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CALIBRATION OF THE SNAP-10A PUMP AS A MAGNETIC FLOWMETER

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Abstract

A SNAP-10A permanent-magnet pump was installed in an existing flowmeter-calibration test facility and calibrated as a magnetic flowmeter. The pump was calibrated at NaK flow rates of 0.25 to 5.0 gpm and pump inlet temperatures of 200, 400, 600, and 800°F. Calibration curves show that the signal generated in the pump is strongly affected by a temperature difference between the points where the flow signal leads are attached. The lead junctions should be maintained isothermal if the SNAP-10A pump is to provide good flow measurements at low flow rates and temperatures above 200°F.

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Introduction

Tests of the SNAP-10A reactor system will be conducted at the Oak Ridge National Laboratory to study the radiation from the reactor core and to develop a shielding technology applicable to the reactor system. The flow rate of the sodium-potassium alloy (NaK) coolant in the system will normally be determined by the power delivered to the pump. However, during initial low-power operation of the reactor system in the Tower Shielding Facility, the flow of NaK coolant will be established by natural convection without the aid of the SNAP-10A pump. Under these conditions, it will be necessary to measure the flow rate in the system, and studies have revealed that it is not feasible to install a magnetic flowmeter. A decision was made to calibrate the SNAP-10A permanent-magnet pump as a magnetic flowmeter, and a test was carried out for this purpose. Measurements were made of the signal generated by the pump assembly at various flow rates and at several temperatures of interest for the SNAP-10A test operation.

The SNAP-10A pump was installed in an existing flowmeter-calibration test facility, and data were obtained on the signal generated by the pump assembly at NaK flows of 0.25 to 5.0 gpm and pump inlet temperatures of 200, 400, 600, and 800°F. Calibration of the SNAP-10A pump at inlet temperatures below 200°F was impractical because of the difficulty of removing the relatively large amount of heat generated in the helical induction pump in the test facility.

The curves of NaK flow rate versus the flow signal generated in the pump deviate from the theoretical straight line anticipated with an electromagnetic flowmeter. This deviation is attributed in part to the difference between the configuration of the SNAP-10A pump and that of a regular flowmeter. At flow rates below 0.8 gpm and temperatures above 400°F, the curves also show that the flow signal is strongly affected by a temperature difference between the two electrodes attached to opposite sides of the SNAP-10A pump. However, when the thermocouple effect is eliminated, the flow signal is essentially a linear function of NaK flow at flow rates below 0.8 gpm at all temperature levels tested.

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Calibration Tests

Test Equipment

The SNAP-10A pump was installed in a horizontal leg of the flow meter-calibration test facility as shown schematically in Fig. 1. The system fluid, in this case NaK, was circulated through the test pump by a General Electric Company helical-induction pump Model 5KY414PM1. Each of two parallel piping systems downstream from the pump contained a calibrated venturi. The small venturi located in the 3/8-in.-OD tubing part of the loop was capable of accurately measuring NaK flow rates from 0.25 to 1.20 gpm. The large venturi located in the other leg of the system was capable of accurately measuring NaK flow rates from 3 to 20 gpm.

Pressure taps around each venturi were connected through valves and tubing to either of two differential-pressure-measuring instruments. These instruments have ranges of 0 to 60 and 0 to 200 in. of H_2O , respectively, and are designed to deliver a millivolt signal at the output of the instrument. This signal was read on a single-pen recorder.

The facility also contained a zirconium hot trap to remove impurities from the circulated fluid and a surge tank to accommodate thermal expansion of the liquid during initial system heatup. An inert-gas line connected to the top of the surge tank provided a means of varying the system pressure.

The facility piping was heated by metal-sheathed electrical heaters strapped to the outside of the piping and connected to 0- to 135-v 9-amp variable-voltage controls. Chromel-Alumel thermocouples placed on the outside of the system piping and connected to 0 to 2000°F multi-point recorders were used to measure the desired temperatures. Thermocouple placement on the SNAP-10A pump was as shown in Fig. 2. The flow-meter leads were welded to the pump power lugs. These two leads were connected to a 0- to 10-mv single-pen recorder, and the electrical signal generated in the pump assembly by the NaK flow was read from the recorder.

Fig. 1. Schematic Diagram of the Flowmeter Calibration Loop.

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Fig. 2. Thermocouple Installation on SNAP-10A Pump.

Test Procedures

Following installation of the SNAP-10A pump in the facility, the line containing the 0.25- to 1.20-gpm venturi was cut and sealed to prevent the possibility of NaK flowing simultaneously through both venturi tubes as a result of valve leakage. The differential-pressure-measuring instruments were heated to their operating temperatures and the instruments, along with the readout equipment, were calibrated. Calibration checks were also carried out on the temperature recorders.

