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EXPERIMENTAL SYSTEM AND COMPONENT
PERFORMANCE ANALYSIS

Keith Peterman

October 1, 1984

Lawrence
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EXPERIMENTAL SYSTEM AND COMPONENT
PERFORMANCE ANALYSIS

BUILDING 169 FLOW LOOP

KEITH A. PETERMAN

OCTOBER 1, 1984

1412k

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1. Introduction

A prototype dye laser flow loop was constructed to flow test large power amplifiers in Building 169. The flow loop is designed to operate at supply pressures up to 900 psig and flow rates up to 250 GPM. During the initial startup of the flow loop experimental measurements were made to evaluate component and system performance. Three candidate dye flow loop pumps and three different pulsation dampeners were tested.

2. Flow Loop Description

The flow loop is described in detail on Drawing AAA84-103047, sheets 1 through 4. The various candidate components were tested in the configurations illustrated in Figure 2-1.

3. Test Objectives

Experimental measurements were made with the following objectives:

- To evaluate the performance of each candidate pump at three operating points. The candidate pumps are listed in Table 3-1.

Table 3-1

Candidate Dye Laser Flow Loop Pumps

Manufacturer	Model	Size	Serial No.
Sundstrand	Sundyne LMV 311		84116101
Goulds	3335	HDB-210-8	272B017
Ingersoll-Rand	HSP C5200		048443

- To measure pump discharge pressure pulsations.
- To evaluate the effectiveness of three pulsation dampeners. The dampeners tested are listed in Table 3-2.

Table 3-2

Candidate Pulsation Dampeners

Manufacturer	Serial No.
Hitco	None
Grand Steel (Zemarc)	2103
Fluid Kinetics	017

- To evaluate flow loop static pressurization stability.
- To evaluate the heat exchanger performance.
- To measure short term process temperature fluctuations.

4. Instrumentation

The flow loop was instrumented as shown in Figure 2-1. The transducers are summarized in Table 4-1.

Table 4-1

Transducer Summary

Measurement	Transducer
Process Pressure	Endevco Model 8510-500
Process Temperature	Thermometrics Thermister A133A-FP07DA102N
Process Flow Rate	Hoffer Turbine Meter Model HO 4x4-75-1250-B-1-MX-F6SS
Cooling Water Temperature	YSI #405 Thermister
Cooling Water Flow Rate	RCM Industries Flow Meter Model 2"-71-R-60

5. Experimental Results

5.1 Pump Performance

The candidate pumps were purchased to the following specification:

Total Differential Pressure:	475 psi
Maximum Discharge Pressure:	800 psi
Maximum Suction Pressure:	325 psi
Flow Rate:	110 GPM
Fluid:	Water

The experimental test points are plotted on each of the manufactures performance curves in Figures 5-1 through 5-3. The nominal suction pressure for these tests was 330 psig.

5.2 Pump Discharge Pressure Pulsations

• Sundstrand Sundyne LMV311

The Sundyne LMV311 is a high speed (11,344 RPM) centrifugal pump having an eight bladed impeller. This pump was initially operated without a pressure pulsation dampener installed in the loop. Pressure fluctuations sensed by each pressure transducer are shown for a typical run in Figures 5-4 through 5-10. Each plot presents pressure fluctuations recorded during the same 100 millisecond time interval. A comparison of the time shift in the wave form between adjacent transducers indicates that the primary wave is traveling away from the pump at sonic velocity (approx. 4800 ft/sec in water). The signal, however, is a composite of two principal noise sources; the pump and the throttling valve, 8P3. Disturbances created at the throttling valve travel both upstream and downstream toward the pump and it is difficult to separate the two signals. However, it was observed that the sporadic intensification of the measured pressure fluctuations correlated with the audible valve noise leading one to attribute these disturbances to the valve. These suspected valve disturbances are identified in the 10 second time plots shown in Figures 5-11 and 5-12. Notice that there is no significant attention of the dominant signal between P1 and P5, a distance of 16.5 feet.

Sundstrand Fluid Handling

EST 8441 AVENUE, P.O. BOX 174, ARVADA, COLORADO 80004
Unit of Sundstrand Corporation

PREDICTED PUMP PERFORMANCE CURVE. THE CURVE IS
DRAWN BY COMPUTER AND MAY REFLECT MINOR CURVE
FITTING IRREGULARITIES.

