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パルス運転型および定常運転型トカマク炉における比較研究

A Comparison of Pulsed and Steady-State Operation Tokamak

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We are comparing cost in order to clarify possibility of pulsed and steady-state operation tokamak because the both of those are being studied as a realistic tokamak demo reactor. We have evaluated cost of the both reactor using FUSAC[1] system code. We defined a normalized cost point as an unit for this evaluation instead of particular currency. 100 cost point is defined to equivalent direct cost of ITER[2] and correspond generating system totally. Structure of the evaluated cost is shown in Figure 1. We choose a representative of pulsed tokamak which has Rp=10m and an another representative of steady-state which has Rp=7.25m, that is equivalent to demo-CREST[3], where Rp is plasma major radius. Their utility powers are set to be about 600MWe. We have added new calculation for cost of the NBI device to be inversely proportional to beam energy of MeV. Because the cost must be directly proportional to rather beam current, which is ∝ (1/acceleration voltage) ∝ (1/beam energy), than power. In order to apply FUSAC to not only steady-state but pulsed tokamak design, also we have arranged code for the NBI power calculation to be around 60MWe with an efficiency multiplier. 2GW$_{th}$h of thermal storage by molten salt is assumed to be installed only for pulsed tokamak so as to supply utility and plant circulating power in dwell time. Its direct construction cost is estimated 100-200M$, which is based on 50～100$ per 1kWh unit[4]. So it is equivalent 2 points of normalized cost. As the result, both reactors are clarified to cost almost equally. In case of pulsed tokamak, blanket, structures and shield cost high because of its large body. On the other hand, coil and BOP don't cost so high because of comparably lower B_{tmax} and P_f than those of steady-state reactor. Those effects canceled each other and led to almost same cost of between steady-state and pulsed tokamak. We are now modifying PF coil calculation module because of its much lower cost than TF cost. Fatigue, that is one of major issues in pulsed tokamak, has not be considered yet also.

So next we have scanned design window for fatigue stress of CS coil of pulsed operation. We applied S-N curve extrapolated from experimental data and Morrow's law for cryogenic JJ1 austenitic stainless steel at 4K[5]. Also we adopted paris' law, that is the most popular fatigue crack growth model, for JJ1 at 4K[6]. We scanned cycles to failure at S_m/1.5, S_m/3, S_m/5 of stress amplitude, and Rp=10m, 11m, 12m of reactor size, where S_m is design stress intensity, which of JJ1 at 4K is equal to 800MPa. This result is plotted on Figure 2. As a result, it is derived that CS fatigue is not so dominant but constraint of current density is more dominant. The current constraint do not let CS coil be thin.

And now TF coil fatigue evaluation is undertaken.

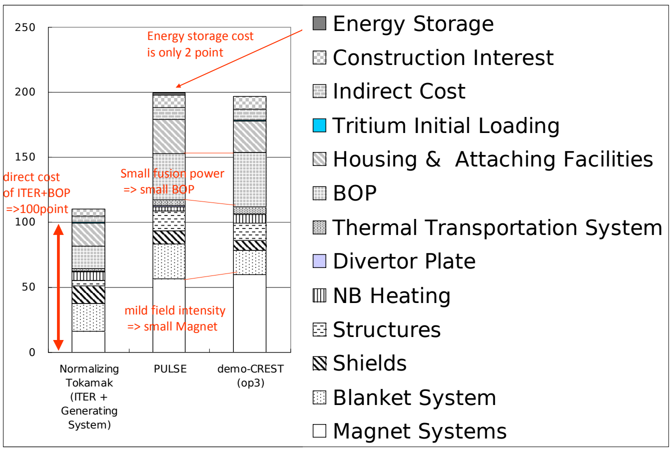

Figure 1: Normalized capital costs of tokamaks

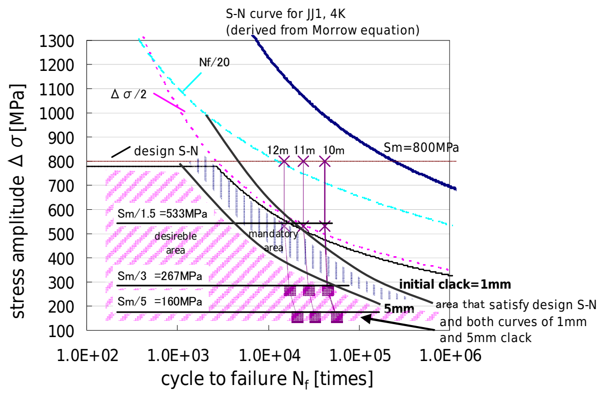

Figure 2: Scan for fatigue life various reactor size

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[3] K.Okano et al., J. Plasma Fusion Res. 80 241 (2004)
[4] http://www.scientificamerican.com/article.cfm?id=how-to-use-solar-energy-at-night
[5] K. Hamada et al. / Fusion Engineering and Design 75-79 (2005) 87-91
[6] T.N.Todd et al. / CCFE-R(12)17 THE KEY IMPACTS OF PULSED OPERATION ON THE ENGINEERING OF DEMO pp.48