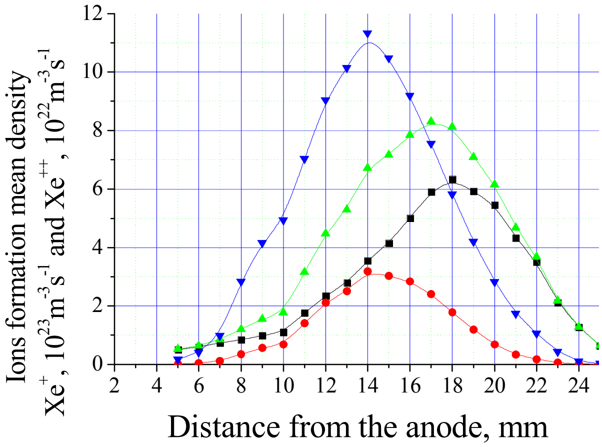

Figure 1. Distribution of Xe^+ and Xe^{++} ions formation mean density along model A-3 channel ($\dot{m}_{anode} = 2mg/s$, U_d=350V):

▼ - $q^+(z)$; ■ - $q_{ion}^{++}(z)$; ● - $q_{atom}^{++}(z)$;

▲ - $q^{++}(z) = q_{ion}^{++}(z) + q_{atom}^{++}(z)$.

Having integrated obtained dependencies by the channel volume we obtain, that the number of doubly charged ions, having appeared in the channel as a result of neutral atoms ionization, is equal to ~1/3 of the total number of doubly charged ions produced in the channel, and the number of doubly charged ions, having appeared in the channel as a result of singly charged ions ionization is equal to ~2/3 of its total number accordingly. The total number of doubly charged ions, produced in the channel, make up ~9% of the total number of the singly charged ions produced in the channel.

The analogous dependencies obtained under model A-3 operation on krypton in the optimal mode ($\dot{m}_{anode} = 2mg/s$, U_d=300V) are shown in the Figs.2, 3*.

It is seen from the Figs. 2, 3, that the maxima of the ions formation density of the krypton singly charged $q^+(z)$ and doubly charged $q_{atom}^{++}(z)$ ions from the neutral atoms fall on the same cross-section z~15,5mm from the source anode, i.e. they are shifted by 1,5mm nearer to the source exit in comparison with their location under the operation on xenon in the optimal mode.

Calculations show that under A-3 operation on xenon in the pointed out optimal mode ($\dot{m}_{anode} = 2mg/s$, U_d=350V) the total current of ions produced in the channel is equal to 2,73A, and the ion current equal to 1,46A (on

* Due to the absence of data on the cross-section of the ionization of singly charged krypton ion, the distribution of the function $q_{ion}^{++}(z)$ under A-3 operation on krypton has not been calculated.

mass flow rate) goes out from the source. Thus, ~1/2 of produced in the channel ions (on the mass flow rate) goes out from the source, and ~1/ 2 of its number falls down on the channel walls. Analogously for the optimal mode on

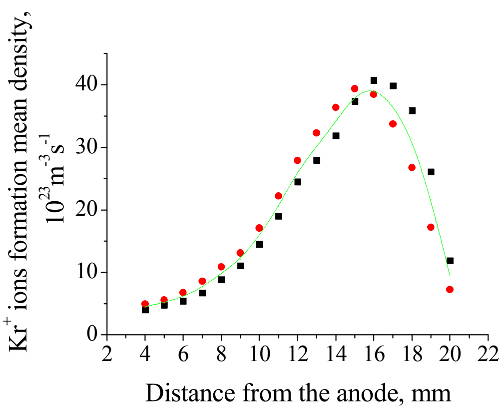

Figure 2. Distribution of Kr^+ ions formation mean density along model A-3 channel ($\dot{m}_{anode} = 2mg/s$, U_d=300V):

■ - **using KrI line 437,6nm;**

● - **using KrI line 446,4nm.**

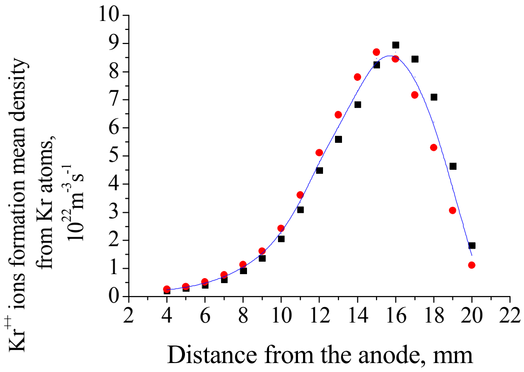

Figure 3. Distribution of Kr^{++} ions formation mean density from Kr atoms along model A-3 channel ($\dot{m}_{anode} = 2mg/s$, U_d=300V):

■ - **using KrI line 437,6nm;**

● - **using KrI line 446,4nm.**

krypton ($\dot{m}_{anode} = 2mg/s$, U_d=300V) it has been obtained that ~1/3 of the produced in the channel ions goes out from the source, and ~2/3 of its number falls down on the channel walls. It is in accordance with the fact that under A-3 model operation in the pointed out optimal mode on krypton the source A-3 efficiency is some lower than under its operation in the optimal mode on xenon.

