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Development of whole CORe Thermal Hydraulic analysis code CORTH

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Abstract *–Subchannel program is the main tool for the core thermal hydraulic analysis. By dividing the core into a series of connected or disconnected channels, the sub channel program can calculate the enthalpy field and the flow field of the core, and further calculate the core DNBR.The whole CORe Thermal Hydraulic analysis program CORTH V1.5 is based on CORTH V1.0.Through the code core matrix algorithm optimization and parallel method，CORTH V1.5 is used to analyze the subchannel of the large scale mode, describing the distribution of thermal parameters of 3D core and give detailed feedback parameters for fuel and Neutron kinetics code.The paper shows that CORTH v1.5 With a high computational efficiency, and give the correct calculation results.*

I. INTRODUCTION

Subchannel program is the main tool for the core thermal hydraulic analysis. By dividing the core into a series of connected or disconnected channels, the sub channel program can calculate the enthalpy field and the flow field of the core, and further calculate the core DNBR. With the implementation of the reactor core neutron dynamics program to pin-by-pin calculation, the subchannel program also needs to reach the same grid to provide the coolant feedback parameters.

II. DESCRIPTION OF THE ACTUAL WORK

CORe Thermal Hydraulic analysis program(CORTH V1.0) is development by Nuclear Power Institute of China (NPIC) with total copyright. The whole CORe Thermal Hydraulic analysis program CORTH V1.5 is based on CORTH V1.0.Through the code core matrix algorithm optimization and parallel method，CORTH V1.5 is used to analyze the subchannel of the large scale mode , describing the distribution of thermal parameters of 3D core and give detailed feedback parameters for fuel and Neutron kinetics code.

1.Software Process and Basic Model

Software Process

The calculation process of the V1.5 CORTH software is shown in Figure 1:

1) read data by user input, generate the corresponding subchannel geometric data;

2) generate look up table, include physical properties, slip ratio, void fraction table;

3) The first order upwind discretization is performed for the conservation equations of each sub channel, and the conservation equations of the whole core are obtained, The field distribution of the core is obtained by solving the matrix;

4) calculate departure from nucleate boiling ratio(DNBR) with core temperature field and flow field distribution.

The core module of the software is the conservation equation solution .

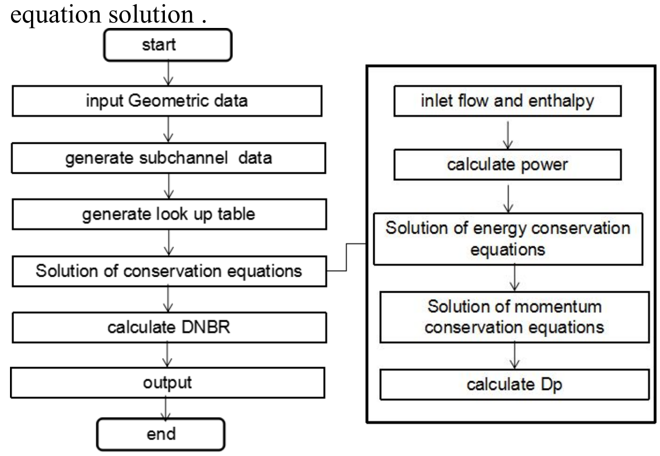


Fig. 1. CORTH V1.5 Process

Basic Model

Energy conservation equation of mixed enthalpy

$$\frac{\partial}{\partial t}(\rho_i H_i)+\frac{1}{S_i}\cdot\frac{\partial}{\partial z}(G_i H_i S_i) + \frac{1}{S_i}\cdot\sum_{k\neq i} l_{ik} g_{ik} H_{ik} + \frac{1}{S_i}\cdot\sum_{k\neq i}\frac{l_{ik}}{L_{ik}} kr_{tik}(H_i - H_k) = \frac{1}{S_i}\cdot q_i \quad (1)$$

