BRAUN ENGINE/COMPRESSOR AS TESTED FOR HEAT PUMP APPLICATION—AN UPDATE

A.T. Braun

ABSTRACT

This paper provides updated information on the Department of Energy/Oak Ridge National Laboratories (DOE/ORNL) Braun Heat Pump Program. This paper includes highlights of the measured Coefficients of Performance (COP) values achieved with the BR-105R.2 engine/refrigerant compressor, which sighificantly exceed contract requirements and measured COP values reported before. It describes the breadboard test rig and the results of corroborating engine efficiency tests performed by a major independent laboratory. This paper also addresses the status test results and selection methods of the critical Braun Hermetic Seal which prevents loss and contamination of the pumped refrigerant. Information is also supplied on qualifying the Braun BR105R.2 model for operation with natural gas.

INTRODUCTION

Progress in the development of the Braun heat pump has been substantially enhanced since mid-1980, when three related DOE/ORNL R & D contracts were granted. The work in the intervening years has yielded very favorable results, including significant improvements of the Coefficient Of Performance (COP), not only over contract requirements, but also over any corresponding measured results reported before (Figure 1).

As shown in Figure 2, the heat pump work proper was preceded by a Seal I program. Indeed, it was perceived from the outset of the heat pump development that a reliable - preferably hermetic - seal between the engine and the refrigerant compressor was an essential prerequisite for a serious heat pump effort.

Demonstration of a proprietary proof-of-concept seal at the completion of the Seal I program was therefore considered the logical starting point for Heat Pump Programs I and II. Under Heat Pump Program I, a BR-105R.1 model, including the proprietary hermetic seal, was developed to satisfactory proof-of-concept status. Program II then followed with the breadboard demonstration of a BR-105.R.2 model through an operating range between -20 F and 120 F ambient temperatures.

This BR-105R.2 engine/compressor unit embodies the essential design features of a first-generation production machine. It combines unusual simplicity with potential for long life, trouble free operation and low manufacturing cost. Figure 1 shows the substantial difference of 60 % (2:1.2 = 1.6) of measured COP values of the BR-105R.2 over the best reported values of the nearest competitive engine-driven heat pump (Kawamoto et al. 1984).

As part of the evaluation of the existing Braun engine technology, a series of tests with the basic BR-105 engine/air compressor module were carried out in 1983 by a prominent independent laboratory. The measured overall efficiency of the combined engine and compressor reported at that time was 30.8 %, (LHV).

A. T. Braun, President and Technical Director, Tectonics Research, Inc., Minneapolis, MN.

HERMETIC SEAL - TESTING AND STATUS

The research on the seals started with extensive analytical work and stringent testing and culminated in the selection of a unique and patented hermetic seal. Because of funding constraints, the initial version of this seal was constructed from off-the-shelf components. Testing included subjecting the seal to sinusoidal motion as well as to the actual engine dynamics in a basic Braun BR-105 engine. Acceptable bellows seal operation requires limitation of maximum bellows stress through control of seal dynamics over a wide range of speeds and strokes. The selected seal concept provided the excellent improvement of seal dynamics necessary for satisfactory stress levels. The drastic effects of this are shown in Figures 3 and 4, where the respective maximum deflections (stress levels) as well as stroke and speed ranges of this Braun hermetic seal are compared with conventional bellows seals.

By using the most suitable of available seal components, a final design was worked out that is well within the design criteria for infinite life, as indicated in Figure 5.

In bench testing, selected bellows seal subassemblies were subjected to the anticipated operating stress and dynamics. In an ongoing endurance testing program a seal subassembly has been subjected to well over one billion cycles without failure.

ENGINE/COMPRESSOR - PERFORMANCE VERIFICATION

Qualification of the Braun engine for natural gas heat pump operation is being carried out and includes the design, fabrication and testing of an appropriate natural gas fuel injection system. Testing and analytical procedures are identical to those followed in earlier phases to determine full-load characteristics and performance.

