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Simulation of vertical plasma position control system of GLOBUS-M tokamak in the frame of Simulink-DINA concept.

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Spherical tokamak GLOBUS-M was constructed for investigation of vertically elongated plasma configurations with a low aspect ratio A ~ 1.5 and an elongation $\kappa \sim 2.2$. While designing of GLOBUS-M the considerable attention has been given to the problem of plasma vertical position control because of the strong elongated plasma and small thickness of vacuum vessel. Carried out studies has shown the growth time of vertical instability is about 5 ms. Therefore active feedback control is required to stabilize the plasma vertical position during the time of plasma discharge.

The poloidal coils system of GLOBUS-M and its plasma configuration are up/down symmetric. Consequently system of vertical plasma position control for GLOBUS-M device can be considered separately from a general problem of plasma shape control. The goal of this work is to simulate the plasma discharge in the GLOBUS-M tokamak using code DINA and real control algorithm of the actuator of the vertical plasma position control system.

The actuator of the vertical plasma position control system of GLOBUS-M tokamak is constructed on the base of controllable thyristor current inverter [1]. It's high maximum available switching frequency together with triangular waveform of output voltage, applied to equilibrium coil (HFC), allows to stabilize strong elongated plasma with high accuracy of plasma position stabilization. Simplified electrical scheme of one phase bridge current inverter is represented on Fig.1. A current inverter operation mode allowing to control a current in the equilibrium coil can be explained as follows. The inductance L_S together with voltage source U_0 can be considered as current source I_S. Inductance L_{HFC} means the load of current inverter-equilibrium coil HFC. Suppose, that a current I_S is already flowing through the inductance L_S and the thyristors VS1, VS4 are in conducting state. Capacitor C is charged by current $I_C=I_S-I_{HFC}$. Voltage U on capacitor C is increased, and when it reaches some positive (in accordance with Fig.1) value, thyristors VS2, VS3 are switched on. Since reverse voltage is applied now to thyristors VS1, VS4, they are closed (switched off), and capacitor C begins recharging by current $I_C = -(I_S + I_{HFC})$. When voltage U on capacitor C reaches some negative value, thyristors VS1, VS4 are switched on again. Now reverse voltage is applied to thyristors VS2, VS3. Further this process is repeated. Choosing properly the levels of voltage U, at which switching of current inverter takes place, one can vary voltage averaged for a period of auto-oscillations), and to control current I_{HFC} in this coil.

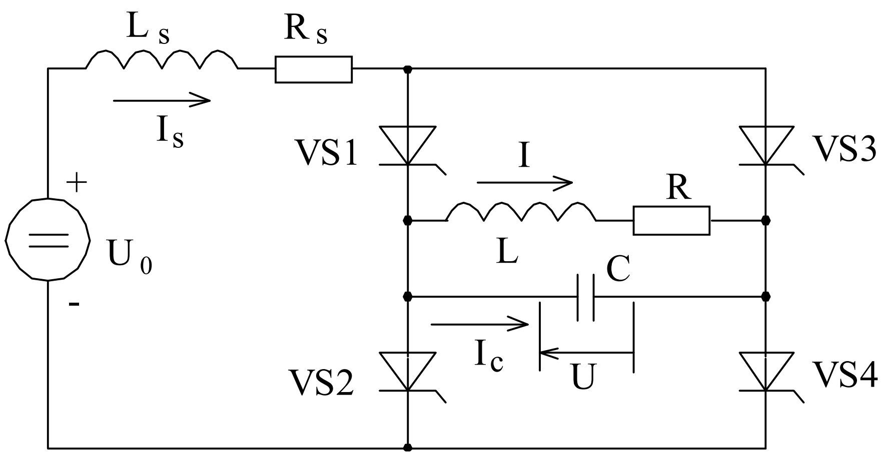

Fig. 1. The electrical scheme of one phase bridge current inverter.

Usually the test of control system is carried out using simplified linear models of plasma displacements. In the frame of DINA-Simulink concept [2] the model for testing of vertical control system of GLOBUS-M was developed. As regards actuator of the control system, its Simulink's subsystem was developed and shown in Fig. 2.