TOTAL DEVELOPED HEAD, FEET

1250

1000

750

500

250

0

FIGURE 5-1.

Experimental pump performance
Sundstrand Sundyne LMV311
Suction Pressure = 330 PSIG

CAPACITY GPM

NPSH

HEAD

EFF

BHP

100

0

NPSH, (H₂O), FEET

EFFICIENCY, %

75

50

25

0

POWER HP

100

0

ITEM NO. 84116101

SERIAL NO.

QUOTE NO. 84116101

REV. NO. 0.

CUSTOMER UNIVERSITY OF CALIFORNIA LLNL

PUMP MODEL LMV-311 RPM 11345 DATE 04/06/84 BY M. Pardo

SP. GR. 1.0000

VISC. = 1.0000 CP

June 1981

DATE 11-16-81

REV. DATE

GOULDS PUMPS, INC.
 MILWAUKEE, WISCONSIN 53142-05

CENTRIFUGAL PUMP CHARACTERISTICS

RPM 3550

CDS 2996

MODEL 3335

SIZE HDB210

IMP. DWG. 110-12-24 & 113-22-02

PATTERN 57155 & 57153

EYE AREA 7.07 in²

MAX. DIA. = 6 7/8 IN.

FIGURE 5-2.

 Experimental pump performance
 Goulds Model 3335
 Suction Pressure = 330 PSIG

CERTIFIED PERFORMANCE DATA

 GOULDS PUMPS, INC.
 MILWAUKEE, WISCONSIN 53142-05
 Dated 11/16/81

 SIGNED: *Barbara J. Reed*
 11/16/81

 GOULDS SER. NO. 2728017
 CUSTOMER UNIVERSITY OF CALIFORNIA
 P.O. NO. 51142-05
 ITEM NO. _____
 SERVICE _____

PROCESS EQUIPMENT / LLNL

Ingersoll-Rand

REF PE-030184

R/V 1

A-03.-14

WATER

CAPACITY: 110.0 gpm EFF: 55.9 %

C5200 - 36- 1-600-12932- 1-3800

TOTAL HEAD: 1100.0 ft

R/H: 12931

14- 698- 90- 1- 18-V -C 11

55bhp SG: 1.00 TEMP: 60 fvp: 1 psi

GS-1-1-1-1

PUMP: HSP - C5200

DRIVER: 75 HP 1.0SF

RPM: 3800

9863.61

50

100

150

CAPACITY

POWER

- 8 -

NPSH

TEST NUMBER: FLT-1C-R2 (1F-R2)

CHAN 3

CE TIME : 07/10/84S

SA RATE : 1

1.6619

UOB/13/84

23:53:12

NOZAMS : 3

22:31:38

LD FREQ : 0.092891 HZ

66690

H1 FREQ : 3100 HZ

1.612E-04

FIGURE 5-4. Discharge pressure fluctuations at P1

Sandstrand Sandyne EMV 311; Flow Rate = 110 GPM;
Suction Pressure = 330 PSIG

TEST NUMBER: FLT-1C-R2 (1F-R2)

CHAN 7

CE TIME : 07/10/84S

SA RATE : 1

LE619

008/13/84

22:45:19

23:53:12

NOVARS : 3

66590

LO FREQ : 0.092991 HZ

1.612E-04

HI FREQ : 3100 HZ

FIGURE 5-5. Discharge pressure pulsations at P3A
Sundstrand Sundyne LMV 31I, Flow Rate = 110 GPM,
Suction Pressure = 330 PSIG

TEST NUMBER: FLT-1C-R2 (1F-R2)

CHAN 9

LC619
008/13/84
22:54:59
56690
1.612E-04

CE TIME : 07/10/84S

SA RATE : 1

23:53:12

NOHANS : 3

LD FREQ : 0.092891 HZ

HI FREQ : 3100 HZ

FIGURE 5-6. Discharge pressure fluctuations at P3B.