A liquid-to-liquid breadboard system is being used to provide a refrigerant compressor test bed for the demonstration of the Braun linear engine/compressor under heat pump application loads. Figure 6 is a simplified schematic, and Figure 7 a photograph, of this system in the test laboratory as well as the present updated BR-105R.2 test demonstration rig. It is basically a quasi-adiabatic test condenser and evaporator and heat transfer tank. The heat source and heat sink are provided by the condenser and evaporator, respectively. The thermal energy transfer is provided by the heat transfer fluid and occurs in the mixing header and the heat transfer tank. The excess heat (work of compression) is purged to the atmosphere.

In Figure 8 the variation of the Braun engine/compressor heating COP as a function of ambient temperature and representative of performance in a heat pump system is shown for both the early BR-105R.1 and the present updated BR-105R.2 unit. Corresponding measured data points are also presented in Figure 9. Figure 10 shows the updated data acquisition system. In Figure 11 the basic elements of the bread board heat pump system test loop are shown. Table 1 reflects measured results of the BR-105R.2 operating on natural gas.

FIELD TESTS

Concurrent with the continuing development and performance improvement work of the updated Braun BR-105R.2, a two-year field-test program for a typical 15-ton commercial heat pump application is being carried out. Significantly, this program is organized as a cost-sharing program between DOE/ORNL and two major gas utilities along with the participation of a prominent U.S. HVAC manufacturer. It involves six Braun BR-105R.2 engine/refrigerant compressors, supplied by Tectonics Research, Inc. (TRI). Of these six BR-105R.2 units, the first is being performance tested in the TRI laboratory on the test rig shown in Figures 6 and 7. A second unit is being evaluated for proper sizing of the system by the HVAC manufacturer. Of the remaining four units, two are being used for performance and durability testing in different, accelerated modes in the laboratory. Units five and six will be installed in two separate commercial field test situations. The field tests are scheduled to last two years and will be carried out under the auspices of the two cost-sharing utilities.

SUMMARY

Since its inception in 1980, the programs for the development of the Braun engine-driven heat pump have produced sound and even remarkable results. In all essential stages of the program, established goals have been met or exceeded. In the engine compressor unit no exotic materials, systems or methods were required to attain these goals. The key elements utilized in the Braun Balancer and the Braun Hermetic Seal have been successfully used in corresponding applications for many decades. The few new components, such as the balancer gear, have been successfully commercialized worldwide by Braun licensees since 1974. The orderly progress and the achievement of the high values are partially attributable to the author's lifetime experience with linear engines and to the existence at the outset of the program of several thoroughly tested and well understood engine/air compressor units.

On the basis of the described status of the BR-105R.2 model, it is believed these machines are ready for early commercial introduction and final development into production units. According to expert testimony at recent U.S. House of Representatives hearings, the market potential of the heat-actuated heat pump over the next two decades is in the several hundred billion dollar range. This averages into annual sales of between ten and twenty billion dollars, and the creation of between 100,000 and 200,000 new jobs. The unusually high efficiency of the Braun heat pump technology can additionally result in annual energy savings in the tens of billions of dollars.

Kawamoto, Hiroshi; Takata, Yukio; and Shibuya, Kenichi, 1984. "Development of a gas engine heat pump for domestic and commercial use." In Proceedings of the 1984 International Gas Research Conference, Gas Utilization Technology Center, Osaka, Japan.