Mass conservation equation

$$\frac{\partial \rho_i}{\partial t}+\frac{1}{S_i}\cdot\frac{\partial}{\partial z}(G_i\cdot S_i)+\frac{1}{S_i}\cdot\sum_{k\neq i} l_{ik} g_{ik} = 0 \quad (2)$$

Axial momentum conservation equation

$$-\frac{\partial P_i}{\partial z}=\frac{\partial G_i}{\partial z}+\rho_i\cdot gv+\frac{1}{S_i}\cdot\frac{\partial}{\partial z}(G_i^2 v_i S_i) \quad (3)$$
$$+(\frac{f_i}{DE_i}\cdot\widetilde{G}_i+\frac{kc_i}{\partial z}\cdot|G_i|)\cdot\frac{G_i}{2\rho_i}+\frac{1}{S_i}\cdot\sum_{k\neq i}\frac{l_{ik}}{L_{ik}}\mu_{tik}(v_i G_i-v_k G_k)$$

Radial momentum conservation equation

$$-\frac{\partial P_{ik}}{\partial y_{ik}}=\frac{\partial g_{ik}}{\partial t}+\frac{f_{ik}}{2\rho_{ik}\cdot DE_{fk}}\cdot\widetilde{G}_{ik}\cdot g_{ik}+\frac{\partial}{\partial y_{ik}}(g_{ik}^2 v_{ik})+\frac{\partial}{\partial z}(g_{ik}v_{ik}G_{ik}) \quad (4)$$

2.Storage optimization and acceleration numerical solution

Storage optimization

The coefficient matrix of the whole core channels conservation equation system can be stored using the Compressed Sparse Row(CSR[1]) format, through the three One-dimensional array, the first array is used for storage all nonzero value in the coefficient matrix in turn; the second array is used for storage the columns of the nonzero value ; the last array is used for storage the first nonzero array for each row. CSR versus direct memory comparison is shown in fig.2.

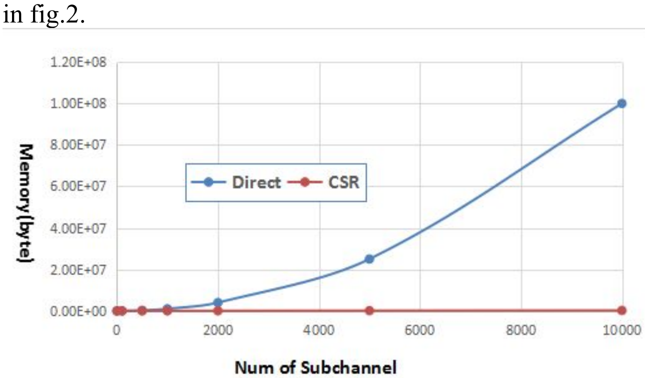


Fig. 2. CSR versus direct memory comparison

acceleration numerical solution

According to the characteristics of the coefficient matrix, we mainly use the generalized minimal residual algorithm(GMRES[2]) with pretreatment algorithm to improve the speed of the matrix.

The target after pretreatment of matrix eigenvalue distribution in the complex plane as small as possible within the region, commonly used with incomplete LU decomposition, ILU0 algorithm, the principle of the coefficient matrix A is decomposed into upper and lower triangular matrix, and A respectively with the upper and lower triangular part have the same non zero structure. Due to the diagonal dominance of the coefficient matrix, can be used to deal with the block JACOBI. GMRES algorithm is proposed by Y Saad and Schultz[3], starting from the Garlekin principle, take the Krylov subspace. The comparison of efficiency of different numerical solutions used to solution conservation matrix is shown in fig.3. It shows that using GMRES to solve conservation matrix with large-scale has higher efficiency.

