CONF-790602--87

AN ANALYTICAL METHOD TO ACCURATELY PREDICT LMFBR CORE FLOW DISTRIBUTION

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An accurate and detailed representation of the flow distribution in LMFBR cores is very important as the starting point and basis of the thermal and structural core design. Previous experience indicated that the steady state and transient core design is as "good" as the core orificing; thus, a new orificing philosophy satisfying a priori all design constraints was developed[1]. However, optimized orificing is a necessary, but not sufficient condition for achieving the optimum core flow distribution, which is affected by the hydraulic characteristics of the remainder of the primary system. Consequently, an analytical model of the overall primary system was developed, resulting in the CATFISH computer code, which, even though specifically written for LMFBRs, can be used for any reactor employing ducted assemblies.

CATFISH is a hydraulic code which models the entire primary system (see Figure 1). It considers all the hydraulic resistances in the core plus those of the inlet and outlet plena and primary loop. It also models all the numerous reactor flow paths: fuel and blanket orificing zones, primary and secondary control assemblies, radial shield, vessel and core barrel and leakage. Each individual core assembly is represented by a separate flow path, accounting for every resistance: lower internals, assembly nozzles, orifice, shield, rod bundle, etc. This complex hydraulic network is coupled with the pump head/flow characteristics curve. Thus, for any specified set of resistances, CATFISH calculates the pump head, the total reactor flow, the flow in each assembly and the pressure drop across each subcomponent.

In the actual design procedure, the minimum flow requirements for the core assemblies and other reactor components have been determined by thermal-structural considerations[1]. All the hydraulic resistances are also defined, except the orifices, which are specified by the designer to achieve the desired flow distribution. CATFISH has proven quite valuable in achieving this goal. For example, it was found for the Clinch River Breeder Reactor Plant (CRBRP) that by judiciously decreasing the orificing resistances, thus moving toward higher flows along the pump characteristics curve, the total reactor flow delivered by the pump could be increased by the order of 5-10%. This has the potential for very substantial savings, since 1% increase in flow corresponds to ~5°F decrease in maximum cladding temperature, which, in turn, corresponds to an allowable burnup increase of ~2500 MWd/ton. For example, an 8% flow increase would yield an increased lifetime of ~6 months for each CRBRP core and fuel cycle cost savings of ~$100M over the plant lifetime.

A feature of several LMFBR designs is that a group of adjacent core assemblies, which are generally of different types and belonging to different orificing zones, are fed from a single source in the lower internals, called a lower inlet module (LIM). Thus, assemblies with identical orificing, but fed by different LIMs will have slightly different flows, depending on the pressure drop across the respective LIMs (which is proportional to the total LIM flow). Only a code like CATFISH modeling the flow network with the pump as boundary condition provides the capability of calculating the individual assembly flows. The particular case of CRBRP, where each LIM feeds seven adjacent assemblies is shown in Figure 1. Maximum flow variations of ~2% between assemblies in the same orificing zone were calculated; since they are significant enough to affect the core thermal design, they had to be considered in the core orificing process.

CATFISH calculates core flow distribution and components pressure drop for nominal conditions as well as accounting for uncertainties on the hydraulic resistances, both positive and negative (higher or lower resistance than nominal). Previously, the maximum reactor pressure drop was calculated increasing the nominal ΔP's along the highest resistance flow path (highest flow orificing zone) by their respective uncertainties. This is obviously overly conservative, since: a) the actual reactor flow when the hydraulic resistance is increased must be less than the flow delivered by the pump for nominal conditions; b) resistance uncertainties are superimposed, while they are statistical in nature; and c) the flow redistribution among the various flow paths is neglected. All the above effects are properly accounted for in CATFISH. For the CRBRP case, the hydraulic resistance in each single component was individually varied (for a total of 83 individual cases) and the corresponding effect on the total reactor flow calculated. A root-mean square of the reactor flow variation due to the individual variations in hydraulic resistance (as well as pump curve) at the 2σ confidence level resulted in 2σ expected flow variations of only ±1.6% over the nominal reactor flow. This compares with variations of over 6% previously attained, thus reducing unnecessary conservatism which penalizes the overall plant design and performance.

In conclusion, the new analytical method presented here provides the designer with a rigorous and very detailed representation of the flow distribution and pressure drops in the reactor and, even more importantly, its implementation enables reduction of unnecessary design conservatism and very substantial cost savings.