TABLE 1

BR105R.3 HEAT PUMP GENERAL PERFORMANCE SUMMARY DATE OF TEST: 05/30/86

PRELIMINARY TEST RUN, APPROXIMATE 47 DEG AMBIENT POINT

	OVER-ALL			EVAPORATOR / INTAKE SIDE								CONDENSER / DISCHARGE SIDE							
TIME	HTONS	COPH	COPC	TEVAP	SHEV	PEVAP	ACI	TCS	TSCI	QER	EBAL	TCOND	SCCOND	PCOND	PCD	TCD	TSCD	QCR	EBAL
10:23:13	28.3	1.90	1.07	45.3	17.3	91.0	81.3	56.4	40.2	192193	10	112.7	8.9	235.5	240.7	170.2	114.5	227890	28
10:23:25	29.0	1.96	1.14	45.3	20.7	90.8	81.0	56.4	40.0	202529	14	113.0	9.2	236.2	241.9	170.6	114.9	238546	30
10:23:38	28.2	1.90	1.09	45.5	22.3	91.1	81.4	56.8	40.3	193179	9	113.3	9.5	237.2	242.9	171.5	115.2	227170	27
10:23:50	27.7	1.88	1.06	45.3	23.8	91.2	81.9	57.9	40.6	188494	9	113.2	9.2	236.9	242.4	172.8	115.1	221773	23
10:24:02	28.2	1.91	1.09	45.5	24.6	91.2	81.7	59.4	40.5	193723	12	113.3	9.1	237.2	242.4	174.1	115.1	228073	27
10:24:14	27.8	1.89	1.07	45.5	25.5	91.2	81.8	60.6	40.5	188769	9	113.3	8.9	237.2	242.4	175.2	115.1	222521	24
10:24:26	28.5	1.91	1.09	45.5	26.1	91.2	81.8	62.1	40.5	195167	12	113.4	8.8	237.4	242.7	176.5	115.1	230338	26
10:24:38	28.1	1.89	1.06	45.7	26.3	91.4	82.0	63.3	40.7	190069	9	113.6	8.8	237.9	242.9	177.8	115.2	224815	24
10:24:51	28.0	1.91	1.09	45.7	26.7	91.4	82.1	64.6	40.7	191449	11	113.6	8.8	237.9	243.1	178.9	115.3	226724	25
10:25:03	27.4	1.87	1.04	45.5	27.3	91.4	82.4	65.6	41.0	183917	7	113.6	8.8	237.9	243.1	179.8	115.3	218069	22
10:25:15	28.6	1.93	1.10	45.7	27.3	91.7	82.0	66.7	40.7	196460	12	113.8	8.8	238.7	243.9	180.7	115.5	232439	27
10:25:27	27.5	1.89	1.06	45.7	27.5	91.6	82.5	67.5	41.1	185117	6	113.7	8.7	238.4	243.4	181.7	115.4	220342	23
10:25:40	29.2	1.97	1.14	45.7	27.8	91.6	81.8	68.3	40.5	202867	16	113.9	8.7	238.9	244.3	182.6	115.7	241650	28
10:25:52	28.4	1.93	1.10	45.7	28.0	91.8	82.2	69.0	40.9	193935	13	114.0	8.8	239.2	244.6	183.1	115.8	231418	25
10:26:08	28.0	1.92	1.08	45.7	28.2	91.8	82.4	69.8	41.0	189963	9	114.1	8.7	239.4	244.6	183.9	115.8	227172	24
10:26:20	28.8	1.95	1.12	45.9	28.0	91.9	82.2	70.2	40.9	197576	14	114.2	8.8	239.9	245.1	184.6	115.9	236557	27
10:26:33	28.0	1.91	1.07	45.9	28.2	91.9	82.4	70.8	41.0	188607	10	114.2	8.8	239.9	245.3	185.4	116.0	226099	23
10:26:45	28.7	1.94	1.09	45.9	28.4	91.9	82.4	71.5	41.0	194886	13	114.2	8.6	239.9	245.3	185.9	116.0	233853	26
10:26:57	28.5	1.94	1.09	45.9	28.4	92.1	82.4	71.9	41.0	193299	12	114.4	8.8	240.4	245.8	186.3	116.2	232585	26
10:27:09	28.7	1.96	1.11	45.9	28.6	92.1	82.4	72.3	41.0	196153	13	114.4	8.6	240.4	245.8	186.9	116.2	235776	27
10:27:21	28.6	1.95	1.11	46.1	28.4	92.1	82.5	72.5	41.1	194796	12	114.6	8.8	240.9	246.3	187.4	116.3	234506	25
10:27:34	28.5	1.92	1.07	46.1	28.6	92.2	82.7	72.7	41.2	192336	11	114.6	8.8	241.2	246.5	187.8	116.4	231627	24
10:27:46	28.7	1.94	1.09	45.9	28.8	92.2	82.5	72.9	41.1	194621	12	114.6	8.6	241.2	246.8	188.3	116.5	234720	25
10:27:58	28.7	1.94	1.09	46.1	28.8	92.3	82.7	73.3	41.2	194702	10	114.7	8.7	241.4	246.8	188.7	116.5	234901	25
