Energy-Related Inventions Program ERIP 704
An Efficient Compressor Valve

Final Technical Report

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Project Aim: To develop and test the new compressor valve and design a full line of valves for use by the natural gas industry.

Technical Objectives: To follow up initial testing with high-quality test data to confirm original results. To determine reliability of new valve.

Task Statement: Briefly, the tasks included independent testing, design of a complete family of the new valves, develop a marketing package for them and issue appropriate reports.

Independent Test:

Test Setup:

Southwest Research Institute (SWRI) conducted formal tests of the valve during the last quarter of 1998. Testing was conducted on a motor driven, single cylinder compressor which was operated in a closed flow loop located in their lab. The compressor, manufactured by Ariel Corporation, is one commonly used for compressing natural gas. For reasons of safety and economy, air was selected as the working fluid. A complete instrumentation system providing accurate measurements of pressures, flows temperatures and power consumption was in place. In addition, dynamic pressure data, suitable for display in the P-T and P-V format, was recorded. The positive displacement flow meter was defective and its readings had to be ignored.

A standard suction and discharge valve for this compressor were loaned to the inventor and a set of comparable valves of the new design were made.

Initial testing was done over a square matrix of operating conditions consisting of three speeds 600, 900 and 1200 RPM and three loading conditions. Baseline performance, using the conventional valves specified by the manufacturer was measured over the matrix. The test series was then repeated with the new valves in place. Pressures of 30 to 45 psig, suction and 55 to 75 psig were present during both series. Data was collected from a total of eighteen runs during the initial series. A second abbreviated test series of twelve runs was conducted after some modifications were made to the new valve.

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Test, Series 1:

The thermodynamic efficiency measured during eighteen runs averaged only 46 percent with a high was 69% and a low of 44%. The corresponding system efficiency numbers, based on work done on the gas versus electrical power consumed were 21, 18 and 41%. Although the new valve showed an efficiency advantage of 0 to 3%, this was considered too small of an advantage to be meaningful. Performance this poor would, by a large margin, not be considered commercially acceptable to the natural gas industry.

Observations:

The cylinder pressures, throughout the discharge event, were much higher than the corresponding manifold pressures with both valve types. A much lower pressure differential was expected with the new valve if they were operating as predicted. That characteristic had been the prime source of the efficiency gain during earlier prototype testing of the new design.

Southwest Research personnel conducted a visual inspection of the compressor cylinder and associated piping to see if a restriction was present. Paralleling this search, the manufacturer and the inventor made a comprehensive review of the cylinder drawings looking for the problem. In addition, a plaster casting was made of the flow port and valve to confirm that the actual geometry of the cylinder conformed to the drawings. No significant restriction was found.

It became apparent that the restricted flow path was located in the valve but its location was unknown. One possible source of the problem was that an error had been made in selecting the rate and pre-load of the coil springs in the new test valves. To check this possibility, the springs of new valves were shortened such that they did not contact the valve plates until the plates reached half of their full lift. It was realized that this modification would likely retard the closing of the valves but this effect could be accounted for when analyzing the P-V cards.

Test, Series 2:

A second series of comparative tests was run with the modified valve springs. This series was conducted over the three speeds but at two loads, the lowest and the highest. Little change was detected during this second series. Again, the new valves showed slight improvement but, due to the gross performance, it was considered insignificant. The effects of delayed closing were barely detectable on the P-V cards. The high pressure differential during the discharge event remained.

Analysis, Both Test Series:

It is rare that such a large block of consistent data on one compressor becomes available. It permitted a wide ranging study of the machine characteristics. Many of the approaches proved fruitless but one seems very promising. Unfortunately, the findings suggest that the efficient valve currently under consideration has serious limitations.

Two points, one early and the other late in the discharge event of each data set, were arbitrarily selected. The cylinder pressure and the cylinder to manifold pressure differential were measured at each point. Next, the piston displacement rate for each of the points at each speed was calculated to determine the effective flow rate producing the pressure drop. These numbers were put into the simple orifice equation which was then solved for area. The apparent flow areas calculated for the sixty points of the first data set were essentially identical. This was surprising considering that a two to one change in speed and a greater than two to one ratio of flows existed among the various data sets.

Because the valve was earlier identified as the most likely location of the flow restriction, the predicted area was transformed into equivalent valve lift. In all sixty data points, the predicted valve lift was approximately 0.018 inches. This is less than twenty percent of the full lift of the plates. At least on the new valves, such a result seemed unlikely.

The simple valve plate force balance model had been used when designing the valves. It predicted that the plates would lift fully under conditions of the test points. It followed that the simple valve plate force model was in error.

The simple model takes into account the plate mass, valve spring force, pressure differential and the velocity head of the fluid approaching the plate. It ignored the Bernoulli effect of the flow moving parallel to the upstream face of the plate. This effect was added to the simple model to see if it would resolve the restricted plate lift problem. The amended model was then set into a spreadsheet program and it was solved for plate force at various plate lifts. The revised model was run, using air as the flowing fluid, over a range of flow rates and pressures similar to those of the test points. When the calculated plate force versus lift was plotted, an inflection was found in the 0.016 to .020 inch lift range. At lifts below the inflection, a force tending to lift the plate existed. When lift was above the inflection, a force in the closing direction was present. A potential well exists in the plate motion relationship and the plate should settle near it during flow.

These results agreed sufficiently with the apparent lift of the test data to warrant further study. When natural gas (specific gravity 0.64) was substituted in the modified force balance model, a lifting force was found at all lift heights. This likely explains the large efficiency improvement measured during the earlier prototype testing which was conducted with natural gas at low pressures. It also indicates that the density of the working fluid has a strong effect on valve lift and therefore, compressor efficiency.

As pressures increase, the density of the working fluid increases. It follows that while the new valve can be very efficient pumping natural gas at low pressures, it will lose its advantage at moderate and higher pressures.

