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QUARTERLY TECHNICAL PROGRESS REPORT
LMFBR TASK 25, TRANSIT TIME FLOWMETER
JULY—SEPTEMBER 1970

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I. PROJECT OBJECTIVES

The objective of the program is the development and demonstration of a flowmeter using noise-analysis techniques, which will be suitable for use as a flow-measurement standard in large liquid-metal systems at temperatures to 1200°F or higher. A secondary objective is the development and testing of a small flowmeter for use in measuring flowrate from individual fuel assemblies in liquid-metal-cooled reactors such as the FFTF.

Operation of the Transit Time Flowmeter (TTF) depends upon the detection of small temperature variations (thermal eddies) at two points a known distance apart in a flowstream. The two signals are cross-correlated with a variable delay time. The delay time which gives maximum correlation is the transit time of the fluid between the sensors, which time is inversely proportional to the fluid velocity.

During 1968 and 1969, under Parts 1 and 2 of the program, the feasibility of the TTF concept for accurately measuring flow rate was developed and demonstrated in a 2-in.-diam system with water to velocities of 15 ft/sec and with sodium to 1200°F.

The current Part 3 program, February 1970 through January 1971, has three objectives as follows: (1) design and assembly of a 6-in.-diam TTF, and testing the TTF in water and in sodium at flow velocities to 30 ft/sec and temperatures to 1050°F; (2) development and testing of an electronics system to provide a direct-reading flow signal from the transit-time detectors, and (3) development and testing of a transit-time thermal flowmeter which has potential application in the FFTF and other reactors for measuring flowrate from individual fuel assemblies.
Project activities during the first quarter of GFY 1971 have been concentrated on assembly of the Transit Time Flowmeter (TTF) and with other preparations for testing the 6-in.-diam TTF in water at the Rocketdyne High-Flow facility and in sodium in the SCTI at temperatures to 1050°F and flowrates to 30 ft/sec.

The test section to be installed in the SCTI is 6 in. in diameter and approximately 24 ft long. Eight TTF sensors and an EM flowmeter will be located on the test section. This arrangement will provide accurate EM flowmeter data for comparison to the TTF results and the eight widely spaced TTF sensors will increase the capability of the test setup for evaluating flow velocity characteristics and for studying the diffusion of thermal patterns. The TTF assembly is shown in Figure 1.

Fabrication of the test section was completed without serious difficulties. Fabrication of the sensors, Figure 2, has continued through the report period and was not completed as planned due to problems with brazes which arose because thermocouples certified by the supplier to have Type 304 stainless-steel sheaths, actually were found to have Inconel-600 as the sheath material.

The requirements for the direct-reading electronics system were defined. These were discussed in detail with three commercial suppliers of this type of equipment, and proposals for development and supply of a complete flow analyzer were obtained from two of these suppliers.

Work on the small in-core flowmeter was deferred during this report period due to concern over the costs of completing the 6-in. flowmeter effort.

A. SENSOR FABRICATION

The sensors for the 6-in.-diam Transit Time Flowmeter employ eight 0.040-in.-diam and two 1/16-in.-diam thermocouples on each of the eight sensors to be used. These were to have been Chromel-Alumel thermocouples with Type 304 stainless-steel sheaths. After they were brazed into the sensor fin tubes it was discovered that the sheath material of the smaller thermocouples was a nickel-base alloy, apparently Inconel-600, from the chemical composition and a statement from the supplier that he had not used other alloys of
Figure 1. 6-in.-diam Transit Time Flowmeter Installation in the Sodium Components Test Installation Primary Loop
Figure 2. Cantilevered Thermocouple Sensor in 6-in. Transit Time Flowmeter
similar composition. The certification received with the wire stated that the sheath material was Type 304 stainless steel, as ordered.

The substitution of Inconel for stainless steel for the thermocouple sheath material poses potential problems with the welded hot junction, with corrosion in sodium service, and with the brazing process. The capability for monitoring temperature is not affected.

After reviewing the alternatives, the funding limitations and the schedule considerations, it was concluded that the objectives of the program would be met and the SCTI would not be in jeopardy if the thermocouples sheathed with Inconel-600 were used without further processing to improve the brazes, providing that they would withstand vibrations more severe than the flow test conditions. The bulkhead braze was changed to use Amdri-100 which is compatible with Inconel-600 whereas the intended braze material, Nicrobraz-50 is not. The problem areas and factors leading to the conclusions are discussed below.

1. **Welded Hot Junction**

   The thermocouple junctions are of the grounded type, and since the sheath was thought to be stainless steel, Type 308 filler wire was used in making the end cap junction welds. The thermocouples were carefully made up, calibrated, and tested for time response and were found to be satisfactory. The thermocouples were X-rayed twice and appear to be sound. Also, the sections which have been metallographically examined appear to be of good quality.

2. **Corrosion in Sodium**

   Generally, Inconel is considered to have a higher corrosion rate in sodium than does stainless steel. For the highest TTF test temperatures, 1050°F, a corrosion rate no greater than two mils per year might be expected. Since there will be only 10 to 20 hours of tests at 1050°F and less than 50 hours above 750°F, corrosion should be insignificant. If the TTF is left in the SCTI loop, it would be exposed to temperatures less than 750°F because this is the maximum temperature during normal SCTI operation. Corrosion of Inconel-600 does not appear to be a significant problem for the planned SCTI tests.
3. Brazes

The thermocouples were brazed into the fin-tubes, using Nicrobraz-50, a Ni-Cr-P alloy containing about 10 wt % phosphorous and known by the AWS designation "BNi-7." This braze material is commonly used with stainless steel, but at Al it has not been considered to be desirable for use with nickel-based alloys because the phosphorous-nickel interaction is more rapid than desired. For nickel-based alloys, AWS BNi-5, also known by the trade names "Nicrobraz-30," "J-8100," and "Amdri-100," has been preferred. BNi-5 is a Ni-Cr-Si alloy with about 11% Si which requires a brazing temperature of 2100 to 2200°F, as compared to 1800 to 1900°F for BNi-7.

