Research of Fast Reactor in-core Fuel Management

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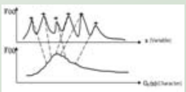
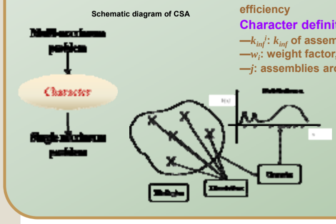
ABSTRACT

As a most important way to improve the reactor's performances like the economy, the breeding ratio etc, in-core fuel management becomes a significant research area for nuclear reactor, including fast reactor which is a main reactor type in the generation IV reactor types. In this paper, an advanced algorithm based on Character Statistic Algorithm(CSA) is proposed and applied in the optimization work of China Experiment Fast Reactor(CEFR), which is the first fast reactor in China and reached its first criticality in 21 July 2010. The work is done for the equilibrium cycle Loading Patterns(LPs) of CEFR and the results show that the advanced CSA can be successfully used for CEFR LPs optimization and provide the method for commercial fast reactor fuel management.

Methodology——CSA



Schematic diagram of CSA



Character Statistic Algorithm(CSA) —developed by Institute of Nuclear and New Energy Technology, Tsinghua University

—for the optimum LPs search, has been proven to be more effective than Gas in previous work

—employ a character related to the global information to guide the search

—kind of Evolutionary Algorithms, good global properties and efficiency

Character definition:

$$G_i = w_i k_{\inf}^i + \sum_{j=1}^{ii} w_j k_{\inf}^j$$

—k_{inf}^i: k_{inf} of assembly in location i

—w_i: weight factor, we can get it according to experience

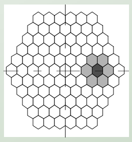
—j: assemblies around the central one i

The main steps of CSA:

- Initialize the sample(the size depend on the problem) randomly: provide the good global properties
- Do the statistic for the character from the sample: to get the statistical curve for the sample
- Generate new LPs(same size as the sample)
- Do the statistic for the character from the sample
- Compare the curves between sample and new solutions
- Update the sample

if stop criteria are not met, go to step 2, otherwise end the search

Methodoloty——Advanced CSA



◆vector of fuel location: [1,2,3,…,N_{fuel}] every number indicates a location in the core

◆vector of fuel assemblies: [1,2,3,…,N_{fuel}] every number indicates a specific fuel assembly

Information that contained in a specific LP:

- Fuel location
- Fuel assembly in this location

Introduce the location factor P_l^i:

Definition of P_l^i: factor of location i

Consider the effect of fuel location, we can get a new description of character:

$$G_i = (w_i k_{\inf}^i + \sum_{j=1}^{ii} w_j P_l^j k_{\inf}^j) P_l^i$$

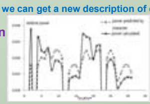
Some assumption:

- k_{inf} for control rods and reflectors: 0
- P_l^i for control rods and reflectors:0

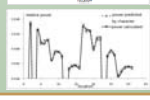
How to get the P_l^i?

- Load the right fuel type to the corresponding
- Do the core calculation to get the power distribution
- Convert the power distribution to location factor P_l^i

Relative power prediction



CSA



Advanced CSA:

It is more close to the real power

Utilization of P_l^i take the core-dependent information into account

Application——Core description of CEFR

CEFR equilibrium cycle:

Number of fuel assembly: 81

Enrichment of fresh fuel: 64.4%wt

Refueling region: 2 (divided to inner core and outer core)

Number of control rods: 8

(A3: 3 KC:3 PC:2)

The fuel assemblies, SAs and SHs are strictly 1/3 of rotational symmetry.

Simplification:

Symmetry property: 1/3

Number of duel assembly: 27

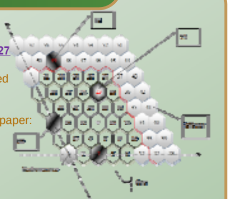
Refueling region: 1

Computing time for simplified CEFR:

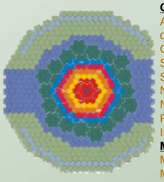
1~2s per LP

Total LPs calculated in this paper: 2000

Total computing time: ~1h



Simplified CEFR



CEFR

Core calculation code:

A three dimension nodal method diffusion code called HND

Computing time for CEFR: >10s per LP

Simplification:

Symmetry property: 1/3

Number of fuel assembly:27

Number of refueling batches: 3

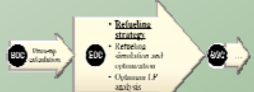
Refueling region: 1

Initial cycle length: 80

Main constraints:

Maximum burn-up: 60MWd/kgHM

Maximum linear power density for fuel pins: 43kW/m



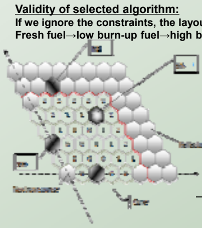
Algorithm selection→Core simplification→Programme work

Application——Results

Validity of selected algorithm:

If we ignore the constraints, the layout of the best LP should be:

Fresh fuel→low burn-up fuel→high burn-up fuel from inner core to outer core



Optimum LP without considering the constraints

0: fresh fuel

1: 1 cycle burn-up fuel

2: 2 cycle burn-up fuel

The layout basically meet the best LP description:

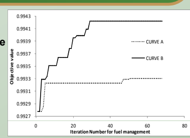
0→1→2 from inner core to outer core

Take the theoretic best LP as central point, interchange the fuel assemblies, we can get a best LPs region

→the optimum LP we get is in this region

→the algorithm and the code programmed can find the best region

→the algorithm and the code programmed is effective



Iteration of optimization for simplified CEFR

Curve A: randomly generate 2000 then choose the best one

Curve B: with optimization algorithm search

Analysis of optimum LP

	k_{eff}^{BOC}	Cycle Length/ d	Maximum Burn-up/ (MWd/kgHM)	Minimum Burn-up/ (MWd/kgHM)	Average Burn-up/ (MWd/kgHM)	Maximum Linear Power/ (kW/m)
Curve A	1.0162	103	52.76	47.39	50.88	38.8
Curve B	1.0165	106	53.64	50.09	52.36	38.9
CEFR		80	48.08	37.97	43.78	38.4

CEFR: means the LP for CEFR equilibrium cycle now

→no simplification,

→no fuel shuffling when refueling,

→2 fuel regions with different discharge fuel numbers

CONCLUSIONS

- The advanced description of character for CSA can predict the power distribution of different LP more accurately, this kind of core-dependent information is good for the LP search.
- The selected algorithm and the code programmed based on it is effective for simplified CEFR LPs optimization, it can find the best solution or the best region.
- The optimization for simplified CEFR is effective, the optimum LP has better cycle length and better average burn-up without exceeding the constraints.
- Comparison with existing LP for CEFR, we can suggest that fuel shuffling should be considered in the refueling process, it can improve the utilization rate of fuel.

Additional information

Some other work in my thesis but not in this paper

Preliminary study of ←large fast reactor fuel management

Preliminary study of fuel management without fuel shuffling→

←kind of multi-cycle optimization problem

Advanced CSA-Perturbation method:

Combined CSA with perturbation theory

Good optimization efficiency.

No harm to the global properties of advanced CSA in this paper.

Results show that optimization efficiency for CEFR increases almost 50%.