----- Sundstrand Sundyne LMV 311; Flow Rate = 110 GPM
Suction Pressure = 330 PSIG

TEST NUMBER: FLT-1C-R2 (1F-R2)

CHAN 11

CE TIME : 07/10/84S

SA RATE : 1

LC620

U08/13/84

19:34:12

66690

1.512E-04

23:53:12

NOCHAN : 3

LD FREQ : 0.092391 HZ

HI FREQ : 3100 HZ

FIGURE 5-7. Discharge pressure pulsations at P3C
Sundstrand Sundyne LMV 311, Flow Rate = 110 GPM
Suction Pressure = 330 PSIG

TEST NUMBER: FLT-1C-R2 (1F-R2)

CHAN 13

LE820

068/13/84

19:34:17

86690

1.612E-04

CE TIME : 07/10/84S

SA RATE : 1

23:53:12

NOCHANS : 3

LO FREQ : 0.092891 HZ

HI FREQ : 3100 HZ

FIGURE 5-8. Discharge pressure fluctuations at P4
Sundstrand Sundyne LMV 311, Flow Rate = 110 GPM
Suction Pressure = 330 PSIG

TEST NUMBER: FLT-1C-R2 (1F-R2)

CHAN 15

CE TIME : 07/10/84S

SA RATE : 1

CE620

008/13/84

19:38:19

66690

1.612E-04

LO FREQ : 0.092891 HZ

NOIANS : 3

HI FREQ : 3100 HZ

FIGURE 5-9. Discharge pressure fluctuations at P5
Sundstrand Sundyne LMV 311, Flow Rate = 110 GPM,
Suction Pressure = 330 PSIG.

TEST NUMBER: FLT-1C-R2 (1F-R2)

CHAN 17

CE TIME : 07/10/84S

SA RATE : 1

LE820

23:53:12

HOMANS : 3

U08/13/84

LO FREQ : 0.092991 HZ

19:43:48

HI FREQ : 3100 HZ

66690

1.612E-04

FIGURE 5-10. Pressure fluctuations at P6
Sundstrand Sundyne LMV 311, Flow Rate = 110 GPM
Suction Pressure = -330 PSIG

TEST NUMBER: FLT-1C-R2 (1F-R2)

CHAN 3

LES19

R08/12/84

21:57:03

5130

2.095E-03

CE TIME : 07/10/84S

SA RATE : 13

23:53:12

NOVANS : 3

LO FREQ : 0.092391 HZ

HI FREQ : 236 HZ

FIGURE 5-11. Pump discharge pressure fluctuations combined with throttle valve disturbances. Sundyne LMV 311
Flow Rate = 110 GPM, Suction Pressure = 330 PSIG

TEST NUMBER: FLT-1C-R2 (1F-R2)

CHAN 15

CE TIME : 07/10/84S

SA RATE : 13

LE820

ROB/12/84

23:53:12

NOCHAN : 3

23:00:29

5130

LO FREQ : 0.092991 HZ

HI FREQ : 238 HZ

2.096E-03

FIGURE 5-12. Pressure fluctuations at P5, 16.5 feet downstream from P1. Sundstrand Sundyne LMV 311, Flow Rate = 110 GPM
Suction Pressure = 330 PSIG

The frequency content (0-2000 Hz) of the pressure fluctuations is shown in the Power Spectral Density (PSD) plot, Figure 5-13. The PSD plot was derived from data recorded over a 10 second time interval. Although present, the impeller shaft speed, 189 Hz, and the impeller vane passing frequency, 1510 Hz, are not dominant. The dominant amplitudes occur at 40 Hz and 130 Hz.

The peak composite pressure fluctuations measured in the loop were less than ± 10 psi at 110 GPM flow rate.

- Goulds Model 3335

The Goulds Model 3335 is an eight stage canned centrifugal pump rotating at 3550 RPM. The discharge pressure fluctuations measured at P1 are plotted in Figure 5-14. The peak composite pressure fluctuations measured at 110 GPM are about ± 6 psi. Because the pump pressure fluctuations are smaller than those produced by the Sundyne LMV311, the disturbances created by the throttling valve are clearly visible in the 10 second time plot. If the valve disturbances were eliminated, the pump fluctuations would be expected to be about ± 2 psi.

The PSD plot for P1 is shown in Figure 5-15. Significant pulsation frequencies are present between zero and 200 Hz with dominant amplitudes at 6 Hz and 39 Hz.