Comments:

Ariel, the manufacturer of the test compressor provided the inventor with predicted operating data for some of the test conditions. The thermal efficiency calculated from that data was similar to that measured. Apparently, the compressor does meet the commercially acceptable efficiency levels expected for air compressors.

Other than the absence of the Belleville springs, the geometry and flow paths of conventional valves were similar to that of the new valve. They are thus they are similarly subject to the flow restriction caused by the Bernoulli effect. This was confirmed when the Bernoulli effect was included in a force balance analysis of the valves used in the comparative tests.

Results of other tests:

Two additional tests, one by National Fuel Gas (NFG) and the other by Cooper, were conducted during the grant period. Arrangements for these were made earlier and no ERIP funds were involved in the design and manufacture of valves or in the conduct of the tests.

Natural gas was the working fluid in both cases. Valve operation while at lower pressures (charge density) appeared as predicted. During the NFG run, over fifty million operating cycles were successfully completed. In both cases, when the pressure was increased to the level where the Bernoulli effect on plate lift predominated, the valves failed immediately. Inspection of both valve sets revealed damage consistent with extreme instability during lift. One plate in each of the Cooper valves had fractured and the plate-to-seat contact surfaces of the remaining Cooper plates and the NFG plates were heavily peened and the edges were rolled over.

It appears that the new valves are not only inefficient with high density gas but also prone to rapid deterioration and destruction.

Conclusions:

1. The new valve produced negligible efficiency gains during both test series conducted with higher density gases.
2. With current valve technology, gas density has a strong effect on the pressure difference across the valve during the flow event. Poor compressor efficiency is produced.
3. The efficiency advantage of the new valve is lost at higher pressures (gas density).
4. At high gas densities, the plates of the new valve become unstable during operation and rapid failure can follow.
5. The new understanding of the gas density effect on compressor efficiency should prompt additional study.
6. A radical change to valve design which reduces or eliminates the Bernoulli effect, is required if a generally efficient valve is to be developed.
7. Development of a radically new valve is beyond the scope of the grant. Work on ERIP 704 is therefore terminated.

Attachments:

One copy of the test data supplied by Southwest Research Institute is attached.

SOUTHWEST RESEARCH INSTITUTE

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DATE: October 23, 1998

TO: Compression Dynamics
20029 South Center Street
Corry, PA 16407

ATTN: Norbert Overfield

FAX: 205-325-3865

FROM: R.E. Harris / C.E. Edlund / C.R. Machado
Field and Engineering Services
Mechanical & Fluids Engineering DivisionSUBJECT: Valve Performance Analysis Data
SwRI Project No. 04-2040-064

Please find attached a brief data summary from the valve tests. We have compiled the major performance parameters into charts for your review. Appendix 1 contains the data for the baseline Ariel valves. Appendix 2 contains the summary of key parameters for this data. Appendices 3 and 4 contain the corresponding data for your valves. At this time, we are able to notice only a minimal improvement in performance with your valves. It may be prudent to run the tests with CO₂ to increase gas dynamic effects, mass flow valve, etc. in order to amplify any differences.

If you have any questions, please call Ralph E. Harris at (210) 522-2689, Carl E. Edlund at (210) 522-2550 or Cory R. Machado at (210) 522-2555.

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Appendix 1

Baseline Data for Ariel Valves

Compression Dynamics

SwRI Project 04-2040-064

COMPRESSION DYNAMICS VALVE DATA																													
RPM	VALVE POS.	TOT. HP	FLOW (MMSCFD) ROOTS METER	FLOW (MMSCFD) CARD INDICATED	PPM/MSCF	TOTAL DP	VOLTAGE	CURRENT	HP (ELEC.)	FLOW PRES.	BP	RATIO	MMSCFD	%DEV	HEAD %DEV	%DOP	TOT. HOIP CYL. EFF. %	BP	RATIO	MMSCFD	%DEV	%DEV	%DOP	TOT. COMP CYL. EFF. %					
1200 00	1 00	32 66	0 85	0 97	13.16	38 24	25 81	447 80	89 80	53 00	39 00	16 56	1 68	0 47	86 37	58 84	16 55	10 82	27 37	73 73	16 10	1 68	0 50	87 30	59 70	12 94	11 27	24 21	76 43
900 00	1 00	17 84	0 72	0 80	12.84	24 87	16 86	371 70	72 75	36 25	43 30	9 02	1 48	0 40	88 12	64 16	7 16	10 98	18 14	85 73	8 80	1 50	0 40	89 50	64 01	9 40	6 14	15 54	87 03
600 00	1 00	7 79	0 55	0 61	7.79	14 28	18 32	252 14	51 32	17 35	46 40	3 95	1 26	0 31	93 08	77 13	7 40	8 91	16 37	86 13	3 80	1 24	0 30	93 50	76 84	10 75	9 55	20 30	83 01
1200 00	2 00	32 45	0 95	1 03	15.84	34 01	27 23	448 40	89 25	53 05	44 00	16 57	1 56	0 53	88 12	64 16	17 78	11 87	29 65	70 72	15 90	1 59	0 50	88 70	62 78	13 18	11 52	24 70	75 86
900 00	2 00	17 94	0 81	0 83	11.59	22 13	21 05	376 95	77 38	39 10	47 05	9 05	1 40	0 43	89 77	68 71	8 51	12 67	21 18	81 18	8 90	1 40	0 40	91 80	60 42	12 66	10 07	22 73	79 98
600 00	2 00	6 84	0 58	0 63	5.34	11 70	25 19	250 44	51 67	17 35	40 40	3 46	1 19	0 33	94 37	80 48	10 76	13 41	24 17	78 83	3 40	1 18	0 30	94 90	81 58	15 27	10 05	26 22	76 57
1200 00	3 00	34 71	0 91	1 00	17.43	38 08	26 50	448 17	87 53	52 58	43 33	17 03	1 66	0 50	85 91	58 84	17 00	10 92	27 08	73 18	17 10	1 67	0 50	87 30	59 70	14 15	11 07	25 17	75 52
900 00	3 00	19 16	0 76	0 83	13.12	25 36	17 62	379 07	77 39	39 42	46 17	9 68	1 48	0 43	88 12	64 74	7 04	10 86	17 00	85 66	9 50	1 49	0 40	89 80	65 23	10 85	6 46	17 31	85 64
600 00	3 00	7 50	0 55	0 62	6.18	13 53	21 57	248 07	50 18	16 69	49 50	3 78	1 22	0 32	93 42	78 11	9 01	11 51	20 52	82 99	3 70	1 22	0 30	94 10	80 04	11 86	10 78	22 64	80 16