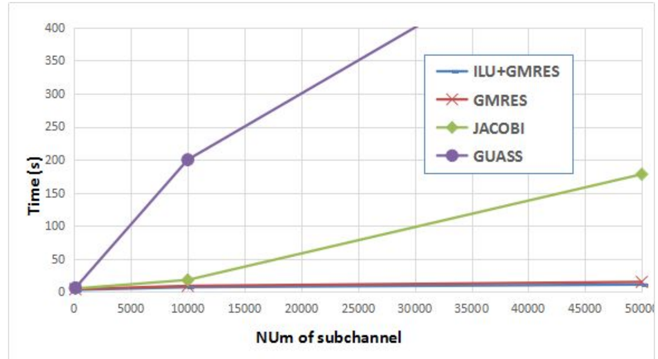


Fig. 3.Comparison of Efficiency of Different Numerical Solutions

3.Parallelization method

Parallel Processing is a computational method in a computer system that can execute two or more processes at the same time. Parallel processing can work on different aspects of the same program at the same time. The main purpose of parallel processing is to save large and complex problem solving time. To use parallel processing, you first need to parallelize the program, that is, the work will be allocated to different parts of the process (thread). This report uses a distributed memory region decomposition parallelism.

The method of domain decomposition is to divide the whole core into a number of mutually independent computing regions. The transverse influence of the region is realized by the subchannels adjacent to the region. Regional decomposition needs to solve the calculation of regional division, the region adjacent to the subchannel location, the regional fixed point communication, regional calculation process design and other issues.

This area is divided by the interface, and prepare the module to generate subchannel geometry information and coupling relationship in the subchannel data and generating region adjacent subchannel information, then according to the adjacent subchannel to determine the communication between regions. The core parallel area division id shown in Fig. 4, for a core comprising 177 fuel assemblies, the region is divided into 8 regions by a graphical interface, The data transfer between regions is performed by the subchannel with the most outer ring.

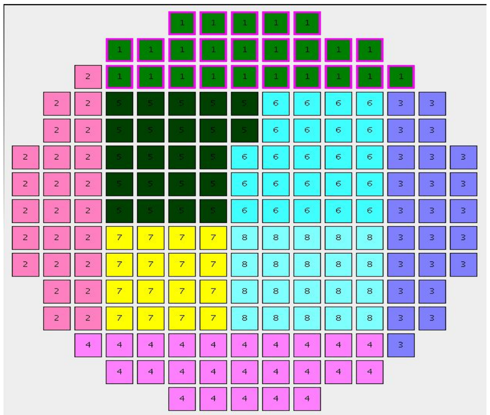


Fig. 4. Core Parallel Area Division

4.Computational efficiency

This paper compares the following methods: Gaussian, GMRES, ILU0 + GMRES, PGMRES, Regional decomposition. The result show that Regional decomposition has the best computational efficiency and especially suitable for large quantum channel problem.

Table I. Case Description

case	Num of Subchannel	Axial nodal	Inlet G (m^3/h)	Inlet Temperature (℃)	Outlet press (bar)
1	107	57	8008.28	294.57	152.9
2	480	54	65159.47	279.82	155.1
3	12717	54	16016.55	294.6	152.9
4	50868	54	64066.2	294.6	152.9

Table Ⅱ Computational time comparison

code	CORTH	CORTH	CORTH	CORTH	CORTH
storage mode	direct	CSR	CSR	CSR	CSR
Numerical solution	gaussian elimination	gaussian elimination	GMRES	PGMRES (one core)	Parallel
case 1	10	9	6	10	/
case 2	8	8	8	4	/
case 3	/	178134	4535	1942	643.2
case 4	/	712793	16013	4802	1170.6

5.Software verification

Examples

This example is the core of 1/4 computing, in which FLICA[4] and CORTH used subchannel division typical, including 41 sub channels. To calculate the DNBR, FC relation is selected in the example.