After learning, during the process of qualifying the thermocouple bulkhead brazes, that the thermocouple sheath material was Inconel-600, several brazes were sectioned and examined metallographically. These showed that there were small cracks in the braze fillets and that the braze material interactions with the Inconel typically extended 20 to 30% of the thermocouple sheath thickness; although some penetrations were greater where there was an excess of braze alloy. There was relatively little braze alloy interaction with the stainless steel in the same specimens, and the brazes of the 1/16-in., stainless-steel-sheathed thermocouples appear to be of good quality. Two of the Inconel-sheathed thermocouples were broken off in handling and the broken ends appeared to be fairly brittle. Others have been bent with the minimum radius in the braze fillet without breaking. These brazes have sodium on both sides of the fin tube. The purpose of the brazes is to hold the thermocouples in place and they do not contain pressure or have to be leak tight. The seal which contains sodium is located at the outer end of the sensor where there are two bulkheads in series with a gas-filled space between them.

Since the Inconel-sheathed thermocouple brazes to the fin tubes were not considered to be of the quality desired, several alternates were considered and a number of test specimens were brazed and examined. The alternates considered are as follows:

1) Replace the thermocouples with new stainless-steel-clad thermocouples.
2) Replace the thermocouples with available new stainless-steel-clad thermocouples of less than the desired quality; i.e., thermocouples from old material on hand or from new "commercial" grade material.

3) Complete and use the sensors with the Inconel-sheathed thermocouples and imperfect brazes if they are shown to be capable of withstanding vibration exceeding that expected in the flow tests.

4) Complete the sensors with the Inconel-sheathed thermocouples, as in Alternate 3, but attempt to improve the brazes by heat treating them to disperse the phosphorous, or by rebrazing with a compatible braze alloy.

4. Sensor Vibration Tests

Two vibration tests were performed on the TTF sensor, one with an as-designed sensor and one with an added component to restrain vibratory motion. These tests were primary go–no-go structural integrity verifications and general vibration surveys which were performed to investigate a potential vibration fatigue problem of the thermocouples. Key problem areas were at the thermocouple-to-fin braze joint and vibration of the thermocouple sheaths within the sensor tube.

The test conditions were a 3-g sweep from 20 Hz to 2 kHz in the horizontal and lateral coordinates. A single accelerometer was mounted at the end of the sensor fin in both tests.

The result of the first test was a failure of three thermocouple sheaths just inside the fin tubing. This fracture was verified on X-rays. Fundamental resonances were observed at 150 Hz and 330 Hz in the horizontal axis and at 300 Hz and 500 Hz in the lateral axis. Additional resonances were observed at 1 and 2 kHz. The cause of the thermocouple sheath failure was believed to be fatigue at high stress points due to the thermocouple bundle and fin acting as two separate bodies. Interbody motion caused high stress at the brazed joint between the thermocouples and the fin.

The second series of tests was conducted on a sensor which had an additional part to restrain the thermocouples. The tests caused no observable damage due to vibration. Fundamental resonances were observed at 160 and 503 Hz in the
horizontal axis and at 334 and 608 Hz in the lateral axis. Additional resonances were observed at about 950, 1200, and 2000 Hz. From the lack of vibration-induced fracture in the second set of tests, it was concluded that the sensor thermocouple structure was acceptable.

B. FLOW ANALYZER SYSTEM

The requirements for the TTF flow analyzer were specified and proposals were received from two suppliers for this equipment. This system will utilize turbulent temperature variations and will produce a digital flow velocity readout. The final on-line device will only have an "on" switch, digital readout, and alarm indicator on the front panel. Setup controls, calibration switches, and recorder outputs will be out of sight to simplify plant operator use.

This device includes a digital adapter to eliminate problems of temperature drift in the time-to-voltage converter circuit. The adapter will also provide both analog and digital output proportional to transit time and flow velocity. This will simplify operation, improve accuracy, and reduce time and costs for data reduction, calibration, and test.

This device is a combination of several basic components including: analog signal processing modules, circuit card rack adapter and power supply, digital readout adapter, and digital display.

The combination of these items into one digital unit will produce a more stable, accurate system at minimum cost.

III. EVALUATION OF EFFORT TO DATE

Earlier work with the Transit Time Flowmeter has shown it to be a very effective and accurate means of measuring fluid velocity. All indications are that it is unaffected by differences in fluids or by temperature.

The current project activities have been predominantly concentrated on the fabrication of test hardware. Because the TTF is to be installed in a sodium system, the design, materials, manufacturing processes and inspections have been carried out under strict standards and controls. As is often the case for first-of-a-kind items, these procedures have increased costs and schedules.
Also, the problem with thermocouple sheath material, described previously, has had unfavorable cost and schedule effects. These types of problems now have been overcome and completion of the sensors is expected to be accomplished without further significant problems. None of the problems so far encountered relate to the feasibility of the TTF concept and the experience gained will be beneficial to future work which must be done to similar standards and to the fabrication of components for future Transit Time Flowmeters.

IV. NEXT REPORT PERIOD ACTIVITIES

During the October-December 1970 period, it is expected that the flowmeter will be completed and tested in both water and sodium, and a substantial part of the test evaluation should be completed.