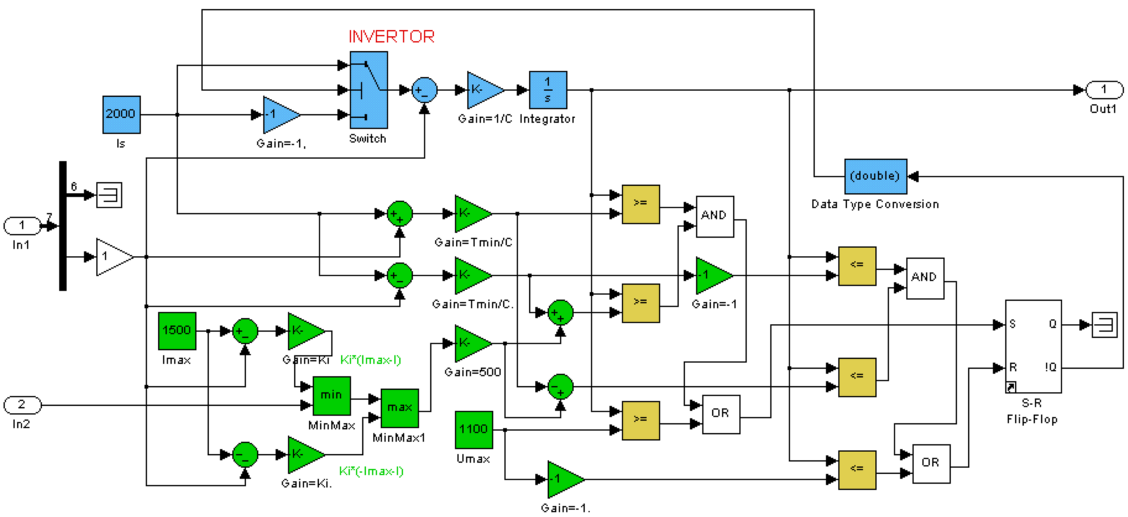

Fig. 2. Simulink-subsystem of the actuator.

Another Z-controller subsystem uses the normalized difference of poloidal fluxes Ψ from loops located up/down symmetrically outside of vacuum vessel to form the control voltage U_{cont},$\equiv U$, which is the input driving signal for actuator. The Z-controller subsystem shown in Fig. 3 is used as feedback loop for control system. To calculate driving voltage a simple PD algorithm $U_{contr} = -\alpha \cdot (\varepsilon + T \cdot \dot{\varepsilon})$ is applied. Here magnitude ε is supposed to be equal to (Z_{mag}- Z_{ref}). The Z_{mag} is proportional to signal $\Delta\Psi/I_p$ defined as $[(\Psi_{14}+\Psi_{16})-(\Psi_{11}+\Psi_{13})]/I_p$, the poloidal flux values Ψ_{11}, Ψ_{13}, Ψ_{14}, Ψ_{16} values are obtained from DINA block.

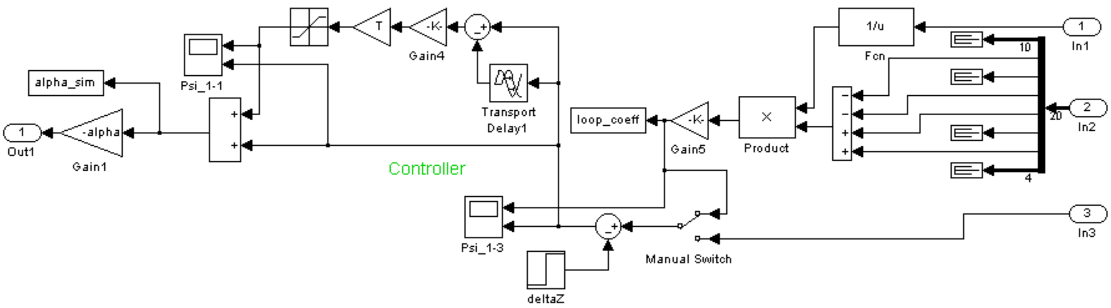

Fig. 3. Simulink subsystem for Z-controller simulation.

Obviously the requirements for a real-time control systems for radial position and plasma current are less cruel because of stable behaviour of these parameters. Although the radial positions are stable, a radial feedback control is required to keep the plasma position inside the vessel, away from vessel wall. The external PF coils are pre-programmed with a specific plasma equilibrium evolution in mind. However any perturbation in equilibrium properties will lead to plasma position and shape changes. These deviations from desired values are corrected with the shape control system. Faster time scale correction of radial position is provided by VFC coils driven by PD feedback terms of gains obtained from DINA. The eddy currents induced in vessel prevents plasma from moving into inboard vessel wall. Plasma current control was absent and magnitude of plasma current was fixed during simulation. The general scheme of Simulink model is shown in Fig. 4. The obtained results shown in Fig. 5-6 demonstrate the possibilities to use Z and R-controllers based on thyristor current inverter to keep vertical position on $Z_{mag} = Z_{ref}^{int} = 0.0\ m$ for on first half of simulation and to move plasma to given $Z_{mag} = Z_{ref}^{fin} = 0.01\ m$ and to keep it further in this position. The carried out study have shown reliability of such approach for testing of vertical control system for GLOBUS-M by non-linear plasma code.

