Structural mechanics of fast spectrum nuclear reactor cores

A fast reactor core is composed of a closely packed hexagonal arrangement of fuel, control, blanket , and shielding assemblies. Thin wall hexagonal ducts made of stainless steel alloys provide both structure for the fuel rods as well as provide a path for the cooling liquid that passes over the fuel rods. The fuel rods provide negligible structure and as such the assembly ducts control the shape and location of the fuel rods. As fuel is brought closer together radially, the reactivity increases whereas the reverse effect occurs as fuel moves further apart. This change in reactivity is termed positive (or negative) structural reactivity feedback and is one of the essential features of an inherently safe fast reactor design.

The core of the first fast reactor, EBR, was supported in such a manner that, as the core heated up, the fuel pins moved closer together. This caused an increase in reactivity, that is, the structural reactivity feedback was positive. Positive structural reactivity feedback was the major contributor to the melting of that core. The EBR experience led to various design attempts to assure negative reactivity feedback. EBR-II used what would later be termed a "free flowering" core restraint design and HFTF was originally designed with an actively clamped core restraint system. These efforts eventually led to what is termed a "limited-free-bow" core restraint design.

In order to properly design and analyze a proper core restraint design, the motion of the fuel assemblies both over time and during power transients needs to be understood. The assembly ducts are exposed to both a radial distribution of elevated temperatures and neutron flux. The temperature gradients across the ducts initially cause the ducts to bow causing contact between adjacent ducts through load pads situated above the core and at the top of the duct. The subsequent contact creates stresses from which thermal and irradiation creep tend to relax the contact forces over time. At the same time, differential irradiation swelling due to the neutron flux gradient causes inelastic bowing that tends to increase the contact forces over time.

We present a survey of core restraint design methodologies and the analysis tools used. The effect of design choices such as choice of load pad spacing, elevation, and material along with modeling assumptions are discussed. Similarly, due to the opposing effects of irradiation creep and swelling, we discuss the sensitivity to irradiation creep and swelling correlations. We discuss the current state of modeling and the opportunities for improvements in this area.