The system was then evacuated, purged with argon, and again evacuated before filling with the operating charge of NaK. The NaK was heated to 800°F and purified by circulating for a 12-hr period through the zirconium hot trap, which was held at 1200°F.

A sample of the NaK taken at the end of the cleanup period showed an oxygen level of 7 ppm. Flow through the hot trap was shut off, and the power to the helical-induction pump was adjusted to deliver the maximum desired flow rate through the SNAP-10A pump. Further flow adjustments were made by throttling a valve located downstream from the venturi.

Electrical heater circuits were adjusted to give the predetermined temperature at the SNAP-10A pump inlet and to maintain, as nearly as possible, an isothermal system. When these conditions had been established, the system was held at steady state for at least 5 min before data were taken. The data included the temperatures around the SNAP-10A pump and the venturi, the flow signal generated in the SNAP-10A pump, and the differential pressure across the venturi. The flow rate was determined from the venturi calibration curve, and the relationship of the pump output signal to the actual flow was noted. The flow through the system was then adjusted to obtain another data point.

The data taken during increasing and decreasing flow modes showed a negligible effect of hysteresis in the flowmeter calibration. Systematic checks of the recorder signals were also carried out during the calibration tests. These checks were performed during steady-state operation by disconnecting the leads from the recorders and reading the generated signal on a potentiometer.

Upon completion of the calibration tests at flow rates between 3.0 and 5.0 gpm, the loop was drained and distilled under a vacuum. An argon supply was then connected to the differential-pressure-measuring instruments, and the calibration of the equipment was rechecked. Data indicated no drift in the instrumentation during the test period. The loop was cooled, the small venturi line was installed, and the large venturi line was sealed off from the flow system. The NaK was then circulated through the zirconium hot trap for a period of 12 hr to remove impurities introduced into the system during alterations.

The test facility temperatures and pressures were established, as in the previous calibration tests; and data were taken at flow rates between 0.25 and 1.20 gpm for the desired temperatures. A sample of the NaK taken just prior to termination of the test program showed the oxygen level to be approximately 5 ppm.

Test Results

Results of the SNAP-10A pump calibration are presented in Figs. 3 through 6. Typical data, including the temperatures around the SNAP-10A pump, are presented in Table 1. The absence of data in the range 1.2 to 3.0 gpm is due to a gap in the ranges of the two venturi tubes. At flow rates below 3.0 gpm, the pressure differential across the large venturi fell below the accuracy range of the instrumentation, and at 1.2 gpm the signal from the small venturi reached the upper limit of the differential pressure instrumentation. Consequently, flow measurements in the range 1.2 to 3.0 gpm were not made.

Flow-Signal Deviations. A deviation from the expected straight line of a standard flowmeter curve was noted in all calibration curves. The apparent reduction in the generated signal at the higher flow rates has been attributed partly to the location of the signal leads on the SNAP-10A pump and partly to the fact that at high flow rates the magnetic flux field tends to shift in the direction of the fluid flow. In a standard flowmeter installation, the signal leads are located in the center, or slightly downstream of the center, of the magnetic field to compensate for the shift in the flux field. The signal leads on the

Fig. 3. Flow Signal for SNAP-10A Pump as Calibrated in 200°F NaK.

Fig. 4. Flow Signal for SNAP-10A Pump as Calibrated in 400°F NaK.

Fig. 5. Flow Signal for SNAP-10A Pump as Calibrated in 600°F NaK.

Fig. 6. Flow Signal for SNAP-10A Pump as Calibrated in 800°F NaK.

Table 1. SNAP-10A Calibration Data

Pump Flow (gpm)	Pump Signal (mv)	TE-1 Inlet (°F)	TE-2 Outlet (°F)	TE-3 Magnet (°F)
200°F Calibration				
5.00	5.00	198	197	115
4.60	4.72	195	196	117
4.05	3.99	200	200	115
3.90	4.00	189	189	112
3.50	3.56	195	196	118
3.15	2.99	200	200	116
0.82	0.84	204	200	115
0.74	0.76	201	198	120
0.61	0.63	200	198	115
0.58	0.59	200	194	119
0.51	0.53	200	196	116
0.45	0.46	204	199	117
0.41	0.42	199	191	117
0.30	0.30	200	192	116
400°F Calibration				
5.90	5.82	396	398	207
5.00	4.98	395	400	209
4.10	4.02	396	398	204
3.30	3.23	393	395	200
1.20	1.18	398	389	191
1.00	1.00	400	391	195
0.74	0.74	404	394	194
0.65	0.66	400	393	200
0.59	0.60	405	390	190
0.46	0.47	400	389	203
0.40	0.42	402	392	200
0.33	0.34	405	390	190