10:28:10	28.1	1.91	1.06	46.1	28.8	92.2	82.9	73.3	41.3	188124	9	114.7	8.5	241.4	247.0	188.9	116.6	227177	22
10:28:23	28.9	1.94	1.09	46.1	29.0	92.3	82.6	73.7	41.1	195812	13	114.8	8.6	241.7	247.2	189.3	116.6	236544	25
10:28:35	28.9	1.95	1.11	46.1	29.0	92.4	82.7	73.7	41.2	197064	13	115.0	8.8	242.2	247.5	189.8	116.7	238339	28
10:28:47	28.6	1.93	1.08	46.1	29.0	92.2	82.7	74.2	41.2	193122	13	114.9	8.5	241.9	247.5	190.2	116.7	233693	24
10:28:59	28.0	1.90	1.05	46.1	29.2	92.3	82.9	74.2	41.3	186782	6	114.9	8.5	241.9	247.5	190.4	116.7	226123	22
10:29:11	27.9	1.87	1.03	46.1	29.2	92.4	83.0	74.4	41.4	184232	6	114.9	8.5	241.9	247.7	190.5	116.8	223250	21
10:29:24	28.3	1.90	1.06	46.1	29.4	92.3	83.0	74.6	41.4	189244	12	115.0	8.4	242.2	247.7	190.9	116.8	229400	23
10:29:37	28.4	1.93	1.08	46.1	29.4	92.4	82.9	74.8	41.4	191676	10	115.0	8.4	242.2	247.7	191.3	116.8	232570	25
10:29:49	28.4	1.92	1.07	46.1	29.6	92.4	82.9	74.8	41.4	190586	12	115.0	8.4	242.2	248.0	191.5	116.9	231134	22
10:30:01	28.3	1.91	1.06	46.1	29.6	92.5	83.1	75.2	41.5	189223	10	115.0	8.4	242.4	247.7	191.6	116.8	229674	25
10:30:13	28.7	1.93	1.08	46.1	29.8	92.4	82.9	75.2	41.3	193051	13	115.0	8.4	242.4	248.2	191.8	116.9	234382	25
10:30:26	27.4	1.85	1.01	46.1	29.8	92.3	83.4	75.4	41.7	179215	6	115.0	8.4	242.2	247.7	192.0	116.8	217680	19
10:30:38	27.5	1.86	1.01	46.1	29.8	92.4	83.5	75.6	41.7	180386	5	115.0	8.4	242.2	248.0	192.4	116.9	219214	20
10:30:50	27.0	1.82	0.98	45.9	30.2	91.6	82.4	75.6	41.0	174247	3	115.0	8.4	242.4	247.7	192.7	116.8	211682	18
10:31:02	28.6	1.94	1.09	45.7	30.5	91.4	82.0	75.6	40.7	193277	13	114.9	8.3	241.9	247.2	193.1	116.6	235027	26
10:31:15	27.6	1.88	1.03	45.7	30.7	91.3	82.3	75.8	40.9	182058	7	114.9	8.3	241.9	247.5	193.1	116.7	221342	22
10:31:27	27.9	1.88	1.04	45.7	30.7	91.6	82.4	76.0	41.0	184477	7	114.9	8.3	241.9	247.5	193.5	116.7	224518	25
10:31:29	27.9	1.90	1.06	45.7	30.7	91.4	82.4	76.0	41.0	185842	9	115.0	8.6	242.2	247.5	194.0	116.7	226309	25
10:31:51	27.7	1.88	1.04	45.7	30.9	91.6	82.4	76.2	41.0	183301	9	115.0	8.4	242.4	247.7	194.4	116.8	223308	23
10:32:03	28.7	1.94	1.09	45.7	30.9	91.6	82.1	76.2	40.7	193624	12	115.1	8.7	242.7	248.0	194.9	116.9	236023	28
10:32:15	28.0	1.91	1.06	45.7	31.1	91.3	82.3	76.5	40.9	187232	11	115.0	8.4	242.4	247.5	195.3	116.7	228235	26
10:32:28	28.6	1.93	1.08	45.7	31.1	91.4	82.1	76.7	40.7	192297	14	115.2	8.6	242.9	248.2	195.5	116.9	234382	28
10:32:40	28.2	1.93	1.08	45.7	31.1	91.6	82.2	76.7	40.9	189741	12	115.3	8.7	243.2	248.4	195.8	117.0	231459	27
10:32:52	27.7	1.88	1.04	45.5	31.5	91.4	82.4	76.9	41.0	183339	10	115.3	8.5	243.2	248.4	196.0	117.0	223648	23
10:33:04	28.4	1.94	1.08	45.7	31.3	91.4	82.1	76.9	40.8	191837	13	115.2	8.6	242.9	248.2	196.2	116.9	233321	27
AVERAGE =	28.3	1.91	1.07	45.9	28.4	91.8	82.4	71.0	41.0	190492	10	114.5	8.7	240.6	246.0	186.9	116.3	229165	25

