UDC 533.9

D. N. LAZUCHENKOV

MATHEMATICAL MODELING OF DETERMINING THE KINETIC PARAMETERS OF CHARGED PLASMA PARTICLES USING AN INSULATED PROBE SYSTEM IN THE IONOSPHERIC CONDITIONS

Institute of Technical Mechanics
of the National Academy of Sciences of Ukraine and the State Space Agency of Ukraine
15 Leshko-Popel St., Dnipro 49005, Ukraine; e-mail: lazuch.dn@gmail.com

The goal of this article is to theoretically substantiate the possibility of determining the kinetic parameters of charged particles of the ionospheric plasma by measuring the currents of an insulated probe system in the electron saturation region.

Methods of physical modeling, numerical integration of nonlinear differential equations, measurement uncertainty analysis, and computer modeling were used.

The probe system consists of cylindrical electrodes: a probe and a reference electrode. The ratio of the reference electrode and the probe areas can be significantly smaller than required by the single cylindrical probe theory. The electrodes are placed transversely in a supersonic free-molecular plasma flow.

The charged particle composition of the ionospheric plasma is modeled by positive ions of atomic oxygen and atomic hydrogen and by electrons, which ensure plasma quasi-neutrality. Along with a mathematical model of plasma with two ion species, a model of a one-component plasma is considered with the ion mass selected so that the ion saturation current to the cylinder may be the same for both models. Based on an earlier asymptotic solution for the electron saturation current in a one-component plasma, the kinetic parameters of charged particles (the ion temperature and directed velocity and the electron temperature) were related to the measured probe currents. A numerical and an analytical study of this relationship within the framework of the mathematical model of a plasma with two ion species resulted in analytical expressions for determining the kinetic parameters of charged particles from the measured currents of the insulated probe system in the electron saturation region.

The errors of the analytical expressions in determining the kinetic parameters of a plasma with two ion species were estimated numerically and analytically as a function of the probe system's electrode area ratio and the probe current measurement accuracy.

The ranges of the probe system parameters that maximize the measurement reliability in the ionospheric conditions were determined.

Keywords*: collisionless plasma, probe system with cylindrical electrodes, plasma models with one and two ion species, mathematical models of current collection, directed velocity of ions, temperatures of charged particles.*

1. Chung, P.M., Talbot L., Touryan K.J. Electric Probes in Stationary and Flowing Plasmas. Springer-Verlag, 1975. 150 pp.
https://doi.org/10.1007/978-3-642-65886-0

2. Shuvalov V. A., Lazuchenkov D. N., Gorev N. B., Kochubei G. S. Identification of seismic activity sources on the subsatellite track by ionospheric plasma disturbances detected with the Sich-2 onboard probes. Advances in Space Research. 2018. V. 61. No. 1. Pp. 355-366.
https://doi.org/10.1016/j.asr.2017.08.001

3. Akhoondzadeh M., Parrot M., Saradjian M. R. Electron and ion density variations before strong earthquakes (M>6.0) using DEMETER and GPS data, Nat. Hazards Earth Syst. Sci. 2010. V. 10. Pp. 7-18.
https://doi.org/10.5194/nhess-10-7-2010

4. Jiang S-B., Yeh T-L., Liu J-Y., Chao C-K., Chang L.C., Chen L-W., Chou C-J., Chi Y-J., Chen Y-L., Chiang C-K. New algorithms to estimate electron temperature and electron density with contaminated DC Langmuir probe onboard CubeSat. Advances in Space Research. 2020. V. 66. No. 1. Pp. 148-161.
https://doi.org/10.1016/j.asr.2019.11.025

5. Ranvier S., Lebreton J.-P. Laboratory measurements of the performances of the Sweeping Langmuir Probe instrument aboard the PICASSO CubeSat. Geosci. Instrum. Method. Data Syst. 2023. V. 12. No. 1. Pp. 1-13.
https://doi.org/10.5194/gi-12-1-2023

6. Boyd R. Langmuir probes on spacecraft. In: Plasma Diagnostics. W. Lochte-Holtgreven (Ed.). New York: AIP Press, 1995. Pp. 732-776.

7. IRI. Version: 2020. URL: https://ccmc.gsfc.nasa.gov/models/IRI~2020/

8. Lazuchenkov D. N., Lazuchenkov N. M. Mathematical modeling of probe measurements in a supersonic flow of a

four-component collisionless plasma. Tech. Mech. 2020. No. 4. Pp. 97-108.
https://doi.org/10.15407/itm2020.04.097

9. Lazuchenkov D. N., Lazuchenkov N. M. Mathematical simulation of ionospheric plasma diagnostics by electric current measurements using an insulated probe system. Tech. Mech. 2024. No. 2. Pp. 112-123.
https://doi.org/10.15407/itm2024.02.112

10. Lazuchenkov D. N., Lazuchenkov N. M. Calculation of the ion current to a conducting cylinder in a supersonic flow of a collisionless plasma. Tech. Mech. 2022. No. 3. Pp. 91-98.
https://doi.org/10.15407/itm2022.03.091

11. Lazuchenkov D. N., Lazuchenkov N. M. Determination of the kinetic parameters of a supersonic plasma flow of a gas-discharge source from the current measured by an insulated probe system. Tech. Mech. 2023. No. 4. Pp. 40-49.
https://doi.org/10.15407/itm2023.04.040

12. Plasma Diagnostics. W. Lochte-Holtgreven (Ed.). New York : AIP Press, 1995. 945 pp.

Received on October 25, 2024,
in final form on December 10, 2024