Table 1. (Continued)

Pump Flow (gpm)	Pump Signal (mv)	TE-1 Inlet (°F)	TE-2 Outlet (°F)	TE-3 Magnet (°F)
600°F Calibration				
5.90	5.83	598	592	290
5.65	5.45	600	596	290
4.95	4.71	600	597	291
4.25	4.00	599	544	292
3.10	2.74	598	596	290
1.22	1.20	605	605	290
0.96	0.95	597	590	280
0.86	0.85	620	620	290
0.74	0.71	600	600	280
0.62	0.63	615	615	290
0.53	0.55	600	600	285
0.50	0.55	630	615	300
0.44	0.50	600	590	280
0.34	0.50	615	600	290
0.24	0.50	620	595	280
800°F Calibration				
6.25	5.83	796	795	375
6.15	5.72	798	798	352
5.30	4.97	802	800	380
5.25	4.79	796	794	360
4.20	3.70	791	791	356
4.05	3.70	795	795	380
3.10	2.50	797	792	354
3.05	2.45	800	800	380
1.27	1.21	802	787	349
1.23	1.19	800	788	330
1.02	1.00	803	786	345
0.98	0.98	801	790	376
0.87	0.90	799	785	370
0.80	0.83	807	784	343
0.77	0.83	800	787	375
0.64	0.78	803	782	359
0.57	0.75	807	780	346
0.55	0.75	802	778	359
0.42	0.70	800	770	360
0.35	0.67	808	770	354
0.27	0.63	787	739	362
0.23	0.63	783	727	345

SNAP-10A pump, however, are located on the power lugs at the inlet of the throat area, where the flux density is at a minimum. This reduction in the magnetic flux in the area of the signal leads produces less than a maximum output signal, and the location at the throat inlet produces a nonlinearity with increasing flow.

Deviations from the theoretical straight line were also noted in the low-flow portions of each curve. At 200°F a flow signal of 0.04 mv was measured at zero flow, and an error of similar magnitude appears to exist in the 400°F data, as indicated by extrapolation of the data to zero flow. No direct measurement was made, however. The deviations in the curves at 600 and 800°F started at flow rates of approximately 0.5 and 0.9 gpm, respectively, and were more pronounced, since the generated signal approached a nearly constant value at flow rates below approximately 0.5 gpm. Extrapolation of the curves to zero flow for 600 and 800°F operation indicated a zero offset of approximately 0.1 and 0.2 mv, respectively. Measurements of the generated signal at zero flow and temperatures of 400, 600, and 800°F could not be obtained because heat losses from the test pump caused a drift in both the test pump temperatures and the generated signal.

Investigation of Low-Flow Deviations. The possibility that the low-flow deviations were caused by temperature differences at the attachments of the two flowmeter leads to the pump lugs prompted the installation of thermocouples 5 and 6 at the locations shown in Fig. 2. Measurements showed a higher temperature at thermocouple 5 than at thermocouple 6, and thus a thermocouple effect did exist between the two signal leads. Measurements made while operating at 200, 400, and 800°F, as presented in Table 2, show for the worst case (800°F) that the temperature difference varied from 10°F at a flow rate of 1.27 gpm to 40°F when the flow was 0.24 gpm.

Attempts were then made to equilibrate the lug temperatures to determine the effect of the temperature difference on the generated signal. During each run, after steady-state conditions were obtained, the warmer lug was cooled with a stream of air until the temperature difference was approximately zero. Flow signal measurements showed that the temperature

Table 2. Effect of Temperature Differential On
SNAP-10A Pump Signal

Flow (gpm)	Pump Signal (mv)	TE-5 (°F)	TE-6 (°F)	ΔT (°F)	Pump Signal When $\Delta T \sim 0^\circ\text{F}$ (mv)	Δmv (°F)
200°F Test						
0.61	0.63	182	176	6	0.59	0.007
0.51	0.53	181	174	7	0.48	0.007
0.39	0.39	182	175	7	0.35	0.006
0.30	0.30	179	173	6	0.26	0.007
0.45	0.46	183	177	6	0.41	0.008
0.58	0.59	180	175	5	0.54	0.010
0.74	0.76	180	175	5	0.72	0.008
0.82	0.84	186	180	6	0.80	0.007
0	0.04	174	168	6	>0.01	0.005
400°F Test						
1.20	1.18	360	349	11	1.15	0.003
1.00	1.00	364	353	11	0.97	0.003
0.74	0.74	368	359	9	0.69	0.006
0.59	0.60	369	357	12	0.52	0.007
800°F Test						
1.27	1.21	737	727	10	1.15	0.006
1.02	1.00	737	727	10	0.95	0.005
0.80	0.83	741	730	11	0.76	0.006
0.57	0.75	740	721	19	0.61	0.007
0.24	0.66	719	679	40	0.40	0.007

equilibration produced changes ranging from 0.03 to 0.26 mv, as may be deduced from the data presented in Table 2.