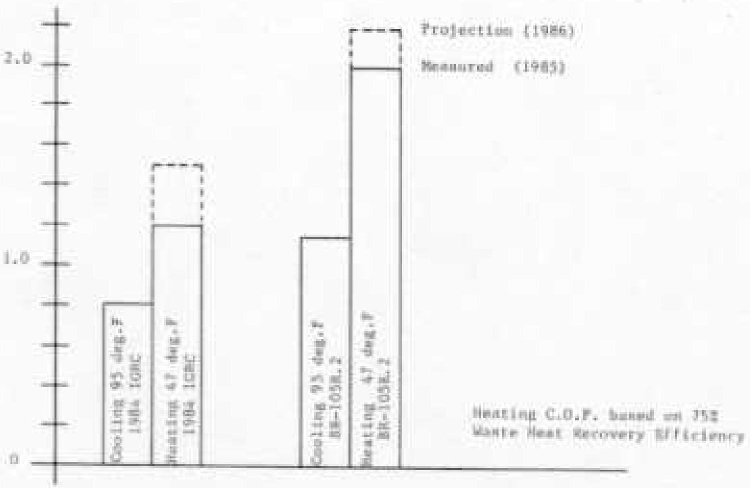

Figure 1. Comparative COPs for experimental engine-driven gas-fired air-to-air heat pumps

