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# Calculation of the Reactivity Feedback due to Core Assembly Bowing in LMFBRs

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A computational model to calculate the reactivity feedback due to material displacements induced by assembly bowing effects has been developed and embodied in a new code called BOWPERT. While previous bowing feedback models[1] were based on an R-Z representation of the core with user defined worth tables, the BOWPERT model is Hex-Z and requires only unambiguously defined quantities such as cross sections and fluxes.

The nonuniformity of the temperature distribution in an LMFBR leads to differential thermal expansion of the walls of the assembly hexcans. These thermal expansion differentials cause the hexcan to distort or "bow." Consequentially, the assembly experiences a spatial displacement, thereby resulting in a change in reactivity for the core. Although bowing effects are not expected to be sizable in large heterogeneous LMFBRs, it is important to quantify these effects. For the purpose of many reactor design calculations, an estimate of the magnitude of the bowing feedback is all that is required, and high accuracy is not requisite.

Since the displacements are quite small, on the order of 1 cm or less, no additional transport effects are to be expected, and the traditional tools of LMFBR neutronics analysis are applicable. It will therefore be assumed that the analysis can be carried out within the context of multigroup diffusion theory. It can further be assumed that first-order perturbation theory can be employed if care is taken to avoid the mathematical anomalies discussed recently in the literature.[2,3,4]

The central idea is to recognize that the core materials themselves have not been perturbed, but only displaced. The key to the new approach is the application of a coordinate transformation on the reactivity integral for the perturbed state. This coordinate transformation is the inverse transformation of the physical displacement of the assemblies, and maps the material distribution back into its original unperturbed state. If the diffusion operator for the critical condition is denoted by $H(\underline{r})$, one can then write an expression for the perturbed (distorted) diffusion operator, $H'(\underline{r})$, by writing explicitly the spatial dependence of this operator in terms of the displacement vector $\underline{\Delta n}$ of the volume element, Vn:

$$H'(\underline{r}) = H(\underline{r}-\underline{\Delta n}) \text{ for } \underline{r}-\underline{\Delta n} \in Vn \qquad (1)$$

If one then substitutes Eq. 1 into the first-order perturbation expression for reactivity, one obtains:

$$\delta(1/k) = \frac{\langle \phi^*(\underline{r})/H(\underline{r}-\underline{\Delta n})/\phi(\underline{r})\rangle}{\langle \phi^*(\underline{r})/F(\underline{r})/\phi(\underline{r})\rangle} \qquad (2)$$



ps

One can then apply the coordinate transformation:

$$\underline{r}' = \underline{r} - \Delta\underline{n} \tag{3}$$

and subsequently suppress the primes to obtain:

$$\delta(1/k) = \frac{\langle \phi^*(\underline{r}+\Delta\underline{n})/H(\underline{r})/\phi(\underline{r}+\Delta\underline{n})\rangle}{\langle \phi^*(\underline{r})/F(\underline{r})/\phi(\underline{r})\rangle} \tag{4}$$

In first-order perturbation theory, the flux is assumed to be unchanged by the physical perturbation and remains stationary with respect to an unperturbed coordinate system. However, when the above coordinate transformation is applied, the assumed stationary flux appears to be shifted with respect to the new coordinates. Therefore, what was a shift in the discontinuous material distribution has been transformed into a shift in the physically continuous flux distribution. The small perturbations to a continuous quantity may be evaluated more readily than perturbations of identical magnitude made to a discontinuous quantity.

In practice, however, the flux distribution is not a continuous function but is represented by a discretized function in the context of the finite difference approximation. Therefore, it is desirable, for this application, to develop a continuous representation of the flux from the results of a finite difference calculation. An expansion of the spatial flux shape in a three-dimensional polynomial which preserves integral reaction rates and leakages yields the desired continuous flux shape. Once a continuous approximation for the flux is obtained via the polynomial expansion process, the spatial shift, as well as the differentiation and integration implicit in Eq. 4, can be done analytically.

An estimate of the error bound for BOWPERT results was desired. This error was inferred from a numerical experiment with a rather severe model problem. Since BOWPERT calculates the total reactivity effect by summing the contributions from individual assemblies, a test problem consisting of calculating the bowing reactivity error for a single assembly is meaningful. The reference bowing reactivity was determined by explicit representation of the bowed and unbowed configurations in the diffusion code DIF3D.[5] To this end, a small 3 ring 60-degree sector of a typical LMFBR was considered in which each hexagon was divided into 5400 mesh triangles (30 triangles/side). Each hexagonal unit cell in the test problem consisted of an inner fueled region surrounded by an explicit representation of the sodium gap which was modelled by a 1 fine mesh row thick layer of mesh triangles containing sodium. The perturbation consisted of moving the row 2 hexagon outward along a skewed line which passes through the hexagon center and one of the outermost vertices.

The reactivity effect of the above perturbation in the explicit model as determined by the eigenvalue difference of two DIF3D eigenvalue calculations was:

$$\delta(1/k) = -0.0022565 \ (-0.645\$) \qquad (\text{Beta} = 0.0035) \tag{5}$$

In this case the magnitude of the bowing reactivity for a single assembly is unrealistically large due to the small value of the perturbation denominator

in a problem of such small size. The result obtained with BOWPERT for the analogous perturbation and using flux and adjoint distributions computed on a 6 triangle per hexagon mesh is:

$$\delta(1/k) = -0.0017675 \; ( -0.505\$) \qquad (6)$$

The BOWPERT results are accurate within 0.15$ for a very severe model problem. It is expected that BOWPERT will be more accurate for more realistically sized problems with perturbation denominators of reasonable magnitude. For many applications, accuracies of even 0.15$ will suffice.

BOWPERT represents a unique capability for the study of the effects of reactivity feedbacks due to assembly bowing. For example, the reactivity effect of taking the reactor from cold critical to hot critical has been calculated for several recent ANL core designs. The distorted condition of the core can be calculated with the NUBOW-3D[1] computer code, and the results can be input to BOWPERT. The reactivity perturbation due to the "startup transient" ranged from +0.016$ to -1.12$ depending on the design. Thus the degree to which the bowing feedback adds/subtracts from the inherent stability of the reactor can be estimated.

## REFERENCES


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