High performance computing of non-linear MHD modelling for nuclear fusion research

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The study of the alternative energy source is one of the absolutely imperative research topics in the world as our present energy sources such as fossil fuels are limited. This work is dedicated to the nuclear fusion physics research in close collaboration with existing experimental fusion devices and the ITER organization (www.iter.org) which is an huge international nuclear fusion R&D project. The goal of the ITER project is to demonstrate a clean and safe energy production by nuclear fusion which is the reaction that powers the sun. One of the ideas of the nuclear fusion on the earth is that the very high temperature ionized particles, forming a plasma can be controlled by a magnetic field, called magnetically confined plasma. This is essential, because no material can be sustained against such high temperature reached in a fusion reactor. Tokamak is a device which uses a powerful magnetic field to confine a hot plasma in the shape of a torus. It is a demanding task to achieve a sufficiently good confinement in a tokamak for a 'burning plasma' due to various kinds of plasma instabilities.

One of the critical unsolved problems is MHD (MagnetoHydroDynamics) instabilities in the fusion plasmas. The MHD instabilities at the plasma boundary damages the plasma facing component of the fusion reactor. One of techniques to control the MHD instabilities is injection of pellets (small deuterium ice bodies). The physics of the interaction between pellet ablation and MHD dynamics is very complex, and uncertainties still remain regarding the theoretical physics as well as the numerical modelling point of view. The simulation of the plasma physics, which includes wide range of spatio-temporal scales, especially, the non-linear interaction of plasma particles and magnetic fields requires significantly large computing resources within highly sophisticated numerical scheme. Numerical modelling of MHD instabilities and the control by pellet injection for existing fusion experiment machines has been carried out with the non-linear MHD code JOREK (www.jorek.eu) using the high-performance computing via PRACE project. JOREK is one of the recognized codes in the fusion community as it allows to determine the consequences caused by the MHD instabilities in fusion plasmas. The numerical experiment of the pellet injection studies contributes the design and the optimization of the pellet injector and the injection conditions in the fusion devices.

In the PRACEdays22, our recently published work which reproduced an experimentally observed phenomenon qualitatively will be presented [S. Futatani et al. Nucl. Fusion 61, 046043 (2021)]. In this work, the non-linear MHD simulations are advanced beyond previous studies (presented in PRACEdays21) in two ways; firstly, realistic diamagnetic background flows are included, and secondly, the pellet is injected at different time points of the build-up process of the plasma boundary profiles. This allows us to recover the experimentally observed phenomena, called lag-time, where pellets do not excite the MHD instabilities. This work is the first time to reproduce it with the numerical simulation. This work reveals the pronounced differences of pellet parameters and injection times in the non-linear dynamics, and the results shed a light on the physics understanding of pellet effects on the non-linear MHD physics.