Calculation result analysis

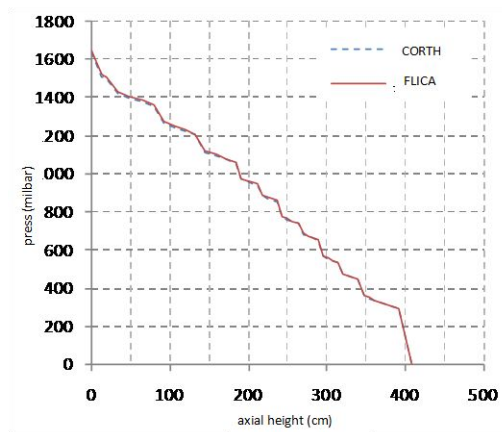
Calculation results of the software includes 3 parts: the main parameters of the reactor core, including pressure drop, specific enthalpy, mass flow rate; the parameters of DNBR, including minimum DNBR value and its position; core output temperature. It can be seen from the results, CORTH V1.5 and FLICA calculated the main parameters and minimum DNBR basically the same; the DNBR , specific enthalpy, press drop and the height of MDNB of the hottest channel also Also very close. The maximum error of mass flow rate is 1.16%.

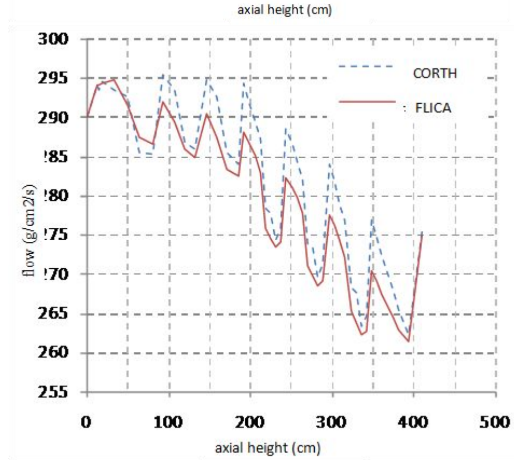
Main parameters and minimum DNBR

Table Ⅲ. The main calculation results

Validation	CORTH	FLICA	err，%
MDNBR	2.578	2.59	0.42
MDNBR Axial height (cm)	126.65	126.65	same
MDNBR ubchannel	3	3	same
Outlet enthalpy (kJ/kg)	1527.94	1527.94	0.0
Dp (Mpa)	0.025	0.025	0

parameters of the hottest channel





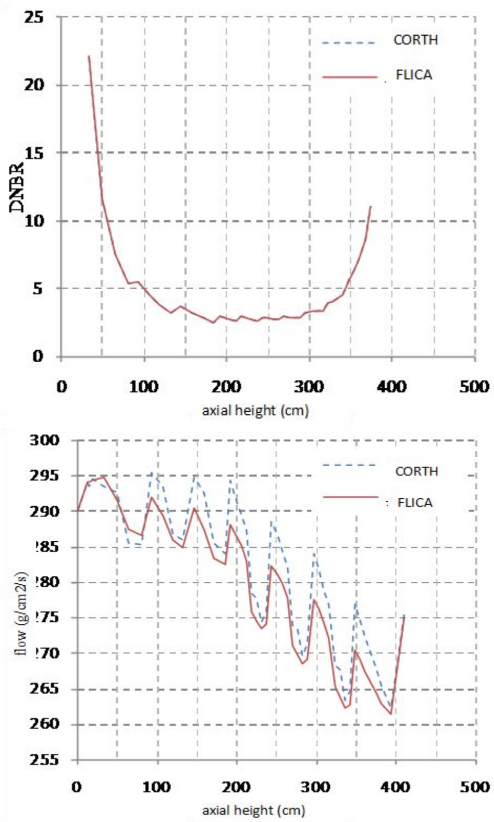
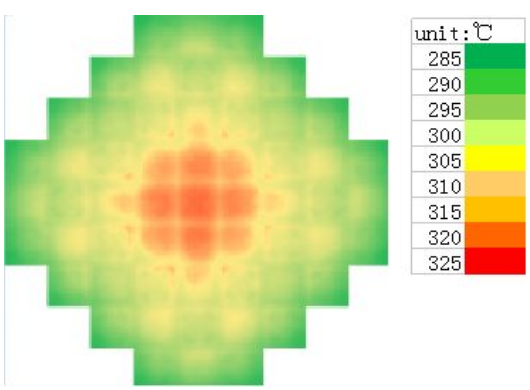