- Ingersoll-Rand HSP C5200

The Ingersoll-Rand HSP C5200 is a high speed (12, 931 RPM) centrifugal pump having a four bladed impeller. Pressure fluctuations measured at P2 are shown in Figure 5-16. The peak pressure fluctuations measured at 110 GPM are about ± 9 psi. Actual pump fluctuations appear to be about ± 4 psi.

The PSD for the discharge pressure fluctuations are shown in Figure 5-17. The dominant frequency is 860 Hz, the impeller vane passing frequency.

5.3 Pulsation Damper Performance

The pressure pulsation dampeners were evaluated using the Sundstrand Sundyne LMV311 pump. The dampeners were installed in the supply line between P1 and P3A as illustrated in Figure 2-1 and were evaluated at the following operating conditions:

TEST NUMBER: FLT-1C-R2 (1F-R2)

CHAN 3

 LE819
 R09/CS/84
 02:44:35
 86690
 1.508E-04

B = 4.98

T = 10.00

DOF = 98.

ERROR(95%CONF) = 28.6

AUTOSPECTRAL DENSITY IN UNITS SQUARED / HERTZ, P1 (EXPAN)

FIGURE 5-13. Power Spectral Density, P1, Sundstrand
 Sundyne LMV 311, Flow Rate = 110 GPM,
 Suction Pressure = 330 PSIG

FIGURE 5-14. Discharge pressure fluctuations. Goulds Model 3335, Flow Rate = 110 GPM
Suction Pressure = 330 PSIG.

TEST NUMBER: FLT-8C-R2 (8F-R2)

CHAN 3

FJ502
R09/16/84
23:27:25
86690
1.500E-04

B = 4.68
T = 10.00
DOF = 98
ERROR(95%CONF) = 28.6

AUTOSPECTRAL DENSITY IN UNITS SQUARED / HERTZ, P1 (EXPAN

FIGURE 5-15. Power Spectral Density, P1. Goulds Model 3335,
Flow Rate = 110 GPM, Suction Pressure = 330 PSIG

FIGURE 5-16. Pump discharge pressure fluctuations. Ingersoll-Rand HSP C5200,
 Flow Rate = 110 GPM; Suction Pressure = 330 PSIG

AUTOSPECTRAL DENSITY IN UNITS SQUARED / HERTZ. P1 (EXPAN

TEST NUMBER: FLT-6C-R2 (6F-R2)

CHAN 3

FJ502
R09/05/84
23:30:12
66690
1.500E-04

B = 4.68
T = 10.00
DOF = 98
ERROR(95%CONF) = 28.6

FIGURE 5-17. Power Spectral Density, P1. Ingersoll-Rand HSP C5200,
Flow Rate = 110 GPM, Suction Pressure = 330 PSIG

Discharge Pressure: 805 psig
Suction Pressure: 330 psig
Flow Rate: 110 GPM

PSD's for P1 and P3A pressure fluctuations without a dampener installed are shown in Figure 5-18 for reference purposes. The high frequencies are significantly attenuated between P1 and P3A, a distance of 14.6 feet. The amplitude ratio at 1510 Hz is determined by Equation (5.3-1).

$$\left[\frac{\delta P_{3A}}{\delta P_1} \right]_f = \left[\frac{PSD_{3A}}{PSD_1} \right]_f^{1/2} \quad (5.3-1)$$

$$\left[\frac{\delta P_{3A}}{\delta P_1} \right]_{1510} = \left[\frac{0.014}{0.021} \right]_{1510}^{1/2} = 0.82$$

Between P1 and P3A the 1510 Hz amplitude has decreased 18 percent.

- HITCO

The HITCO pressure reducer consists of a short pipe spool filled with stainless steel spheres. PSD's for P1 and P3A with the HITCO pressure reducer installed are shown in Figure 5-19. The device was found to dampen frequencies above 200 Hz. Quantitatively, the amplitude at 1510 Hz was reduced 67 percent between P1 and P3A. The pressure drop across the device at 110 GPM was 50 psi.

- Grano Steel

The Grano Steel dampener was specifically designed to dampen pulsations in ethanol at frequencies between 500 Hz and 2000 Hz. The PSD's at P1 and P3A for water are shown in Figure 5-20. For all practical purposes, the dampener effectively eliminates all pulsations between 400 Hz and 2000 Hz. The effectiveness of the dampener is demonstrated by the reduction in amplitude of the 860 Hz pulsation generated by the Ingersoll-Rand HSP C5200 pumping 80 GPM, Figure 5-21. The calculated reduction in amplitude between P1 and P3A is 93 percent. The pressure fluctuation - time plots are shown in Figure 5-22 to further illustrate the effectiveness of the dampener.