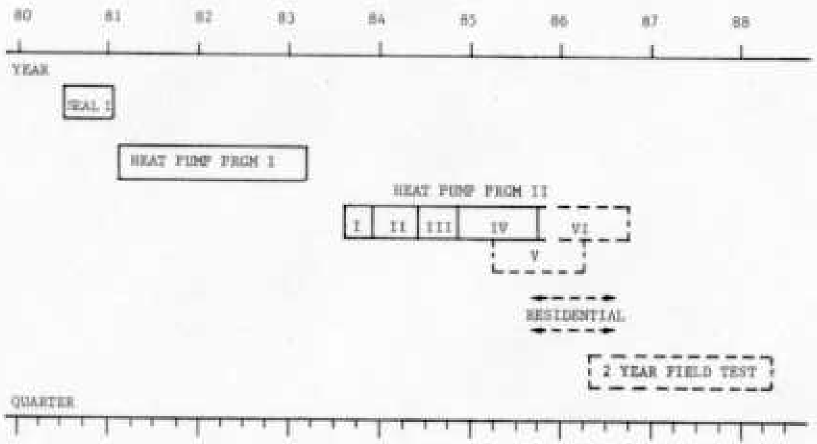

Figure 2. Braun engine-driven heat pump, program schedule

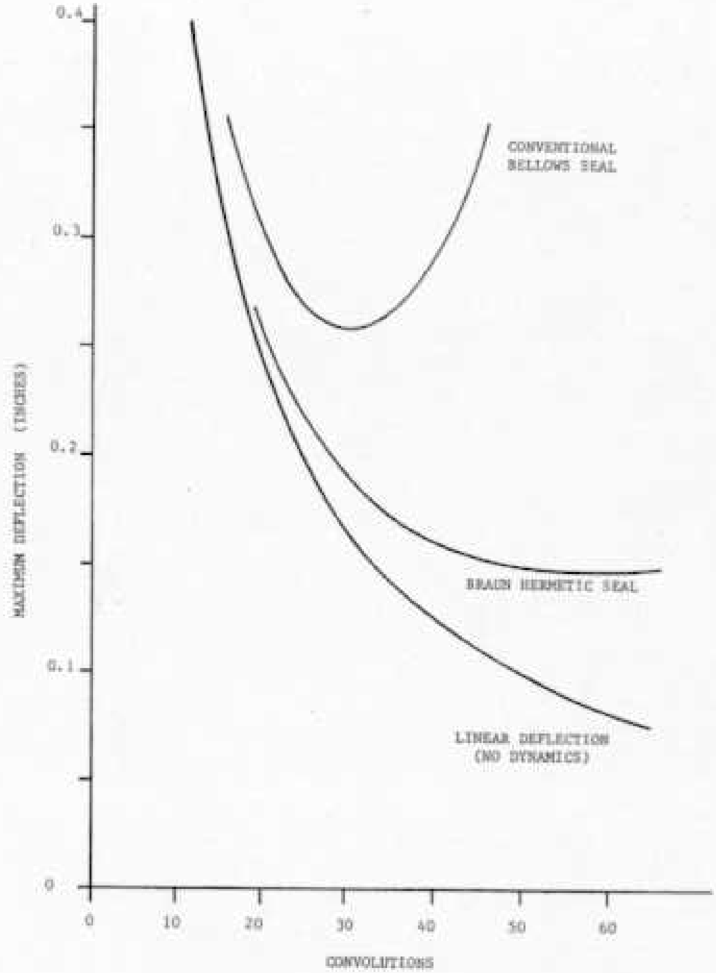

Figure 3. Seal dynamic performance comparison

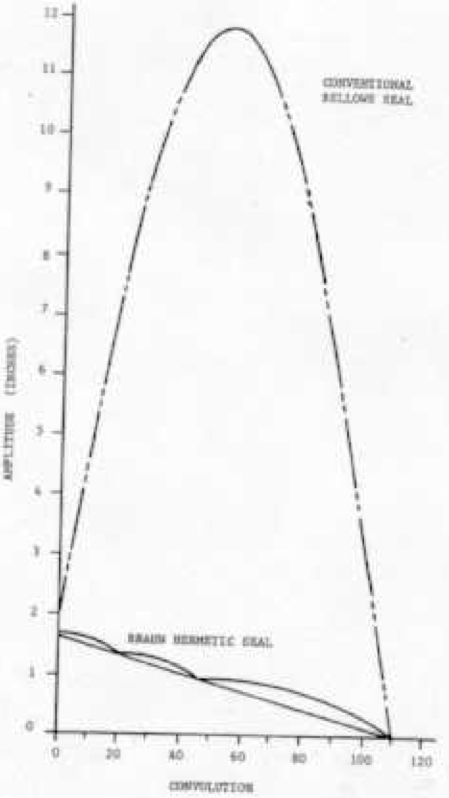

