Advanced Preconditioner for the non-linear MHD code JOREK

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The non-linear MHD code JOREK allows using large HPC systems to simulate potentially harmful large-scale instabilities in realistic tokamak fusion plasmas. Spatial discretization is done via 2D Bezier finite elements combined with a toroidal Fourier decomposition. Fully implicit time stepping employed in the code requires solving a huge sparse matrix system in every time step with a typical dimension of up to 4×10^7 and 500 billion non-zero entries. This is done via iterative GMRES solver which requires an efficient and scalable preconditioning, since the physics problem is associated with a very large conditioning number.

In this contribution, we present a new preconditioner which generalizes and extends the previously used one, and improves computational efficiency in particular in highly non-linear scenarios. The original preconditioner is based on the assumption of a weak toroidal coupling and uses the idea of extracting diagonal blocks from the global left-hand side matrix representing individual toroidal harmonics. Each block matrix can then be solved separately, and the corresponding solutions are used in the GMRES cycle to find the global solution. Our approach extends the existing preconditioner to so-called mode families. These mode families can contain several strongly coupled modes, which increases the accuracy of the preconditioner significantly over the original one since it is accounting for some of the non linear interactions. This new approach is very favourable in particular for stellarator simulations planned with JOREK in the future, where linear eigenfunctions consist of several toroidal harmonics, and in case of highly non-linear tokamak scenarios such as ELMs disruptions or VDEs. We demonstrate the improvement in solver performance in several real life production cases. Our contribution will also provide insights into the challenging multi

physics multi-scale problems which are investigated with the code and provide an outlook to future numeric developments.