AUTOSPECTRAL DENSITY IN UNITS SQUARED / HERTZ, P1 (EXPA

TEST NUMBER: FLT-20-R2

CHAN 3

10/18
00:53:51
00:53:51
00:53:51
1.500E+04

0.1 4.00
1.10 00
0.0 10
FROM (1112347) = 10.0

FREQUENCY IN HERTZ

AUTOSPECTRAL DENSITY IN UNITS SQUARED / HERTZ, P3A (EXPA

TEST NUMBER: FLT-20-R2

CHAN 7

10/18
00:53:51
00:53:51
00:53:51
1.500E+04

0.1 4.00
1.10 00
0.0 10
FROM (1112347) = 10.0

FREQUENCY IN HERTZ

FIGURE 5-19. Power Spectral Densities at P1 and P3A with the HITCO pressure reducer installed. Sundstrand Sundyne LMV 311, Flow Rate = 110 GPM, Suction Pressure = 330 PSIG

AUTOSPECTRAL DENSITY IN UNITS SQUARED / HERTZ, P1 (EXPA

TEST NUMBER: FTU-3D-R2

CHAN 3

LEN18
00 37 30
00 37 30
00 37 30
1 3000-04

AUTOSPECTRAL DENSITY IN UNITS SQUARED / HERTZ, P3A (EXPA

TEST NUMBER: FTU-3D-R2

CHAN 7

LEN18
00 37 30
00 37 30
00 37 30
1 3000-04

FIGURE 5-20. Power Spectral Densities at P1 and P3A with the Grano Steel pulsation dampener installed. Sundstrand Sundyne LMV 311, Flow Rate = 110 GPM, Suction Pressure = 330 PSIG

FIGURE 5-22. Upstream, P1, and downstream, P3A, pressure-time plots for the Grano Steel pulsation dampener. Ingersoll-Rand HSP C5200, Flow Rate = 80 GPM, Suction Pressure = 330 PSI (C).

- Fluid Kinetics

The Fluid Kinetics dampener, like the Grano Steel dampener, was designed for use with ethanol and was designed to be effective above 500 Hz. Figure 5-23 shows the PSD's for P1 and P3A. Notice that the presence of the dampener alters the frequency spectrum upstream of the dampener at P1 compared to the spectrum without a dampener, Figure 5-18. The dampener effectively eliminates all frequencies above 300 Hz.

- Dampened Discharge Pressure Comparisons

The Goulds and Ingersoll-Rand pumps were tested with the Grano Steel dampener installed in the flow loop. The pressure fluctuations down stream from the dampener are compared for the three test pumps in Figure 5-24 and 5-25. The PSD's are shown with fixed scales for easy comparison in Figure 5-24. Since the dampener effectively removes all frequencies above 400 Hz, the PSD's are scaled from zero to 400 Hz. The corresponding time plots are shown in Figure 5-25. The Ingersoll-Rand HSP C5200 pressure pulsations are comparable to those generated by the Goulds Model 3335 after filtering out the dominant 860 Hz discharge pressure pulsations. The Ingersoll-Rand pump is sensitive to pressure disturbances caused by the throttling valve which produce an intense 3-5 Hz peak in the PSD. In all cases, the 3-10 Hz peaks present in the PSD's are attributed to throttle valve disturbances.

5.4 Static Pressure Stability

A four-hour run was made to study the stability of the flow loop pressurization system. The flow loop is pressurized by applying gas pressure to a reservoir containing a metal bellows that separates the gas from the liquid as illustrated in Figure 5-26. The gas source is a 2000 psig nitrogen cylinder equipped with a standard industrial pressure regulator.