APREL VALVE DATA																													
RPM	VALVE POS.	TOT. HP	FLOW (MMSCFD) ROOTS METER	FLOW (MMSCFD) CARD INDICATED	PPM/MSCF	TOTAL DP	VOLTAGE	CURRENT	HP (ELEC.)	FLOW PRES.	BP	RATIO	MMSCFD	%DEV	HEAD %DEV	%DOP	TOT. HOIP CYL. EFF. %	BP	RATIO	MMSCFD	%DEV	%DEV	%DOP	TOT. COMP CYL. EFF. %					
10 1200 00	1 00	33 90	0 84	0 88	2.13	40 14	19 52	446 78	78 40	46 95	39 92	17 04	1 72	0 48	87 69	58 24	12 65	7 67	20 52	80 28	16 90	1 78	0 40	88 00	59 70	10 38	8 14	18 52	79 81
11 900 00	1 00	19 05	0 72	0 79	14.81	26 59	14 33	374 05	50 43	25 29	42 97	9 66	1 50	0 39	90 94	67 03	7 17	6 08	13 25	87 13	9 40	1 52	0 40	91 50	67 04	8 31	7 13	15 44	85 32
12 600 00	1 00	8 30	0 55	0 60	8.23	15 12	18 94	252 76	32 56	11 03	46 19	4 16	1 26	0 30	94 96	79 07	6 75	6 79	13 54	86 87	4 20	1 24	0 30	93 30	85 91	17 57	6 72	24 29	71 07
13 1200 00	2 00	31 80	0 81	1 01	16.13	39 31	20 87	446 23	72 20	43 10	37 11	16 07	1 59	0 51	89 37	63 58	12 79	9 21	22 00	77 81	15 70	1 63	0 50	90 10	64 01	10 22	9 48	19 70	79 27
14 900 00	2 00	16 61	0 72	0 82	11.97	23 15	18 69	367 45	46 09	22 70	41 90	8 38	1 37	0 42	92 74	72 51	10 47	8 59	19 06	81 03	8 20	1 39	0 40	93 30	72 91	10 34	7 98	18 32	81 92
15 600 00	2 00	6 74	0 55	0 61	5.77	12 29	17 21	248 14	28 08	9 34	45 70	3 40	1 20	0 31	96 06	82 29	9 59	7 63	17 22	84 09	3 30	1 21	0 30	96 20	82 08	9 05	8 16	17 21	84 16
16 1200 00	3 00	32 82	0 86	0 88	19.65	37 08	20 65	446 29	69 00	41 28	41 31	16 53	1 65	0 48	88 54	61 23	13 94	8 09	22 03	78 14	16 30	1 71	0 40	89 50	61 55	10 54	8 70	19 24	79 54
17 900 00	3 00	18 97	0 77	0 81	14.32	24 69	16 05	379 20	50 99	25 92	44 09	9 55	1 47	0 41	91 31	68 15	7 13	6 71	13 84	86 71	9 40	1 48	0 40	92 10	69 42	10 17	8 11	18 28	81 97
18 600 00	3 00	7 58	0 55	0 60	7.67	13 74	14 97	249 15	33 06	11 04	46 88	3 83	1 24	0 30	94 96	80 01	9 25	5 22	14 47	86 19	3 70	1 25	0 30	95 60	80 04	9 59	5 89	15 48	85 68

RPM. $\frac{TPP}{TAP} \times 100$

1200 1 55.9

900 1 53.9

600 1 53.1

2 41.8

2 49.1

2 46.5

3 51.7

3 58.0

3 55.8

AVG 51.8%

C-D VALUES

47.5

52.0

49.9

46.5

52.1

45.8

45.3

49.1

48.9%

11.6-5

12/ .316 112/

Disch. Noz (psi)
Suct. Noz. (psi)
Crank End (psi)
Head End (psi)

RPM : 909.30

73.09

66.37

59.66

52.94

46.23

39.51

32.79

File : C:\Comp_Dyn\hoerbigger_valves2\900rpmv3.vbd

10-01

Disch. Noz (psi)
 Suct. Noz. (psi)
 Crank End (psi)
 Head End (psi)

RPM : 601.20

7.67 IHP / 11/11

Disch. Noz (psi)
 Suct. Noz. (psi)
 Crank End (psi)
 Head End (psi)

22.45 11/2

85.04

RPM : 1198.20

75.30

65.57

55.83

46.10

36.36

26.63

File : C:\Comp_Dyn\hoerbigger_valves2\1200rpmv1.vbd

10-6

14.3/6 1H/10/1

File : C:\Comp_Dyn\hoerbigger_valves2\900rpmv1.vbd

10-7

3314
1/10

File : C:\Comp_Dyn\hoerbigger_valves2\600rpmv1.vbd

10-01

Disch. Noz (psi)
 Suct. Noz. (psi)
 Crank End (psi)
 Head End (psi)

10.45 117/418

81.24

RPM : 1215.90

72.57

63.91

55.24

46.57

37.91

29.24

File : C:\Comp_Dyn\hoerbigger_valves2\1200rpmv2.vbd

Disch. Noz (psi)
 Suct. Noz. (psi)
 Crank End (psi)
 Head End (psi)