The cooling of the warmer lug during 200 and 400°F operation had very little effect on the other temperatures around the test pump; however, at 800°F and flow rates of 0.24 and 0.57 gpm, the cooling air on the warmer lug caused cooling of other parts of the test pump, including the cooler lug and magnet. The configuration of the SNAP-10A pump would not permit installation of appropriate baffles to completely shield the pump from the cooling air streams; however, a temporary nonmagnetic shield was placed along the warmer lug, and a change was made in the flow direction of the cooling air in an effort to reduce the cooling

effect. The flow through the SNAP-10A pump was then set at 0.25 gpm with an inlet temperature of 800°F. At steady state the temperature difference between the two sides of the pump again reached 38 to 40°F, and the generated signal showed 0.67 mv. Cooling air was put on the warmer lug, and the temperature difference was reduced to approximately zero. The signal generated in the test pump then indicated between 0.43 and 0.45 mv. Despite the shield, air leakage again affected the temperature of the magnet and cooler lug, and it was difficult to maintain a near zero temperature difference between the two thermocouples. Cooling was continued, however, until the previously warmer lug was approximately 10°F cooler than the previously cooler lug, whose temperature was observed to decrease also. The indicated signal at this time was reduced to a value between 0.32 and 0.35 mv. This test further confirmed the temperature effect on the flow signal and demonstrated that an error in the opposite direction could be created by reversal of the temperature difference.

Tests of the thermocouple effect at 600°F and at higher flow rates were not undertaken because of the necessity of returning the SNAP-10A pump to the Tower Shielding Facility.

Estimated Corrected Calibration Curves. Based on a study of the data obtained at 200, 400, and 800°F, where the thermocouple effect had been eliminated, an average correction factor of 0.007 mv per °F variation from temperature equilibrium appeared to be reasonable for flow rates below 1.0 gpm. At flow rates of 1.0 to 1.27 gpm, an average correction factor of 0.004 mv per °F difference appeared to be more reasonable. This trend in the size of the correction factor may indicate that the thermocouple effect will be of little significance at even higher flow rates. These values of the correction factor were applied to the low flow range data, and the resulting flow signals for zero temperature difference at 200, 400, 600, and 800°F are presented in Figs. 7 through 10.

Application of these correction factors to the generated signals at the low end of the 200 and 400°F calibration curves gave a good check at zero flow. The correction factors, when applied to the low-flow 800°F data, improved the zero offset but did not completely correct

Fig. 7. Flow Signal for SNAP-10A Pump as Estimated for 200°F NaK and Zero Temperature Difference Between Flowmeter Leads.

Fig. 8. Flow Signal for SNAP-10A Pump as Estimated for 400°F NaK and Zero Temperature Difference Between Flowmeter Leads.

Fig. 9. Flow Signal for SNAP-10A Pump as Estimated for 600°F NaK and Zero Temperature Difference Between Flowmeter Leads.

Fig. 10. Flow Signal for SNAP-10A Pump as Estimated for 800°F NaK and Zero Temperature Difference Between Flowmeter Leads.

the curve distortion. However, based on the lower temperature data, where the thermocouple effect was eliminated, the curve was drawn through zero. Although data were not obtained for 600°F operation with a zero temperature differential between the lugs, the 400 and 800°F data indicated a differential in the order of 10°F. This value was then assumed, and the correction factors were applied to the low-flow calibration signals in an attempt to correct the distortion in the curve. As in the 800°F curve, the correction factors did not completely correct the curve distortion, and the curve was drawn through zero.

Conclusions

The SNAP-10A pump can be operated as a magnetic flowmeter over the flow range of 0.25 to 5.0 gpm at pump inlet temperatures between 200 and 800°F. The flow signal calibrations, as obtained with NaK in the flowmeter calibration test facility, are presented in Figs. 3 through 6.

When operated as a flowmeter, the output signal at low flow rates is appreciably affected by any temperature difference between the two points of attachment of the flowmeter leads to the pump lugs. Consequently, the pump installation should provide means to minimize this temperature difference. Thermocouples should also be installed near the leads to monitor the temperatures.

The flow-signal test data were modified by estimates of the effects of temperature difference between flowmeter electrodes. The estimated signals for zero temperature difference are presented in Figs. 7 through 10.

The signal leads could be relocated toward the outlet end of the SNAP-10A pump to obtain a more linear flow-signal relationship when the pump is operated as a flowmeter at flow rates above 3.5 gpm. The available calibration curves probably would not exactly represent this case.

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