The results of the run are plotted in Figure 5-27. The suction pressure, P_g , was observed to increase to 332 psi followed by a slow decay to 327 psig which is near the set point pressure. During the last 45 minutes of the test, the pressure began falling and had decrease to 316 psig at the end of the test period. This was not the expected behavior. One would expect the pressure to increase with an increase in water and nitrogen temperature, since the regulator is non-relieving, and remain at an elevated

AUTOSPECTRAL DENSITY IN UNITS SQUARED / HERTZ, P1 (EXPAN)

TEST NUMBER: FLT-4D-R2

CHAN 3

 10/19
 09/25/84
 01:11:17
 10000
 1 3001-04

FREQUENCY IN HERTZ

AUTOSPECTRAL DENSITY IN UNITS SQUARED / HERTZ, P3A (LYPA)

TEST NUMBER: FLT-4D-R2

CHAN 7

 10/19
 09/25/84
 01:04:25
 10000
 1 3001-04

FREQUENCY IN HERTZ

FIGURE 5-23. Power Spectral Densities at P1 and P3A with the Fluid Kinetics pulsation dampener installed. Sundstrand Sundyne LMV 311, Flow Rate = 110 GPM, Suction Pressure = 330 PSIG

Syndyne LMV 311

Gould's Model 3335

I-R HSP C5200

Figure 5-25. Comparison of pressure fluctuations for the three test pumps downstream from the Grano Steel pulsation dampener. Flow Rate = 110 GPM, Suction Pressure = 330 PSIG

FIGURE 5-26. Building 169 flow loop plan view and gas pressurization system diagram.

FIGURE 5-27. Suction pressure stability test results
Sundstrand Sundyne LMV 311

pressure until the temperature decreased. If the temperature were decreased below the initial pressurization temperature, the pressure would remain near the set-point since the regulator would open and allow gas to flow into the reservoir from the supply cylinder. The observed behavior indicates the presence of a gas leak and that perhaps the nitrogen cylinder valve was turned off.

5.5 Heat Exchange Performance

The heat exchanger was designed by the Alaskan Copper Works to have the following counter flow performance characteristics with water.

Total Heat Load (Btu/Hr)		204,184
Overall Heat Transfer Coef. (Btu/Hr.-Ft ² -°F)		
(Req'd), (Clean), (Actual)	298.62/485.59/314.34	
Effective Surface Area (Ft ²)		32.7
	<u>Cold Shellside</u>	<u>Hot Tubeside</u>
Flow Rate (GPM)	40	170
Temperature, In/Out (°F)	45.0/55.2	72.4/70.0

Although the heat exchanger was designed for counter flow, the heat exchanger was installed and plumbed in the Building 169 flow loop for parallel flow. This configuration resulted from an error on the assembly drawing and it was decided not to reverse the cooling water flow direction. The actual performance data is tabulated on the data sheet, Figure 5-28.

The overall performance of the heat exchanger is evaluated using the following equations.

$$q = \dot{m} c_p \Delta T \quad (5.5-1)$$

where q = total heat transferred (Btu/Hr.)

$\dot{m}$ = mass flow rate (lb_m/Hr)

c_p = specific heat (Btu/lb_m - °F)

ΔT = inlet/outlet temperature difference, (°F)

$$U = \frac{q}{A \Delta T} \quad (5.5-2)$$

HEAT EXCHANGER DATA SHEET

MANUFACTURER ALASKAN COPPER

CONSTRUCTION SHELL/TUBE - SINGLE PASS

FLUID: SHELL SIDE WATER (LCW) TUBE SIDE WATER (PROCESS)

DATE	RUN	SHELL SIDE			TUBE SIDE				
		FLOW-RATE (GPM)	TEMPERATURE (°F)		FLOW-RATE (GPM)	TEMPERATURE (°F)			
			INLET	OUTLET		INLET		OUTLET	
			T _{C1}	T _{C2}		T ₁	T ₂	T ₃	T ₄
7/25/84	1	35	69	75.5	80	85.4	85.4	82.5	82.5
7/25/84	2	35	68.5	75.8	110	85.4	85.6	83.1	83.1
7/25/84	3	35	69.5	76.5	130	86.1	86.2	83.9	83.9

REMARKS:

PARALLEL FLOW

FIGURE 5-28. Heat exchanger experimental data

where

U = overall heat transfer coefficient (Btu/Ft² - Hr - °F)

A = effective heat exchanger surface area (Ft²)

$\overline{\Delta T}$ = logarithmic mean over-all temperature difference (LMTD) (°F)

$$\overline{\Delta T} = \frac{\Delta T_a - \Delta T_b}{\ln \left(\frac{\Delta T_a}{\Delta T_b} \right)} \quad (\text{See Figure 5-29}) \quad 5.5-3)$$

Using the experimental data from Figure 5-28, the over-all performance data are tabulated in Table 5.5-1.