Fig. 5. The hottest channel axial parameter of ACP100 core

6.Analysis of the whole reactor core

The power of this paper comes from the NGMC fuel rod level power distribution, which is divided into 5 sections in the axial direction. Fig. 6 is the detailed temperature distribution of the core with channel cross mixing and Fig. 7 is the detailed temperature distribution of the core without channel cross mixing (1 is the core of the core and 2 for the core outlet). It can be seen that the cross mixing between the channels makes the core temperature distribution more uniform.



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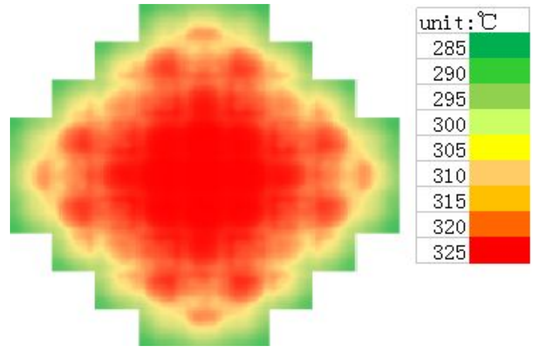

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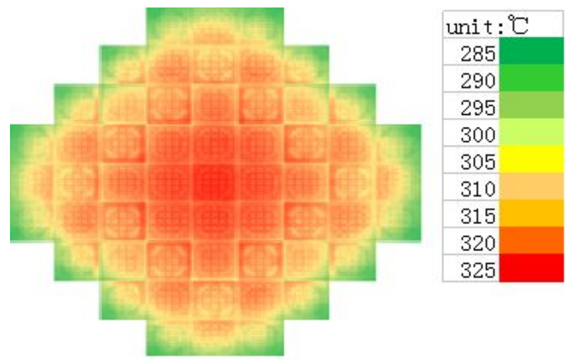
Fig. 6.core temperature distribution with channel mixing



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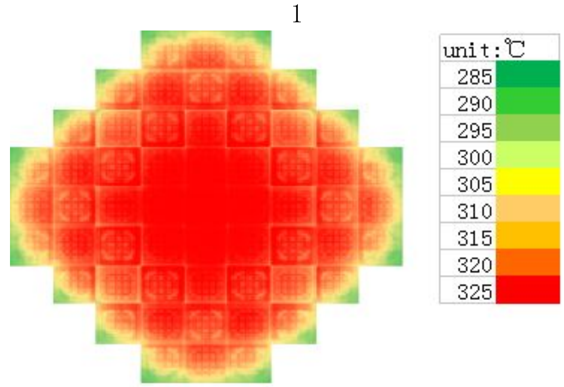

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Fig. 7. core temperature distribution without channel mixing

III. RESULTS

The whole core subchannel software CORTH v1.5 is based on CORTH V1.0 software. Through the code core matrix algorithm optimization and parallel method， CORTH V1.5 is used to analyze the subchannel of the large scale mode, describing the distribution of thermal parameters of 3D core and give detailed feedback parameters for fuel and Neutron kinetics code. The paper shows that CORTH v1.5 With a high computational efficiency, and give the correct calculation results.

IV. CONCLUSIONS

The development of the software CORTH v1.5 provides a effective tool for the core thermal hydraulic analysis. Through the whole core analysis may provide a higher safety margin, and more accurate calculation of the core coupling.

NOMENCLATURE

t =time
ρ =density
H =specific enthalpy
S =flow area
z =nodal axial length
l =length
g =transverse mass velocity
L =length of between subchannel
kr =mixing heat diffusion coefficient
q =surface heat flux
G = mainstream mass flow rate
P =pressure
gv =gravity acceleration
v =specific volume
f =friction coefficient
kc =resistance coefficient
DE =hydraulic diameter
μ =mixing viscosity coefficient

i =current subchannel
k = adjacent subchannel

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