RPM : 894.10

69.93

64.17

58.41

52.64

46.88

41.12

35.36

File : C:\Comp_Dyn\hoerbigger_valves2\900rpmv2.vbd

10-10

File : C:\Comp_Dyn\hoerbigger_valves2\600rpmv2.vbd

Appendix 2

Summary of Key Parameters for Ariel Valves

Compression Dynamics

SwRI Project 04-2040-064

ARIEL VALVES
(IHP/MMSCFD VERSUS TOTAL FLOW)

ARIEL VALVES
(TOTAL DIP VERSUS TOTAL FLOW)

ARIEL VALVES
(HE DVDIP VERSUS TOTAL FLOW)

**ARIEL VALVES
(HE SVDIP VERSUS TOTAL FLOW)**

ARIEL VALVES
(TOTAL HE DIP VERSUS TOTAL FLOW)

**ARIEL VALVES
(CE DVDIP VERSUS TOTAL FLOW)**

**ARIEL VALVES
(CE SVDIP VERSUS TOTAL FLOW)**

ARIEL VALVES
(TOTAL CE DIP VERSUS TOTAL FLOW)

Appendix 3

Baseline Data for Compression Dynamics Valves

Compression Dynamics

SwRI Project 04-2040-064

COMPRESSION DYNAMICS VALVE DATA																												
RPM	VALVE POS.	TOT. HP	FLOW (MMSCFD)	FLOW (MMSCFD)	HP/MMSCF	TOTAL DP	VOLTAGE	CURRENT	HP (ELEC.)	FLOW PRES.	HP	RATIO	MMSCFD	%REV	%DEV	%DPD	%DP#	TOT. HOIP	CYL. EFF. %	HP	RATIO	MMSCFD	%REV	CRANK			TOT. COMP	CYL. EFF. %
			ROOTS METER	CARD INDICATED																				%DEV	%DEV	%DP#		
1200 00 900 00 600 00 1200 00 900 00 600 00 1200 00 900 00 600 00	100	32.00	0.85	0.87	38.24	25.81	447.80	89.80	53.90	39.00	16.56	1.68	0.47	86.37	58.84	16.55	10.82	27.37	73.73	10.10	1.08	0.50	87.30	59.70	12.94	11.27	24.21	76.43
	100	17.84	0.72	0.80	24.87	16.86	371.70	72.75	36.25	43.30	9.02	1.48	0.40	88.12	64.16	7.16	10.98	18.14	85.73	8.80	1.50	0.40	89.50	64.01	9.40	6.14	15.54	87.93
	100	7.79	0.55	0.61	14.28	18.32	252.14	51.32	17.35	46.40	3.95	1.26	0.31	93.08	77.13	7.46	8.91	16.37	80.13	3.80	1.24	0.30	93.50	76.84	10.75	9.55	20.30	83.01
	200	32.45	0.95	1.03	34.01	27.23	448.40	89.25	53.05	44.00	16.57	1.56	0.53	88.12	64.16	17.78	11.87	29.05	70.72	15.90	1.59	0.50	88.70	62.78	13.18	11.52	24.70	75.86
	200	17.94	0.81	0.83	22.13	21.95	376.95	77.38	39.10	47.05	9.05	1.40	0.43	89.77	68.71	8.51	12.67	21.18	81.18	8.90	1.40	0.40	91.80	69.42	12.06	10.07	22.73	79.98
	200	6.84	0.58	0.63	11.79	25.19	250.44	51.67	17.35	49.40	3.46	1.19	0.33	94.37	80.48	10.76	13.41	24.17	78.83	3.40	1.18	0.30	94.90	81.58	15.27	10.95	26.22	76.57
	300	34.71	0.91	1.00	38.08	26.59	448.17	87.53	52.58	43.33	17.63	1.66	0.50	85.91	58.84	17.06	10.92	27.98	73.18	17.10	1.67	0.50	87.30	59.70	14.15	11.02	25.17	75.52
	300	19.16	0.76	0.83	25.36	17.62	379.97	77.39	39.42	46.17	9.68	1.48	0.43	88.12	64.74	7.04	10.86	17.90	85.66	9.50	1.49	0.40	89.80	65.23	10.85	6.46	17.31	85.64
300	7.50	0.55	0.62	13.53	21.57	248.07	50.18	16.09	49.50	3.78	1.22	0.32	93.42	78.11	9.01	11.51	20.52	82.99	3.70	1.22	0.30	94.10	80.04	11.86	10.78	22.64	80.16	