TABLE 5.5-1

Parallel Flow Heat Exchanger Performance Data

Run	Process Flow Rate (GPM)	$\overline{\Delta T}$ (°F)	q (Btu/Hr) / (HP)	U Btu/Hr-Ft ² -°F
1	80	11.0	115,884 / 45.5	321
2	110	11.5	137,425 / 54	365
3	130	11.8	149,350 / 58.6	387

5.6 Process Temperature Fluctuations

Water temperature measurements were made using fastip thermoprobes which have a time constant of seven milliseconds in water. Typical recorded temperatures are plotted in Figures 5-30 through 5-33. This data was filtered to 100 Hz and most of what you see is data acquisition system noise and not actual temperature fluctuations. The sensitivity of the thermistors is not high enough to obtain a high signal to noise ratio using magnetic tape. The low frequencies, 1 to 10 Hz, may represent actual temperature changes. It can be concluded, however, that the short term temperature fluctuations are small since the recorded variation, noise included, does not exceed 0.035°C in any of the plots.

FIGURE 5-29. Temperature distribution in single-pass parallel-flow heat exchanger.

TEST NUMBER: FLT-1C-R2 (1F-R2)

CHAN 19

LE620
SD9/04/84
23:32:35
3375
3.225E-04

CE TIME : 07/10/84S

SA RATE : 2

23:53:12

NOHANS : 3

LD FREQ : 0.018748 HZ

HI FREQ : 1550 HZ

FIGURE 5-30. Typical T1 temperature plot. Sunstrand Sundyne LMV 311,
Flow Rate = 110 GPM, Suction Pressure = 330 PSIG

TEST NUMBER: FLT-1C-R2 (1F-R2)

CHAN 21

LEG21
R09/05/84
01:11:03
3375
3.225E-04

CE TIME : 07/10/84S

SA RATE : 2

23:53:12

NOVANS : 3

LD FREQ : 0.918748 HZ

HI FREQ : 1550 HZ

FIGURE 5-31. Typical T2 temperature plot. Sundstrand Sundyne LMV 311,
Flow Rate = 110 GPM, Suction Pressure = 330 PSIG

TEST NUMBER: FLT-1C-R2 (1F-R2)

CHAN 23

CE TIME : 07/10/84

SA RATE : 2

LEB21

R09/05/84

23:53:12

NOHWS : 3

01:21:33

3375

LO FREQ : 0.918748 HZ

HI FREQ : 1550 HZ

3.225E-04

FIGURE 5-32. Typical T3 temperature plot. Sundstrand Sundyne LMV 311,
Flow Rate = 110 GPM, Suction Pressure = 330 PSIG

TEST NUMBER: FLT-1C-R2 (1F-R2)

CHAN 25

CE TIME : 07/10/84S

SA RATE : 2

LE621

23:53:12

NOHANS : 3

R09/05/84

01:21:58

3375

LO FREQ : 0.818748 HZ

HI FREQ : 1550 HZ

5.225E-04

FIGURE 5-33. Typical T4 temperature plot. Sundstrand Sundyne LMV 311,
Flow Rate = 110 GPM, Suction Pressure = 330 PSIG

5.6 Conclusions

The following conclusions are based on the experimental measurements and observations:

- Each test pump performed as specified in the purchase orders.
- The Goulds Model 3335 produced the smallest discharge pressure fluctuation of the three pumps tested, about ± 2 psi.
- The HITCO pressure reducer is not an efficient pulsation dampener.
- The Fluid Kinetics and the Grano Steel pulsation dampeners are efficient at frequencies above 300 Hz and 400 Hz respectively. The Grano Steel dampener reduced the amplitude of the 860 Hz I-R HSP C5200 discharge pulsations by 93 percent.
- The heat exchanger performs well with parallel flow.
- The system pressurization stability requires more evaluation. A twenty-four hour test is recommended.
- Short term process temperature fluctuations are less than 0.05°C.
- The globe valve used to throttle the test pumps contributed adversely to the system pressure fluctuations. Entrapped air may also have been a factor.