Overview on Fast-ignition Laser Fusion Reactor with a Dry Wall

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This is an introduction to the following two presentations;
@ T. Goto : Design of a core plasma and chamber wall for dry wall fast ignition ICF power plan
@ R. Hiwatari : Maintenance method for blanket and final optics of dry wall fast ignition ICF power plant
Fast Ignition vs Central Ignition

<table>
<thead>
<tr>
<th>Central ignition</th>
<th>Fast ignition</th>
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<tr>
<td>Isobaric</td>
<td>Isochoric</td>
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A volume in Fast ignition is 1/5~1/10 times as small as that in Central ignition.

Fig. 2 Comparison of the central ignition isobaric core plasma structure (a) and the fast ignition isochoric core plasma structure (b).

Fig. 3 Laser energy dependents of fusion gains for fast ignition and central ignition.
The minimum fusion pulse energy with acceptable target gain is 40MJ.

In this case, we can design the solid wall chamber with $R = 5.6 \text{ m}$ if pulse heat load limit of $2 \text{ J/cm}^2$ is allowed.

We can find that the design point of the target gain $G > 100$ is achievable with the injection energy of 400kJ under a condition of $\alpha = 2$, $\eta_c = 5\%$ and $\eta_h = 20\%$.

If $\eta_c = 7\%$ is allowed, $G = 135$ can be achieved with the injection energy of 300kJ (implosion 250kJ, heating 50kJ).

The minimum fusion pulse energy with acceptable target gain is 40MJ.

In this case, we can design the solid wall chamber with $R = 5.6 \text{ m}$ if pulse heat load limit of $2 \text{ J/cm}^2$ is allowed.
**Dilemma with liquid metal wall**

Using a liquid metal wall design will allow a higher heat load pulse than that in a dry wall design.

However, the evaporation of liquid metal on the wall deteriorates a vacuum condition in the chamber, and **the repetition rate of laser pulse is restricted (< a few Hz).**

A lower fusion power in a shot with a lower repetition rate will result in a lower fusion output and a higher cost of electricity.

A noble solution to remove this restriction is to introduce **multiple chambers** in a plant.

**⇒ Koyo-Fast reactor design at OSAKA University**

But such multi-chamber concept might require complicated laser transmission lines. This fact should increase the construction cost.
Basic Concept of UT/CRIEPI Laser Fusion Reactor Design

Design Concept is based on
@ Fast ignition
@ Dry wall
@ High repetition laser

@ Low laser energy : \( P_{\text{laser}} = 0.3 \sim 0.4 \text{MJ} \)
with a pellet gain \( G = 100 \sim 150 \)

@ Low wall loading : \( P_{\text{wall}} = 2 \sim 3 \text{ J/cm}^2/\text{shot} \) with \( R = 5 \sim 6 \text{ m chamber} \)
\( \Rightarrow T \sim 2000 \text{ K} \)

@ High repetition laser : frequency = 20 \sim 40 \text{ Hz} \)

\( \Rightarrow \) Moderate size fusion reactor

\( \text{e.g., } (P_{\text{laser}}=0.4 \text{MJ}, \ G=100 \text{ and } 30 \text{ Hz}) \) gives Pf \( \sim 1.2 \text{ GWth} \)
Pe \( \sim 0.4 \text{ GWe} \)
Role in Electric Grid System

Load Curve and role of power source

- **Load Manager** (Power source to manage the demand change in a day)
  - Moderate output
  - Low construction cost
  - LNG and Hydro. Power St.

- **Backbone power source**
  - Large output (Scale merit)
  - Low COE
  - Fission Power Station

- **Tokamak fusion power plant**
  - Large output (Scale merit)
  - Low COE

- **Fast Ignition ICF power plant**
  - Both Roles possible?

**Fig. Typical Load Curve in a day for Japan**

- Load Curve
- Oil
- LNG, LPG
- Coal fire
- Hydro (draw up)
- Drawing up water

- Hydro.
## Comparison between Central and Fast ignitions

<table>
<thead>
<tr>
<th></th>
<th>Central ignition</th>
<th>Fast ignition</th>
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<tbody>
<tr>
<td><strong>Physics</strong></td>
<td>Uniform implosion</td>
<td>PW laser physics (e-beam heating)</td>
</tr>
<tr>
<td><strong>Laser</strong></td>
<td>High power (3-4MJ)</td>
<td>PW laser</td>
</tr>
<tr>
<td><strong>Target</strong></td>
<td>Hot spark</td>
<td>High core density</td>
</tr>
<tr>
<td></td>
<td></td>
<td>→ low aspect ratio pellet,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>→ slow implosion (pulse shaping)</td>
</tr>
<tr>
<td><strong>Chamber</strong></td>
<td>Wetted wall</td>
<td>Wetted wall</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dry wall</td>
</tr>
<tr>
<td><strong>Blanket</strong></td>
<td>Liquid</td>
<td>Liquid</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Liquid or solid</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td>~192 beam lines</td>
<td>~ 32 beam lines</td>
</tr>
<tr>
<td><strong>Fusion power</strong></td>
<td>&gt; 1 GWe</td>
<td>~ 1.3 GWe</td>
</tr>
<tr>
<td>(or COE)</td>
<td></td>
<td>Low electric power (e.g., Pe ~ 0.4GWe)</td>
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Brief Summary

- A fast ignition has revealed a new feasibility for a laser fusion reactor. In comparison with a central ignition scenario, some issues for a fusion reactor might be mitigated; e.g., uniformity of implosion, reduction of a laser (and fusion) power in one shot, and so on.

- While, we encounter new concerns and R&D issues related with a fast ignition; e.g., PW laser physics, development of PW lasers, high repetition and so on.

- Design of a fast ignition laser reactor should be optimized, by taking advantages of a fast ignition scenario into account.

- We are now designing a laser fusion reactor based on a fast ignition scenario with a dry wall and a high repetition.

- If a dry wall is feasible in a laser fusion reactor, complementary R&D with a magnetic fusion reactor (e.g., divertor / first wall) might be available.

- A medium size plant (the chamber radius $R = 5.6$ m and electric output $P_e = 400$ MWe) can be designed with a solid wall chamber and a repetition rate of 30Hz. This design would be a candidate of the first-step reactor in the laser fusion development, and it has the possibility of realizing low power commercial fusion plant.