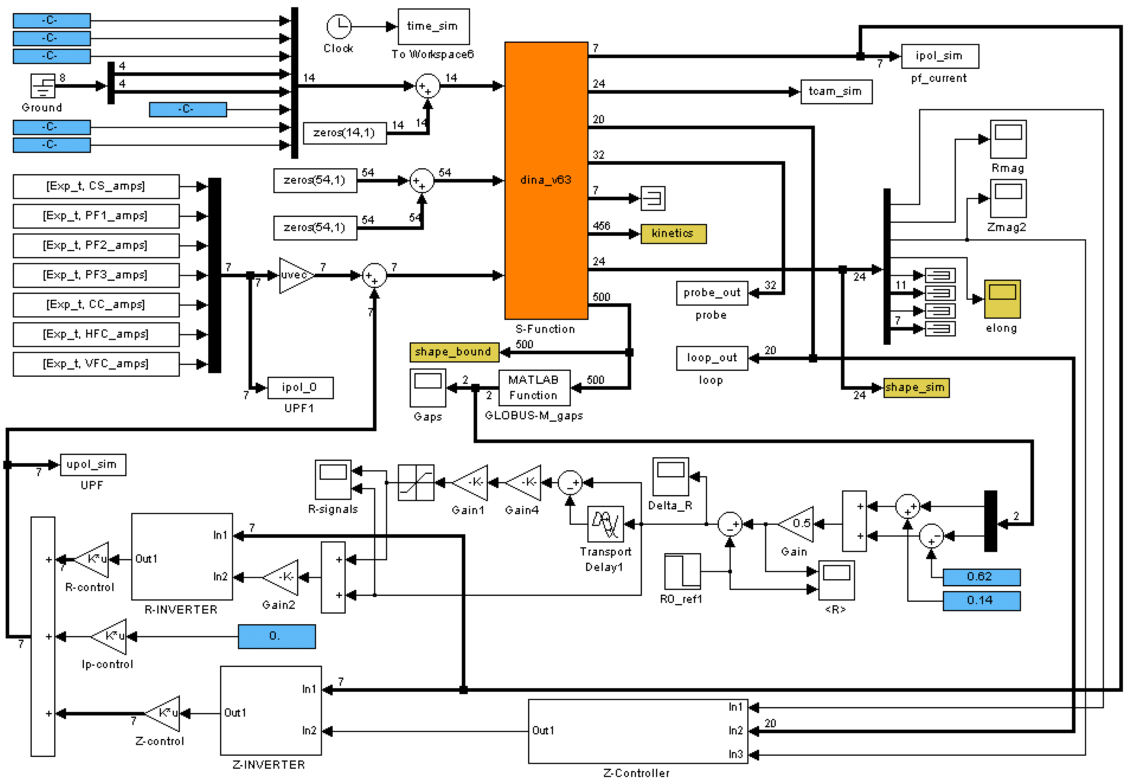

Fig. 4. General scheme for Simulink model developed for GLOBUS-M device.

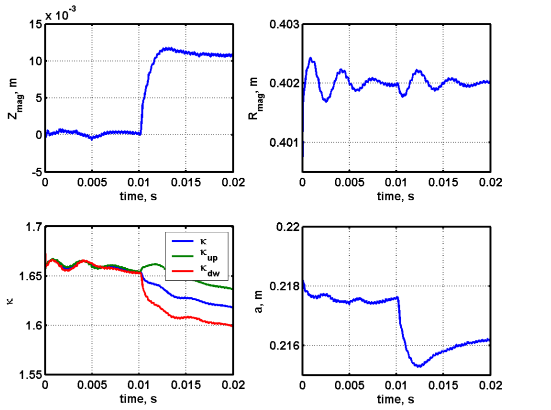

Fig. 5. Time trajectories of the vertical and radial plasma positions, elongation and minor radius.

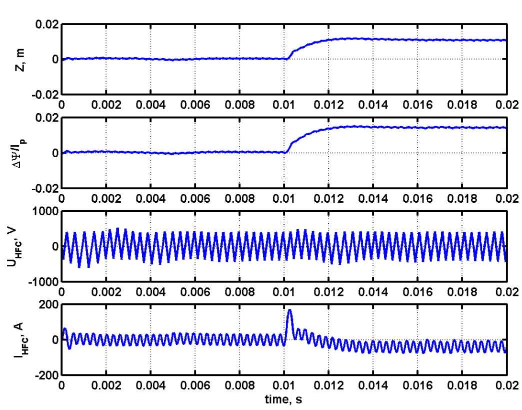

Fig. 6. Time trajectories of the plasma vertical position, voltage and current in HFC.

1. V.N. Scherbitsky, V.A.Yagnov, E.A. Kuznetsov, "A new application of current inverter", Electrotechika, Moscow, V. 7, 1994.
2. R.R. Khayrutdinov, J.B. Lister, V. Dokuka, B.P. Duval, J.Y.-Faser, V.E. Lukash, D.Raju "An Open Architecture Version of the DINA 1.5D Simulation Code", 30th EPS Conference on Controlled Fusion and Plasma Physics, P-3.163, St.-Petersburg, Russia, July 7-11, 2003.