REFERENCES

1. M. D. Carelli, et al., "An Optimized Method for Orificing LMFBR Cores", Trans. Am. Nucl. Soc., 26, pp. 437-438, June 1977.

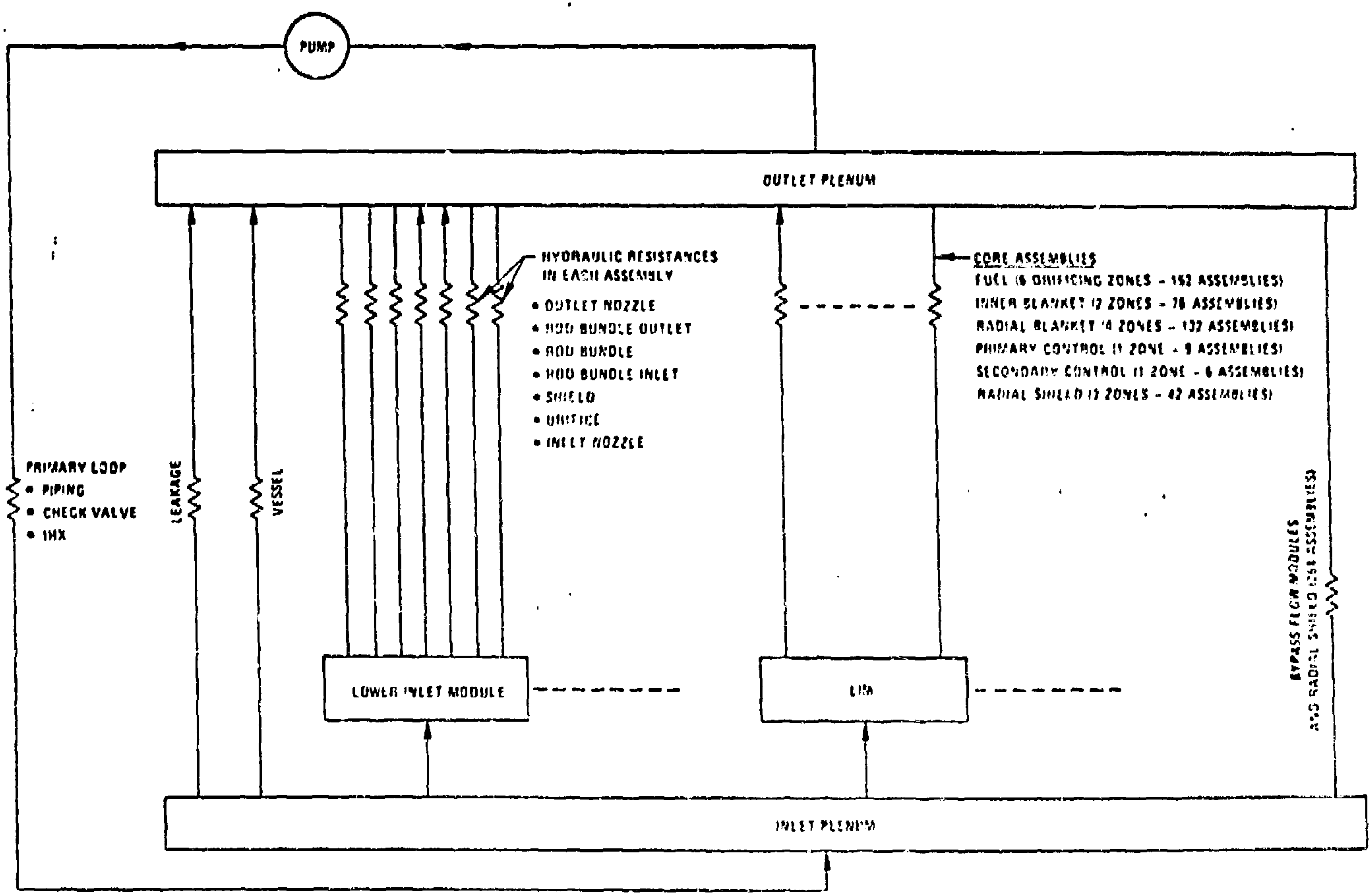

Figure 1. Schematic of CRBRP Primary System Hydraulic Network Modeled by CATFISH