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Parallel solution of Surface-Volume Integral Equations for the design of Helicon Plasma Thrusters

Davide Melazzi*, Piergiorgio Alotto†, Vito Lancellotti‡, Marco Manente§, Fabio Freschi¶, Daniele Pavarin†

*University of Padova, CISAS “G.Colombo”, Padova, Italy
†University of Padova, Department of Industrial Engineering, Padova, Italy
‡Eindhoven University of Technology, Faculty of Electrical Engineering, Eindhoven, The Netherlands
§hit09 S.r.l, Padova, Italy
¶Politechnic of Torino, Energy Department, Italy

Abstract—Radiofrequency (RF) magnetized Helicon plasma sources have been proposed as propulsive devices for space thrusters. In order to optimize the antenna-plasma coupling in a Helicon source the ADAMANT code, which implements the numerical solution of surface-volume integral equations, has been developed; the approach leads itself to parallel execution. Results concerning the speed-up obtained through parallelization will be discussed.

Index Terms—Antenna, MoM, parallelization, plasma.

I. INTRODUCTION

A Helicon Plasma Thruster (HPT) [1] is a propulsive device derived from magnetized Helicon plasma sources. An HPT consists of a gas feeding system, an RF antenna and magnetic coils which generate a weak magneto-static field. Optimization of the antenna-plasma coupling requires an accurate design of the antenna shape and size, and this task can only be accomplished through a full-wave solution of Maxwell’s equations.

II. FORMULATION AND NUMERICAL APPROACH

By invoking the Surface and the Volume Equivalence Principle, we substitute the antenna with an equivalent electric surface current density \( J_A \), and the plasma with a volume polarization current \( J_P = \mu_0 (\mathbf{I} - \varepsilon_\infty \varepsilon_0) \cdot \mathbf{D}_P = \mu_0 \varepsilon_\infty \mathbf{E}_P \); here, \( \varepsilon_\infty \) denotes the Stix dielectric tensor [2]. We formulate the problem as a surface integral equation on the antenna surface \( S_A \), and a volume integral equation within the plasma region \( V_P \)

\[
\begin{align*}
\mathbf{E}_A^S(r) - j\mu_0 \mathbf{G}(r) \cdot \mathbf{J}_A(r) & = 0, \quad r \in S_A, \\
+\omega^2 \mu_0 \mathbf{G}(r) \cdot [\mathbf{E}_A(r) \cdot \mathbf{D}_P(r)]_{tan} & = 0, \quad r \in S_A,
\end{align*}
\]

\[
\varepsilon_\infty^{-1} \cdot \mathbf{D}_P(r) = -j\omega \varepsilon_\infty \mu_0 \mathbf{G}(r) \cdot \mathbf{J}_A(r) + k_0^2 \mathbf{G}(r) \cdot [\mathbf{E}_A(r) \cdot \mathbf{D}_P(r)], \quad r \in V_P,
\]

where \( \mathbf{G}(r) \) is the dyadic Green’s function, \( \cdot \) indicates the 3-D spatial convolution and scalar product, and \( \mathbf{E}_A \) models the excitation of the antenna.

The system of equations is then solved numerically by means of the Method of Moments (MoM) in combination with sub-sectional surface and volume basis functions to expand \( \mathbf{J}_A \) and \( \mathbf{D}_P \). This numerical approach has been implemented in the ADAMANT code (Advanced Code for Anisotropic Media and ANTennas) [3]. The numerical solution through the MoM leads to large dense matrices. Both matrix filling- and inversion-time can be reduced by parallelization.

III. PARALLELIZATION AND RESULTS

ADAMANT has been parallelized by means of OpenMP on two hardware/software platforms (Intel/OSX and Power7/AIX). Results shown in Fig. 1 indicate that the obtained speedup is almost optimal according to Amdahl’s law. A detailed discussion of the parallelization strategy and results for different discretizations will be provided in the final paper. ADAMANT has been validated against the well-established LEGO code [4] on a problem consisting of two flat-dipole antennas radiating near two identical dielectric spheres. Impedances predicted by the two codes are in perfect agreement, as shown in Fig. 2.

![Fig. 1. Speedup obtained with OpenMP compared with Amdahl’s law one.](image1)

![Fig. 2. Impedance matrix of two flat-dipole antennas facing two dielectric spheres vs. electric length of the dipoles: (○, □) ADAMANT; (---) LEGO method [4].](image2)

REFERENCES