DEVELOPMENT OF HEAT EXCHANGERS FOR NUCLEAR SERVICE

Nuclear service imposes constraints on heat exchangers more severe than normal commercial practice. Development of design techniques to improve the safety, economics, and reliability of heat exchangers is pursued by the Engineering Research Branch at the Chalk River Nuclear Laboratories.

Certain components, e.g., tube-in-shell heat exchangers, are regarded as conventional equipment because of their widespread use in industry. When incorporated into CANDU (Canada Deuterium Uranium) nuclear power plants they are subjected to design constraints not commonly applied for general industrial use: in particular, minimum tube side volume (because of the high cost of heavy water) and ultra-reliability. The first constraint leads the designer towards small-diameter tubes in close-packed lattices, arrangements which are prone to tube vibration, in conflict with the second constraint.

The Engineering Research Branch has a program of work, both in-house and under contract, directed toward providing design techniques to accurately estimate the degree of tube vibration and its consequences such as fretting. This program includes

- studies of tube excitation in liquid and two-phase cross flow
- studies of the response of multi-span tubes with various support arrangements
- development of a three-dimensional thermal hydraulic computer program for estimating boiler internal flow conditions in detail
- model studies of the distribution of flow in heat exchangers and boilers
- studies of the fretting process.

The study of tube excitation in liquid cross flow is underway at the University of Ottawa under contract. Different arrays (i.e., square and triangular lattices of various pitch:diameter ratio) are mounted in a water tunnel. Specially instrumented tubes give the exciting force distribution in terms of frequency spectrum and longitudinal and circumferential correlation. Two-phase tests of a similar nature will be carried out soon in a new air-water facility under construction at CRNL (Chalk River Nuclear Laboratories). Figure 1 shows a preliminary test, in which tube response was measured, in a small air-water facility.

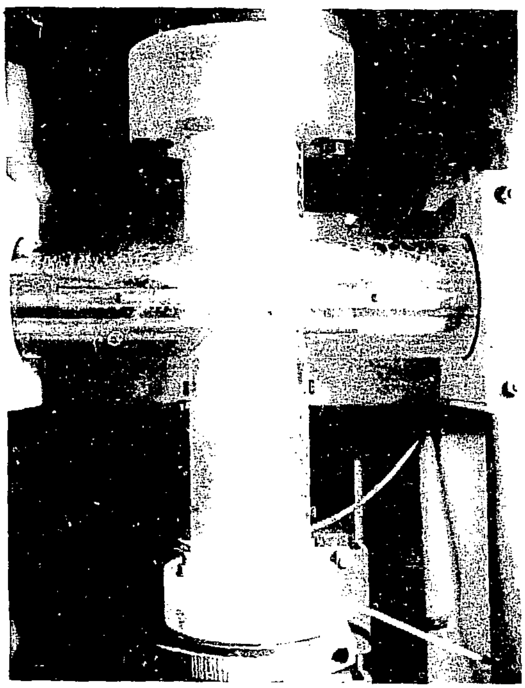

Figure 1 – Rig for examining the vibration of tubes in two-phase cross flow

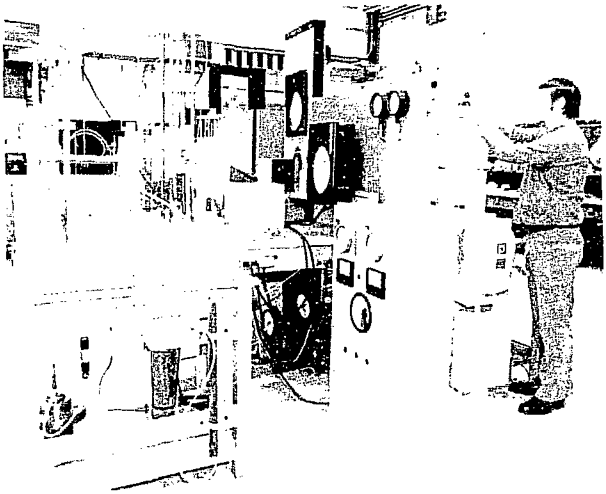

Figure 2 – Rigs for measuring fretting rate in simulations of heat exchanger tubes vibrating within support plate holes