Due to the increased interest to the research of SPT characteristics at high discharge voltages there have been carried out spectral and probe investigations of the plasma of model A-3 channel up to the discharge voltages 900V. The ions formation mean density distribution[7] for xenon singly charged ions $q^+(z)$ along model A-3 channel under the anode mass flow rate $\dot{m}_{anode} = 1{,}3mg/s$ and discharge voltages 300V, 600V, 900V is represented in the Fig.4. It is seen from the Fig.4, that under the increase of the discharge voltage the re-distribution of the ions birth density takes place in the investigated channel field (at the distances 14mm<z<20mm from the anode), namely: under the increased discharge voltages the decrease of ions formation density is observed in the investigated field of the channel, except its exit part*. The ions formation density of the doubly charged $q^{++}_{atom}(z)$ ions from the neutral atoms of the propellant undergoes the analogous re-distribution in the investigated channel field.

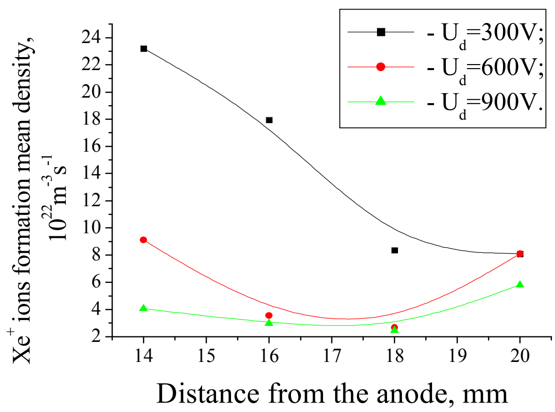

Figure 4. Distribution of Xe^+ ions formation mean density along model A-3 channel under $\dot{m}_{anode} = 1{,}3mg/s$

* The slit in the channel was ended at the distance z~12m from the anode in order to avoid break-downs on high discharge voltages.

Calculated by the probe measurements the distributions of the ions formation mean density of doubly charged xenon ions from the singly charged xenon ions $q_{ion}^{++}(z)$ under the anode mass flow rate $\dot{m}_{anode} = 1{,}3mg/s$ and discharge voltages 300V, 600V, 900V are represented in the Fig.5, and under the anode mass flow rate $\dot{m}_{anode} = 2mg/s$ and discharge voltages 300Vand 600V are represented in the Fig.6. It is seen from the Figs.5, 6, that under the increase of the discharge voltage the maximum of the function $q_{ion}^{++}(z)$ is shifted to the source exit. At the anode mass flow rate 1,3mg/s maximum of $q_{ion}^{++}(z)$ function for U_d=300V corresponds to the co-ordinate z=17,5mm from the anode, and for U_d=900V it is located at z=20mm.

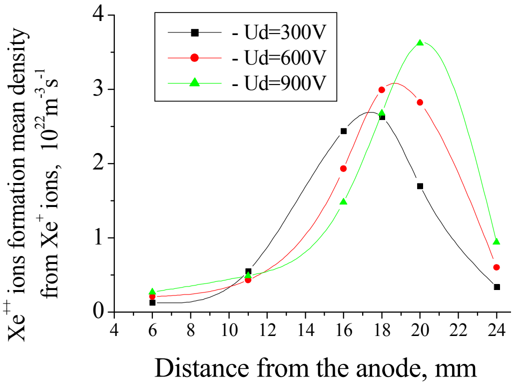

Figure 5. Distribution of Xe^{++} ions formation mean density from Xe^{+} ions along model A-3 channel under $\dot{m}_{anode} = 1{,}3mg/s$.

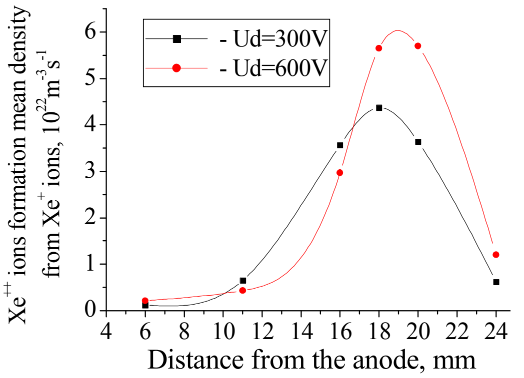

Figure 6. Distribution of Xe^{++} ions formation mean density from Xe^{+} ions along model A-3 channel under $\dot{m}_{anode} = 2mg/s$.

Having integrated the dependencies, represented in Fig.5, by the channel volume we obtain that for the anode mass flow rate $\dot{m}_{anode} = 1{,}3mg/s$ the number of doubly charged ions, having appeared in the channel as a result of singly charged ions ionization, increases by 15% under the increase of the discharge voltage from 300V to 600V, and it increases else by 10% under discharge voltage increase from 600V to 900V.

Analogously for the xenon anode mass flow rate $\dot{m}_{anode} = 2mg/s$ we obtain from the dependencies, shown in Fig.6, that the number of doubly charged ions, having appeared in the channel as a result of singly charged ions ionization, increases by 19% under the increase of the discharge voltage from 300V to 600V.

IV. Conclusion

The ionization of the propellant is the main processes determining SPT operation. The using of the data of the spectral and probe measurements has allowed to reconstruct the ions formation pattern in the channel of source A-3 of SPT ATON type, which is the characteristic one for its optimal operation modes on xenon an krypton.

It has been found experimentally that under operation on xenon at the transition to high discharge voltages the re-distribution of the ions formation mean density of the singly charged $q^{+}(z)$ and doubly charged $q_{atom}^{++}(z)$ ions from the neutral atoms of propellant takes place in the source channel at the distances 14mm<z<20mm from the anode. In order to reconstruct the total pattern of ions formation all over the source channel at high discharge voltages it is necessary to carry out optical investigations in the near-anode field of the channel (0<z<14mm).

By probe measurements data the change of ions formation mean density of doubly charged xenon ions from the singly charged xenon ions $q_{ion}^{++}(z)$ in the source channel under the increase of the discharge voltage is determined.

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