ANVEL VALVE DATA																												
RPM	VALVE POS.	TOT. HP	FLOW (MMSCFD)	FLOW (MMSCFD)	HP/MMSCF	TOTAL DP	VOLTAGE	CURRENT	HP (ELEC.)	FLOW PRES.	HP	RATIO	MMSCFD	%REV	HEAD	%DPD	%DP#	TOT. HOIP	CYL. EFF. %	HP	RATIO	MMSCFD	%REV	CRANK	%DPD	%DP#	TOT. COMP	CYL. EFF. %
			ROOTS METER	CARD INDICATED											%DEV									%DEV				
1200 00	1 00	33 90	0 84	0 88	40 14	19 52	446 78	78 40	46 95	39 92	17 04	1 72	0 48	87 69	58 24	12 85	7 67	20 52	80 28	16 90	1 78	0 40	88 00	59 70	10 38	8 14	18 52	79 81
900 00	1 00	19 05	0 72	0 79	26 59	14 33	374 05	50 43	25 29	42 97	9 66	1 59	0 39	90 94	67 03	7 17	6 08	13 25	87 13	9 40	1 52	0 40	91 50	67 04	8 31	7 13	15 44	85 32
600 00	1 00	8 36	0 55	0 60	15 12	18 94	252 76	32 56	11 03	40 19	4 10	1 26	0 30	94 90	79 07	6 75	6 79	13 54	86 87	4 20	1 24	0 30	93 30	85 91	17 57	6 72	24 29	71 07
1200 00	2 00	31 80	0 81	1 01	39 31	20 87	446 23	72 20	43 19	37 11	16 07	1 59	0 51	89 37	63 58	12 79	9 21	22 00	77 81	15 70	1 63	0 50	90 10	64 01	10 22	9 48	19 70	79 27
900 00	2 00	16 61	0 72	0 82	23 15	18 69	367 45	46 09	22 70	41 90	8 38	1 37	0 42	92 74	72 51	10 47	8 59	19 06	81 03	8 20	1 39	0 40	93 30	72 91	10 34	7 98	18 32	81 92
600 00	2 00	6 74	0 55	0 61	12 29	17 21	248 14	28 08	9 34	45 70	3 40	1 20	0 31	90 06	82 29	9 59	7 63	17 22	84 09	3 30	1 21	0 30	96 20	82 08	9 05	8 16	17 21	84 16
1200 00	3 00	32 82	0 86	0 88	37 88	20 65	446 29	69 00	41 28	41 31	16 53	1 65	0 48	88 54	61 23	13 94	8 09	22 03	78 14	10 30	1 71	0 40	89 50	61 55	10 54	8 70	19 24	79 54
900 00	3 00	18 97	0 77	0 81	24 69	16 05	379 20	50 99	25 92	44 09	9 55	1 47	0 41	91 31	68 15	7 13	6 71	13 84	86 71	9 40	1 48	0 40	92 10	69 42	10 17	8 11	18 28	81 97
600 00	3 00	7 58	0 55	0 60	13 74	14 97	249 15	33 06	11 04	46 88	3 83	1 24	0 30	94 96	80 01	9 25	5 22	14 47	86 19	3 70	1 25	0 30	95 60	80 04	9 59	5 89	15 48	85 68

Disch. Noz (psi)
 Suct. Noz. (psi)
 Crank End (psi)
 Head End (psi)

RPM : 1209.70

18.18 TAP

File : C:\Comp_Dyn\cd_valves2\1200rpmv1.vbd

10-2-

Disch. Noz (psi)
Suct. Noz. (psi)
Crank End (psi)
Head End (psi)

RPM : 895.70

12.94

File : C:\Comp_Dyn\cd_valves2\900rpmv1.vbd

10-24

RPM : 608.80

62.84

59.21

55.59

51.96

48.33

44.70

41.07

360.00

300.00

240.00

180.00

120.00

60.00

00

File : C:\Comp_Dyn\cd_valves2\600rpmv1.vbd

10-25

Disch. Noz (psi)
 Suct. Noz. (psi)
 Crank End (psi)
 Head End (psi)

RPM : 1208.90

15.81 TIP

File : C:\Comp_Dyn\cd_valves2\1200rpmv2.vbd

10-26

Disch. Noz (psi)
 Suct. Noz. (psi)
 Crank End (psi)
 Head End (psi)

RPM : 913.60

11.33 TAP

72.58

66.53

60.48

54.43

48.38

42.32

36.27

File : C:\Comp_Dyn\cd_valves2\900rpmv2.vbd

10-27

File : C:\Comp_Dyn\cd_valves2\600rpmv2.vbd

Disch. Noz (psi)
 Suct. Noz. (psi)
 Crank End (psi)
 Head End (psi)

File : C:\Comp_Dyn\cd_valves2\1200rpmv3.vbd

Disch. Noz (psi)
Suct. Noz. (psi)
Crank End (psi)
Head End (psi)

RPM : 908.80

76.35

69.56

62.78

55.99

49.20

42.41

35.63

File : C:\Comp_Dyn\cd_valves2\900rpmv3.vbd

10-70

Disch. Noz (psi)
Suct. Noz.(psi)
Crank End (psi)
Head End (psi)

File : C:\Comp_Dyn\cd_valves2\600rpmv3.vbd

Appendix 4

Summary of Key Parameters for Compression Dynamics Valves

Compression Dynamics

SwRI Project 04-2040-064

COMPRESSION DYNAMICS VALVES
(IHP/MMSCFD VERSUS TOTAL FLOW)

COMPRESSION DYNAMICS VALVES
(TOTAL DIP VERSUS TOTAL FLOW)

COMPRESSION DYNAMICS VALVES (HE DVDIP VERSUS TOTAL FLOW)

COMPRESSION DYNAMICS VALVES (HE SVDIP VERSUS TOTAL FLOW)

**COMPRESSION DYNAMICS VALVES
(TOTAL HE DIP VERSUS TOTAL FLOW)**

COMPRESSION DYNAMICS VALVES
(CE DVDIP VERSUS TOTAL FLOW)

COMPRESSION DYNAMICS VALVES
(TOTAL CE DIP VERSUS TOTAL FLOW)

1040

SOUTHWEST RESEARCH INSTITUTE

6220 CULEBRA ROAD • POST OFFICE DRAWER 28510 • SAN ANTONIO, TEXAS, USA 78228-0510 • (210) 684-5111 • TELEX 244846

DATE: December 4, 1998

TO: Compression Dynamics
20029 South Center Street
Corry, PA 16407

ATTN: Norbert Overfield

FAX: 205-325-3865

FROM: *[Signature]*
R.E. Harris / C.E. Edlund / C.R. Machado
Field and Engineering Services
Mechanical & Fluids Engineering Division

SUBJECT: Modified Valve Performance Analysis Data
SwRI Project No. 04-2040-064

RECEIVED
AUG 11 9 1999
OSTI

Please find attached a brief data summary from the valve tests with Compression Dynamics modified valves. We have compiled the major performance parameters into charts for your review. Appendix 1 contains the data for the baseline Ariel valves. Appendix 2 contains the summary of key parameters for this data. Appendices 3 and 4 contain the corresponding data for your modified valves.