The response of multi-span tubes has been measured in both basic and field experiments. Detailed studies on single tubes immersed in a trough using a mechanical transfer function analyser have shown how tubes excited at one point dissipate the motion by distributed structural and fluid damping. Tests at manufacturers' shops during construction have shown how real assemblies differ from ideal, simply supported U-bends. Field tests during the commissioning of station heat exchangers have provided additional data on fluid damping (besides furnishing checks on our overall design analysis).

To calculate flow velocities and qualities throughout the secondary side volume in a nuclear steam generator has been, until recently, a formidable task involving various successive estimates. A large and sophisticated computer code is being developed for the CANDU line of boilers: it is based on an initial program developed under contract by CHAM Ltd. in the U.K. Previously we had to rely on model studies to give the distribution of flow in complex geometries, but we expect the computer code will handle any conceivable arrangement, when fully developed and tested.

The more probable damage from tube vibration in CANDU heat exchangers and steam generators is tube fretting at the support plates, ultimately causing a loss of heavy water into either cooling water or steam. The relation between metal wear rate and tube vibratory motion is complex and affected by the type and condition of the contacting materials, the environment and the nature and degree of the vibratory motion. A number of experiments have been run, both at CRNL and under contract at Westinghouse Canada Limited. Figure 2 shows two test rigs at the left, where test specimen tubes are vibrated within simulated plates supported by four pillars on each rig: accelerometers and force transducers indicate the nature of the intermittent contacts: the technician at the right adjusts a similar test machine contained within an autoclave where the 261°C steam environment of a CANDU boiler is simulated.

The items of this program have much in common with corresponding items in similar programs on fuel vibration. The techniques developed have also proved useful in other jobs, for example in measuring the damping of a 122 m flare stack at the Glace Bay Heavy Water Plant or in determining the cause of cracks in a steam discharge line within a condenser.

Our work in the Engineering Research Branch is not complete until our technology has been transferred to industry. One very successful exercise was the development of tube plugging procedures for Pickering Steam Generator.

In late January 1974 the No. 2 unit at the Pickering Generating Station shut down because an increasing leakage of the reactor heat transport heavy water into the turbine steam system in boiler No. 7 was approaching an uneconomic level, where the cost of lost heavy water would exceed the incremental cost of power from another source in the Ontario Hydro system. Fortunately procedures for such a contingency were in an advanced state of development, and transfer of technology had been incorporated in the development program. A team trained

Figure 3 – This photo, taken during a repair exercise in unit 4 prior to commissioning, illustrates the difficult working conditions. The workman is about to enter the boiler head via the 15 inch diameter manway

in the various repair aspects of leaking tube identification, inspection, plugging and testing within the radioactive and confined environment of a boiler head (see Figure 3) was immediately available. Within five days the unit was back on line; the leak (a hole approximately .254 mm in diameter) had been found within the 2600 tubes totalling 1858 m^2 of surface, plugged and tested.

The five-day period was considerably shorter than for any previous comparable repair of a nuclear steam generator. Here we started to prepare for tube plugging two years previously, when we initiated the development program outlined in Figure 4. The plan recognized that the maintenance of a specialist repair team was more logically an activity for which the boiler manufacturer should be responsible than the station operator; the manufacturer is concerned about the lifetime integrity of his product, and his direct involvement in any failures would ensure feedback into new design and construction. Accordingly, the manufacturer of the Pickering boilers (Babcock and Wilcox Canada Ltd. (B&W Canada)) undertook to develop, under contract to CRNL, most of the hardware required. CRNL was responsible for the general direction of the program and also for metallurgical appraisal of the plugs, leaking tube identification, proof testing and protective clothing.

