Contribution ID: **47** Type: **Oral contribution**

Genetic Stellarator Optimisation in Grid

Wednesday 1 March 2006 16:30 (30 minutes)

Computational optimisations can be found in a wide area of natural, engineering and economical sciences. They may be carried out by different methods, that include classical gradient-based, genetic algorithms, etc.

Stellarator facilities optimisation may be noted as an example of such task. Stellarators are the toroidal devices for magnetic confinement of plasma. In contrast to tokamak (ITER facility, for example), no toroidal current is required here, so that stellarators are principally stationary devices. As a payment for stationary working, stellarators are principally three-dimensional (non axisymmetric) configurations. This can lead to enhanced losses of fast particles - to an enhancement of losses of fast particles - the product of fusion reaction- and plasma.

The plasma equilibrium in stellarator can be found if the shape of the boundary plasma surface and the radial profiles of plasma pressure and toroidal current are prescribed. During the last decades it was shown that the properties of the stellarators can be significantly improved by appropriate choice of the shape of the boundary magnetic surface. Because of the large variety of stellarators the optimisation is still under way.

Boundary surface may be characterised by a set of Fourier harmonics that give the shape of the surface, the magnetic field, and the electric current. The Fourier coefficients compose a multidimensional space of optimisation (free) parameters and their number may exceed a hundred.

The quality parameters are functions depending on optimisation parameters and describing the properties of the considered configuration. As soon as the stellarator plasma equilibrium is found, quality parameters such as stability of different modes, fast particle long time collision-less confinement, neoclassical transport coefficients, bootstrap current, etc. can be computed.

In the optimisation task, the measure of optimum, so called a target function, is based on quality parameters and may be, for example, a weighted sum of such parameters. Computation of a stellarator quality parameters set and target function values for a given optimisation parameters vector takes about 20 minutes on conventional PC.

Such computation may form a single grid job. The technique presented in this work may be useful for tasks having target function calculation large enough for a job.

Splitting each gradient-based optimisation step into several independent grid jobs may be ineffective in case of numerical gradient computation due to hardly asynchronous jobs completion.

For such reason, genetic algorithms have been chosen as optimisation methods. Such method treats parameter vector of a variant as a “genome” and imply three activities in each iteration. The activities are selection of “parents”, their breeding and computation of target function values for each “child” genome.

Initial pool of genomes can be generated randomly inside the optimisation parameters variation domain defined by a user. Genetic method iterations enrich genome pool with new better genomes.

Genetic algorithms behave well for grid computations, because genome pool may be appended by grid jobs results sporadically, so aborting or delaying several jobs completion would not affect the overall optimisation process hardly.

During the selection, genome with better target function value should have a preference among genomes pool. The following algorithm has been used for choosing "mothers" and "fathers" of a new stellarator generation.

Genomes pool is arranged according to target function values, so the better genomes go first. Then, iterations over the pool are carried out until a "father" is chosen. On every iteration, a uniform random number is generated, so current genome is chosen with some user-predefined probability, say 2% or 3%. A "mother" is chosen in the same manner.

Such selection algorithm have no direct influence from target function derivatives, so it suppresses fast appearing of "super genome" (i.e. "inbreeding") that may constrain other potentially fruitful genomes.

Genetic algorithm breeding in case of continual optimisation domain should not change statistical mean and dispersion of genome pool, because there is no reason to shift, disperse or collect optimisation space points in the breeding activity. Only selection activity should put such changes. The following method preserving such statistical parameters have been used for stellarators.

Two coefficients f and m for each Fourier harmonic from every parent vectors pair were bred separately. Every new coefficient was a random number of Gaussian distribution. The distribution had the mean (f+m)/2 and the standard deviation |f-m|/2.

A set of scripts realising the technique in Python language have been developed. One of them generates an initial genome pool, another one spawns new jobs for quality parameters computation, the third gathers already computed results from the grid and the fourth generates new part of genome pool depending on the existing one. The number of concurrently spawned jobs is kept below a given threshold. New, running and complete jobs' genomes and quality parameters are stored in files of special directory hierarchy.

The iteration is realised by a Bash script. The script implies spawning, gathering, genetic generation scripts and scheduling a new iteration using "at" command. The scripts are intended to run controlled by user commands on LCG-2 user interface host.

A test example of stellarator optimisation task have been computed. About 7.500 variant jobs have been spawn, about 1.500 of them were discarded since no equilibria were found. In other 6.000, a set of quality parameters based on the fields and target function values were computed.

Histograms representing distribution of target function values in first, second, third, fourth, fifth and sixth thousands of results in order of appearance show that the sets of best values converge to the believed optimum value with the linear order.

This technique can be employed fruitfully in developing new stellarator concepts with different optimization criteria. Moreover, the proposed technique based on genetic algorithms and grid computing that works for the stellarator optimisation task can be employed in a wide spectrum of applications, both scientific and practical.

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Session Classification: 1b: Astrophysics/Astroparticle physics - Fusion - High-Energy physics

Track Classification: Astroparticle physics - Fusion - High-Energy physics