The Roles of High Performance Computing in Heavy Industry

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Ittetsu Inuzuka
Computation & Mathematical Eng. Dept.
Research Laboratory
IHI Corporation
Profile of IHI Group

IHI Corporation (IHI=Ishikawajima-Harima Heavy Industry)

- Founded: 1853 (End of Edo Era)
- Capital: 107 billion JPY
- Consolidated Net Sales: 1,486 billion JPY
- Employees: 29,659
- Works: 7
- Branches and Sales Offices in Japan: 16
- Overseas Sales Offices: 13

As of March 31, 2017

Ship “Tsu-un-maru”

 Turbojet engine, Ishikawajima Ne-20
CAE in our work

CAE is essential to develop and design products in all of our business area.

**Resource, Energy & Environment**
- Combustion analysis for coal-fired USC boiler

**Social Infrastructure and Offshore Structure**
- Seismic response analysis for bridge
- Tsunami analysis for coastal structure

**Industrial Systems and General-purpose Machinery**
- Bulk material analysis for coal storage facilities
- Structural & Fluid analysis for compressor blade

**Aero Engine. Space and Defense**
- Fluid analysis for engine fan blade
- Bird strike analysis for engine fan blade

HPC in our work

Scale of most precise computation also increases following the trend in the world.

GIGAFLOPS

10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1

1993  1995  1997  1999  2001  2003  2005  2007  2009  2011  2013  2015  2017

CM5  SR2201  CP-PACS  NWT  ASCI-W  ASCI-R  ES  BGL  Roadrunner  Jaguar  Tianhe  K  BGQ  Titan  Tianhe2  Sunway TaihuLight  Summit

50mil. nodes
170mil. nodes
340mil. nodes

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HPC in our work

HPC takes two roles in our works

- **Capability computing**: to analyze large scale / precise phenomenon
- **Capacity computing**: to evaluate a great number of cases in shorter time

Both roles are important and ideal situation is to satisfy both!
Optimize performance of centrifugal compressor by FEM, CFD and GA*

Centrifugal impeller, installed in turbocharger, etc.

- **Objectives**
  - ✓ Maximize isentropic efficiency
  - ✓ Maximize frequency detuning

- **Variables (shape parameters)**
  - ✓ Distribution of blade angle, thickness
  - ✓ Lean angle
  - ✓ L/E position of half blade

- **Constraints**
  - ✓ Shape smoothness
  - ✓ Maximum centrifugal stress
  - ✓ CFD stability

*GA: Genetic Algorithm
Optimization process

- For effective optimization, all of the CAE process should be automated.
- Computation time for each solution (design candidate) is not so long.
- However, Population (can be parallelized) 32, Generations (should be sequential) 128 for GA → Over 3 days & 500 CPU cores are required.

<table>
<thead>
<tr>
<th>For each solution</th>
<th>Computation time</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFD</td>
<td>40min. x 16core</td>
</tr>
<tr>
<td>FEM</td>
<td>15min. x 2 core</td>
</tr>
<tr>
<td>Sum</td>
<td>40min. x 18 core (worst case)</td>
</tr>
</tbody>
</table>

x32 solutions x128 generations 3.6 days. x 576 core

Performed on in-house PC cluster
Example: Optimization for Compressor Blade

Compare genetic algorithms (ranking and constraint handling technique)

- Collaborative research with Dr. Oyama @ JAXA

* Japan Aerospace Exploration Agency

- Algorithm 1: NAGA-II + CD (Constraint-Domination principle)
  - NSGA-II: Solutions are ranked by “Pareto Rank”
  - CD: Treat constraint as top priority.

- Algorithm 2: CHEETAH + MCR (Multiple Constraint Ranking)
  - CHEETAH: Originated by JAXA. Solutions are ranked based on “Chebyshev Distance”
  - MCR: Generate new rank by blending objective function value with number and amount of constraint violation.

Results (for same population and generation size)

✓ NSGA-II + CD finds broadly distributed solutions.
✓ CHEETAH + MCR finds narrower but more optimized solutions.

= High-speed convergence

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Example:1 Optimization for Compressor Blade

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Resultant Solutions

Obtained solutions are depends on algorithms and initial solutions. If there were enough large number of solutions, same ideal solution may be obtained…

Currently, we have to choose better designs from obtained solutions, or manually modify by using knowledge from solutions.

Example: Optimization for Compressor Blade

Better efficiency ← Thin-tip blade

Better detuned ← Thick-tip blade
DEM (Discrete Element Method/Distinct Element Method)

Numerical method for computing motion and interaction of a large number of small particles.

→ Effective to predict and represent bulk solid behavior.

We are attempting to use DEM for design bulk handling facilities.

hopper, conveyer, unloader, …
Estimate internal / wall pressure from bulk solids in the Silo*.

* A tower shape structure for storing bulk materials

There is a theory for simple design of silo, but not universal.

→ Attempting to design by DEM (asymmetry, inside obstructs, feeder system, …)

<table>
<thead>
<tr>
<th>Particle Diameter</th>
<th>50mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silo Height</td>
<td>60m</td>
</tr>
<tr>
<td>Number of Particles</td>
<td>60,000,000</td>
</tr>
</tbody>
</table>

13 days x 128 CPU cores are required to compute behavior during only 120sec.
Parameter fitting is also a matter.

DEM requires properties of each particle and their interaction

- Particle Shape (diameter, single sphere / cluster shape)
- Coefficient of restitution
- Coefficient of friction
- Cohesion model etc…

These are difficult to measure.

→ Measure MACRO behavior and fitting parameters.

Large number of combinations of parameters should be tested.
Overview and two examples of our HPC and CAE activities are introduced.

The roles of HPC in our work are;
✓ to reveal physical phenomenon by computation with large number of nodes/elements.
✓ to find out more sophisticated designs / parameters by computation with large number of design candidates.

Nowadays, we are attempting to use simulation results as training data for AI.
→ More larger number of simulations are required!

We wish the appropriate HPC environment for not only capable computing, but also capacity computing.
IHI
Realize your dreams