Within a year the essential parts of the plug program had been completed. An explosive plug with burning rate and energy release tailored to weld itself into the tubes without overstraining the tubesheet ligaments had been developed at B&W Canada. Methods of finding tubes with very small leaks using fluorscein and ultraviolet light, and of marking the two ends of the failed U-tube by shooting a tethered shuttle through the tube had been devised at Chalk River. Detailed time and motion studies on a mockup of the boiler head had shown how the operations should be broken down to keep the exposure of the repair team within safe limits.

While these procedures were being developed, an eddy current scanning system for inspecting full-length tubes from the inside bore was being developed at CRNL. When a technical difficulty concerned with Monel alloy (the material of the Pickering boiler tubes) was overcome it was decided that scanning should be included in the boiler repair procedure to identify the nature of the leak and to find incipient tube failures. B&W Canada entered into a further cooperative development contract on this topic, and attached an engineer to CRNL for a year to learn the technical details of eddy current flaw detection. On his return to B&W Canada, Cambridge, he developed the field procedures for inspecting the Pickering boiler tubes and trained technicians to

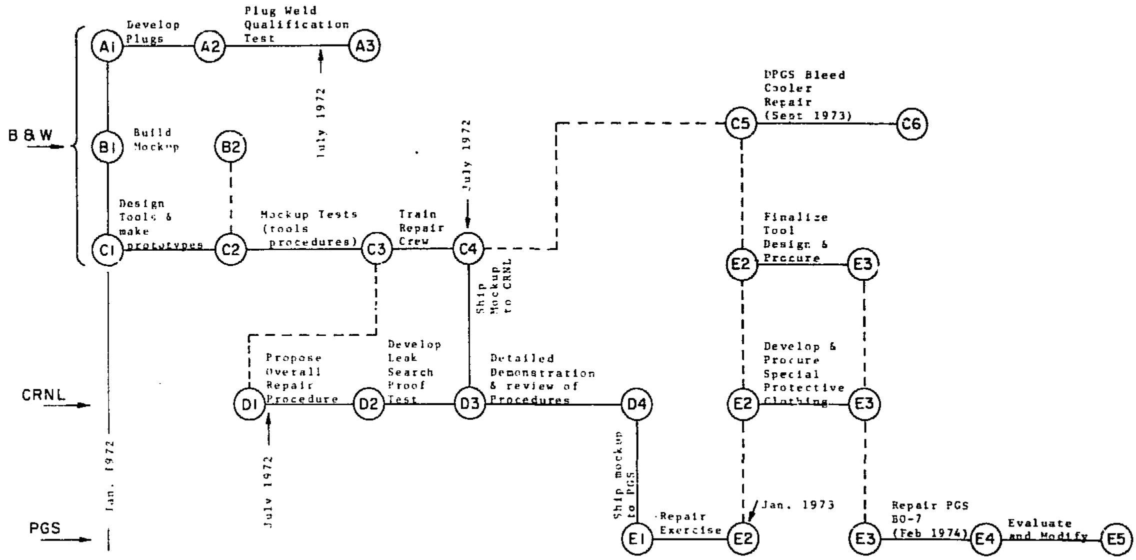

Figure 4 – Outline of Pickering G.S. repair procedures development (time scale indicated by vertical arrows)

operate equipment they had acquired and to interpret the eddy current signals.

As noted on the outline diagram (Figure 4), we experienced a leak in a bleed cooler at the Douglas Point Generating Station in September 1973. This could have been handled by conventional hand welding of plugs, but we applied the procedures under development. This resulted in a minor economy in cost, and at the same time provided a valuable test of all the procedures, including the eddy current scan.

Ontario Hydro now contract directly with B&W Canada to provide the tube plugging service for both their Pickering and Bruce stations, on a five-year renewable basis. B&W Canada have undertaken a number of heat exchanger eddy current surveys and plugging repairs for various companies around the world, in the chemical industry as well as in nuclear stations: this has given them wider experience and has generated revenue for the company. AECL has noted that new designs of boiler, notably for our 600 MW(electrical) stations, have improved provision for maintenance.

R.I. Hodge
D.G. Dalrymple

*