If you have any questions, please call Ralph E. Harris at (210) 522-2689, Carl E. Edlund at (210) 522-2550 or Cory R. Machado at (210) 522-2555.

SAN ANTONIO, TEXAS

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Appendix 1

Baseline Data for Ariel Valves

Compression Dynamics

SwRI Project 04-2040-064

Disch. Noz (psi)
Suct. Noz. (psi)
Crank End (psi)
Head End (psi)

RPM : 1223.00

File : C:\Comp_Dyn\CD2.MOD\ar2 valves\1200V1.vbd

Disch. Noz (psi)
Suct. Noz. (psi)
Crank End (psi)
Head End (psi)

RPM : 1223.00

.00 .17 .33 .50 .67 .83 1.00

Voltage

File : C:\Comp_Dyn\CD2.MOD\ar2 valves\1200V1.vbd

Current

File : C:\Comp_Dyn\CD2.MOD\ar2 valves\1200V1.vbd

16.92 TR/ 10/14/10

Disch. Noz (psi)
Suct. Noz (psi)
Crank End (psi)
Head End (psi)

RPM : 913.20

Voltage

391.53

RPM : 913.20

391.44

391.34

391.24

391.14

391.05

390.95

File : C:\Comp_Dyn\CD2.MOD\ar2 valves\900V1.vbd

Current

File : C:\Comp_Dyn\CD2.MOD\ar2 valves\900V1.vbd

Disch. Noz (psi)
Suct. Noz. (psi)
Crank End (psi)
Head End (psi)

RPM : 603.10

10.44 TR

66.83

61.65
61.44

56.48

51.30

46.13

41.61
40.95

35.77

File : C:\Comp_Dyn\CD2.MOD\ar2 valves\600V1.vbd

Disch. Noz (psi)
 Suct. Noz.(psi)
 Crank End (psi)
 Head End (psi)

Voltage

258.99

RPM : 603.10

258.86

258.73

258.60

258.47

258.35

258.22

File : C:\Comp_Dyn\CD2.MOD\ar2 valves\600V1.vbd

(51)

Current

File : C:\Comp_Dyn\CD2.MOD\ar2 valves\600V1.vbd

Disch. Noz (psi)
 Suct. Noz.(psi)
 Crank End (psi)
 Head End (psi)

RPM : 1215.60 18.90 TR/

Disch. Noz (psi)
Suct. Noz.(psi)
Crank End (psi)
Head End (psi)

Voltage

447.00

RPM : 1215.60

446.67

446.33

446.00

445.67

445.33

445.00

File : C:\Comp_Dyn\CD2.MOD\ar2 valves\1200V3.vbd

Current

File : C:\Comp_Dyn\CD2.MOD\ar2 valves\1200V3.vbd

Disch. Noz (psi)
Suct. Noz.(psi)
Crank End (psi)
Head End (psi)

RPM : 921.60

12.4/2 171/

73.10

66.35

64.46

59.59

52.83

46.07

40.74

39.31

32.55

File : C:\Comp_Dyn\CD2.MOD\ar2 valves\900V3.vbd

611

Disch. Noz (psi)
 Suct. Noz. (psi)
 Crank End (psi)
 Head End (psi)

RPM : 921.60

Voltage

File : C:\Comp_Dyn\CD2.MOD\ar2 valves\900V3.vbd

Current

File : C:\Comp_Dyn\CD2.MOD\ar2 valves\900V3.vbd

Disch. Noz (psi)
 Suct. Noz.(psi)
 Crank End (psi)
 Head End (psi)

RPM : 604.50

6.59 712

62.61

58.76

57.87

54.92

51.07

47.22

45.10

43.38

39.53

Disch. Noz (psi)
Suct. Noz. (psi)
Crank End (psi)
Head End (psi)

RPM : 604.50

Cylinder Performance Summary

TOTAL HP: 7.028
MMSCFD : .650
DDIP% : 9.58
SDIP% : 8.96
DVDIP% : 9.87
SVDIP% : 8.96
Cylinder Efficiency%: 82.4

Rod Load Min: -2288.4
Rod Load Max: 1950.8

Head End Crank End

IHP : 3.53 3.5
RATIO : 1.22 1.20
MMSCFD: .32 .3
POLYK : 1.23 1.24
%SEV : 96.06 96.5
%DEV : 81.85 83.07
%CVOL : 22.68 21.98
%DIPD : 8.07 11.09
%DIPS : 8.66 9.26
%EFF : 84.40 80.35

.00 .17 .33 .50 .67 .83 1.00

Voltage

File : C:\Comp_Dyn\CD2.MOD\ar2 valves\600V3.vbd

Current

File : C:\Comp_Dyn\CD2.MOD\ar2 valves\600V3.vbd

Appendix 2

Summary of Key Parameters for Ariel Valves

Compression Dynamics

SwRI Project 04-2040-064

ARIEL VALVES (BASE LINE)

RPM	VALVE POS.	TOT. IHP.	ROOTS FLOW (MMSCFD)	CARD FLOW (MMSCFD)	TOT. DIP VOLTS	AMPS	HP (ELEC)	FLOW FREQ.	FLOW PRES.	FLOW TEMP.	SUCTION TEMP.	DISCHARGE TEMP.	SUCTION PRES.	DISCHARGE PRES.	
1200	1	38.336	0.809	0.899	18.38	448.25	87.99	52.87	128.59	35	67.9	70.6	185.7	28	76.38
900	1	22.608	0.716	0.768	12.07	391.14	59.12	31.00	104.88	39.24	68.4	70.7	162.5	35	70.55
600	1	9.67	0.556	0.596	12.45	258.6	39.25	13.61	75.49	43.52	68.9	70.7	130.6	38	61.53
1200	3	34.324	0.999	1.085	21.58	448.47	77.95	46.65	135.45	43.77	70.2	70.4	168.6	34	71.75
900	3	18.638	0.843	0.899	20.72	382.18	49.23	25.22	111.26	45.28	69.2	70.3	139.9	38	64.62
600	3	7.028	0.609	0.65	18.83	249.16	30.05	10.04	77.68	47.31	68.6	70.8	116.9	42	57.72

HEAD END

IHP	RATIO	MMSCFD	%SEV	%DEV	%DIPD	%DIPS	TOT. HDIP	CYL. EFF.	IHP/MMSCFD
19.36	1.89	0.47	84.99	63.36	15.91	8.14	24.05	76.37	41.17
11.43	1.88	0.41	88.64	60.04	4.76	6.17	10.92	89.82	27.88
4.87	1.37	0.3	93.74	73.57	2.89	6.6	9.49	91.7	16.23
17.37	1.61	0.55	89.77	63.58	15.74	10.45	26.19	73.5	31.58
9.38	1.42	0.46	92.74	71.98	9.77	9.5	19.27	80.52	20.84
3.63	1.22	0.32	96.06	81.85	8.07	8.66	16.73	84.4	11.03

CRANK END

IHP	RATIO	MMSCFD	%SEV	%DEV	%DIPD	%DIPS	TOT. CDIP	CYL. EFF.	CHP/MMSCFD
19	1.97	0.4	86.1	54.72	13.47	7.04	20.51	77.3	47.50
11.2	1.73	0.4	88.7	59.7	6.91	4.86	11.77	87.59	28.00
4.8	1.36	0.3	93.8	74.05	6.89	4.81	11.7	89.08	16.00
17	1.64	0.5	90.5	64.62	13	9.27	22.27	76.01	34.00
9.3	1.4	0.4	93.5	72.91	12.93	9.54	22.47	77.9	23.25
3.5	1.2	0.3	96.5	83.07	11.09	9.26	20.35	80.35	11.67

TOTAL IHP/MMSCFD

42.64
29.43
16.22
31.64
20.73
10.81

ARIEL VALVES
(TOTAL DIP VERSUS CARD FLOW)

**ARIEL VALVES
(HE DVDIP VERSUS CARD FLOW)**

**ARIEL VALVES
(HE SVDIP VERSUS CARD FLOW)**

ARIEL VALVES
(TOTAL HE DIP VERSUS CARD FLOW)

**ARIEL VALVES
(CE DVDIP VERSUS CARD FLOW)**

**ARIEL VALVES
(CE SVDIP VERSUS CARD FLOW)**

**ARIEL VALVES
(TOTAL CE DIP VERSUS CARD FLOW)**

ARIEL VALVES
(IHP/MMSCFD VERSUS CARD FLOW)

Appendix 3
Baseline Data for
Compression Dynamics Modified Valves

Compression Dynamics

SwRI Project 04-2040-064

Appendix 3

Baseline Data for Compression Dynamics Modified Valves

Compression Dynamics

SwRI Project 04-2040-064

Disch. Noz (psi)
 Suct. Noz.(psi)
 Crank End (psi)
 Head End (psi)

RPM : 1215.70

24.62 *THD*

File : C:\Comp_Dyn\cd valves\1200v1.vbd

62

Disch. Noz (psi)
Suct. Noz (psi)
Crank End (psi)
Head End (psi)

Voltage

File : C:\Comp_Dyn\CD2.MOD\cd2 valves\1200v1.vbd

Current

File : C:\Comp_Dyn\CD2.MOD\cd2 valves\1200v1.vbd

Disch. Noz (psi)
Suct. Noz. (psi)
Crank End (psi)
Head End (psi)

RPM : 915.00

Disch. Noz (psi)
 Suct. Noz. (psi)
 Crank End (psi)
 Head End (psi)

RPM : 915.00

17.10 77P/

0.00 .17 .33 .50 .67 .83 1.00

1

Voltage

File : C:\Comp_Dyn\cd valves\900v1.vbd

25

Current

File : C:\Comp_Dyn\cd valves\900v1.vbd

Disch. Noz (psi)
 Suct. Noz. (psi)
 Crank End (psi)
 Head End (psi)

RPM : 600.60

9.27 TPD

67.96

62.93

61.46

57.91

52.89

47.87

43.49
 42.85

37.82

File : C:\Comp_Dyn\cd valves\600v1.vbd

File : C:\Comp_Dyn\cd valves\600v1.vbd

Voltage

File : C:\Comp_Dyn\cd valves\600v1.vbd

Current

File : C:\Comp_Dyn\cd valves\600v1.vbd

Disch. Noz (psi)
Suct. Noz. (psi)
Crank End (psi)
Head End (psi)

RPM : 1213.30

.00 .17 .33 .50 .67 .83 1.00

1

Disch. Noz (psi)
Suct. Noz (psi)
Crank End (psi)
Head End (psi)

RPM : 1213.30

16.27 778

Voltage

File : C:\Comp_Dyn\cd valves\1200v3.vbd

i

Current

File : C:\Comp_Dyn\cd valves\1200v3.vbd

Disch. Noz (psi)
Suct. Noz (psi)
Crank End (psi)
Head End (psi)

RPM : 898.20

10.75 *mp*

Voltage

File : C:\Comp_Dyn\cd valves\900v3.vbd

Current

File : C:\Comp_Dyn\cd valves\900v3.vbd

Disch. Noz (psi)
Suct. Noz. (psi)
Crank End (psi)
Head End (psi)

RPM : 599.40

5.61 THP / MIN

61.03

57.43

56.72

53.82

50.21

46.60

45.83

42.99

39.39

Cylinder Performance Summary

TOTAL HP: 5.958
MMSCFD : .633
DDIP% : 13.86
SDIP% : 11.53
DVDIP% : 12.94
SVDIP% : 12.17
Cylinder Efficiency%: 77.6

Rod Load Min: -2162.3
Rod Load Max: 2145.5

	Head End	Crank End
IHP :	3.04	2.9
RATIO :	1.18	1.16
MMSCFD:	.32	.3
POLYK :	1.36	1.16
%SEV :	93.08	92.7
%DEV :	82.29	81.58
%CVOL :	52.73	53.70
%DIPD :	11.58	16.22
%DIPS :	8.74	14.44
%EFF :	81.41	73.65

.00 .17 .33 .50 .67 .83 1.00

File : C:\Comp_Dyn\cd valves\600v3.vbd

(53)

Disch. Noz (psi)
 Suct. Noz. (psi)
 Crank End (psi)
 Head End (psi)

59.15

RPM : 599.40

56.23

Cylinder Performance Summary

TOTAL HP: 5.997
 MMSCFD : .635
 DDIP% : 13.71
 SDIP% : 11.11
 DVDIP% : 12.66
 SVDIP% : 11.11
 Cylinder Efficiency%: 77.3

53.32

Rod Load Min: -2032.6
 Rod Load Max: 1978.6

50.41

Head End

Crank End

IHP :	3.06	2.9
RATIO :	1.18	1.17
MMSCFD:	.32	.3
POLYK :	1.35	1.27
%SEV :	93.74	92.7
%DEV :	83.17	82.08
%CVOL :	49.24	56.59
%DIPD :	12.28	15.18
%DIPS :	10.23	12.02
%EFF :	78.89	75.70

47.50

44.58

41.67

.00

.17

.33

.50

.67

.83

1.00

File : C:\Comp_Dyn\cd valves\600v3.vbd

Voltage

File : C:\Comp_Dyn\cd valves\600v3.vbd

Current

i

File : C:\Comp_Dyn\cd valves\600v3.vbd

Appendix 4

**Summary of Key Parameters for
Compression Dynamics Modified Valves**

Compression Dynamics

SwRI Project 04-2040-064

CD VALVES (MODIFIED)

RPM	VALVE POS.	TOT. IHP.	ROOTS FLOW (MMSCFD)	CARD FLOW (MMSCFD)	TOT. DIP VOLTS	AMPS	HP (ELEC)	FLOW FREQ.	FLOW PRES.	FLOW TEMP.	SUCTION TEMP.	DISCHARGE TEMP.	SUCTION PRES.	DISCHARGE PRES.	
1200	1	36.66	0.797	0.909	21.58	447	86.45	51.80	121	37.37	68.5	68.8	191.3	30	78.07
900	1	20.572	0.684	0.762	13.76	389.7	53.8	28.10	98.98	41.12	69.2	70	168.3	35	71.87
600	1	8.287	0.510	0.588	14.82	253.74	33.5	11.30	67.47	45.21	69.9	70.2	140.5	40	62.04
1200	3	31.78	0.967	1.084	28.35	446.51	71.38	42.72	127.56	44.89	65.5	67.8	163.1	36	70.11
900	3	15.997	0.780	0.879	25.64	370.1	42.95	21.31	100.43	46.62	67.7	68.1	138.6	40	63.3
600	3	5.997	0.569	0.635	23.77	243.48	25.72	8.39	71.87	47.77	67.3	68	116.6	45	56.53

HEAD END

IHP	RATIO	MMSCFD	%SEV	%DEV	%DIPD	%DIPS	TOT. IHP	CYL. EFF.	IHP/MMSCFD
18.31	1.84	0.45	80.04	52.12	18.88	9.71	28.57	75.09	40.69
10.38	1.62	0.39	84.99	58.84	8.25	8.28	14.53	89.23	28.62
4.2	1.31	0.3	89.77	73.04	5.84	7.46	13.3	90.48	14.00
18.41	1.52	0.55	86.37	65.32	18.7	13.08	31.78	67.98	29.84
8	1.36	0.45	90.58	89.81	11.14	12.37	23.51	80.9	17.78
3.06	1.18	0.32	93.74	83.17	12.28	10.23	22.51	78.89	9.56

CRANK END

IHP	RATIO	MMSCFD	%SEV	%DEV	%DIPD	%DIPS	TOT. CDIP	CYL. EFF.	CHP/MMSCFD
18.4	1.86	0.5	82.7	54.72	14.63	9.1	23.73	76.26	36.80
10.2	1.66	0.4	83.6	59.08	8.09	6.88	14.97	87.93	25.50
4.1	1.31	0.3	89.5	72.91	7.27	7.44	14.71	89.6	13.67
15.4	1.57	0.5	86.9	62.17	12.8	13.7	26.5	75.37	30.80
8	1.35	0.4	89.8	72.34	16.07	10.47	26.54	75.34	20.00
2.9	1.17	0.3	92.7	82.08	15.18	12.02	27.2	75.7	9.67

TOTAL IHP/MMSCFD

40.33	42.64	5.73
27.00	28.43	9.20
14.09	16.22	15.12
29.32	31.62	7.91
18.20	20.78	13.90
9.44	10.81	14.51

COMPRESSION DYNAMICS MODIFIED VALVES
(TOTAL DIP VERSUS CARD FLOW)

COMPRESSION DYNAMICS MODIFIED VALVES
(HE DVDIP VERSUS CARD FLOW)

COMPRESSION DYNAMICS MODIFIED VALVES
(HE SVDIP VERSUS CARD FLOW)

COMPRESSION DYNAMICS MODIFIED VALVES
(TOTAL HE DIP VERSUS CARD FLOW)

COMPRESSION DYNAMICS MODIFIED VALVES
(CE DVDIP VERSUS CARD FLOW)

COMPRESSION DYNAMICS MODIFIED VALVES
(CE SVDIP VERSUS CARD FLOW)

COMPRESSION DYNAMICS MODIFIED VALVES
(TOTAL CE DIP VERSUS CARD FLOW)

COMPRESSION DYNAMICS MODIFIED VALVES (IHP/MMSCFD VERSUS CARD FLOW)