Figure 4. Bellows seal comparison

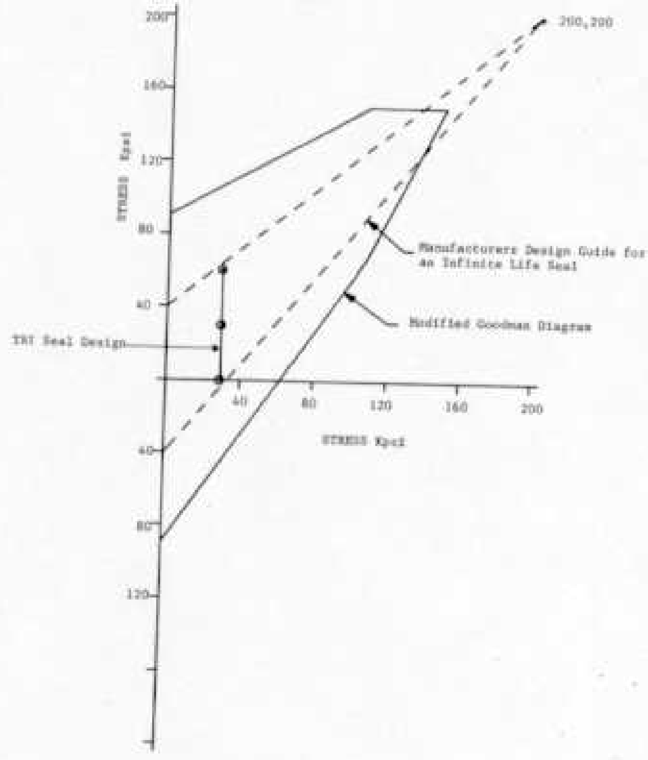

Figure 5. Seal design, infinite life criteria

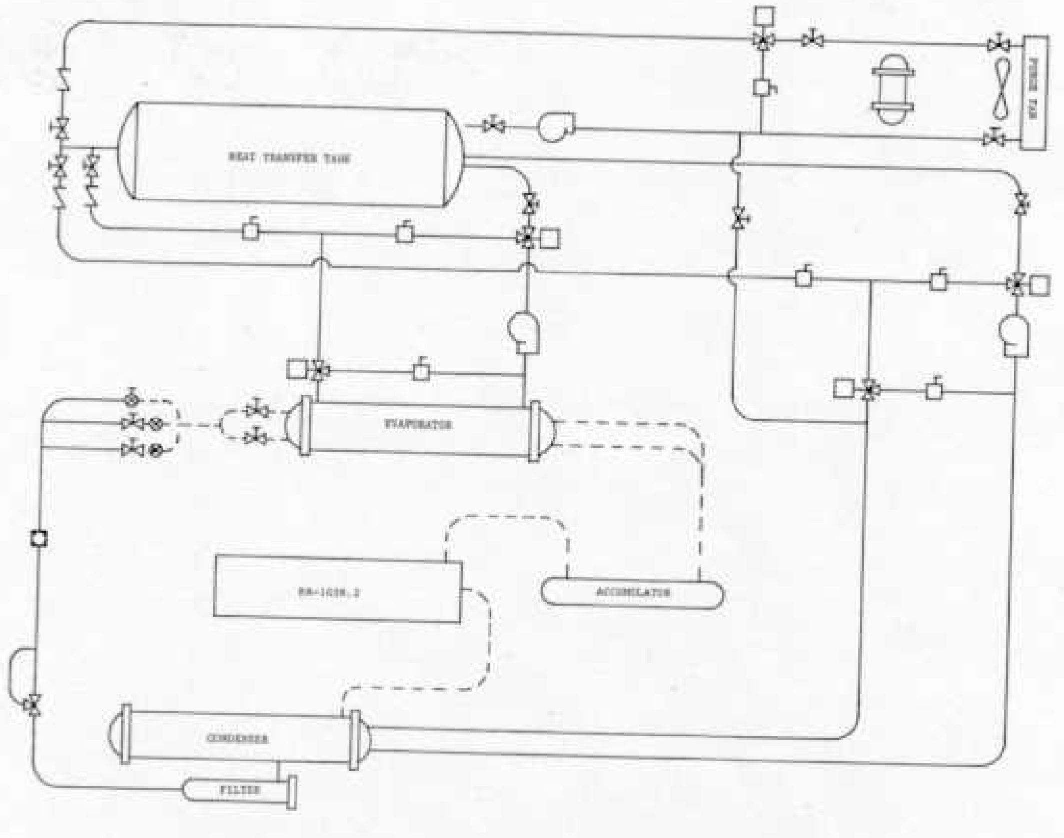

Figure 6. Simplified schematic of test rig

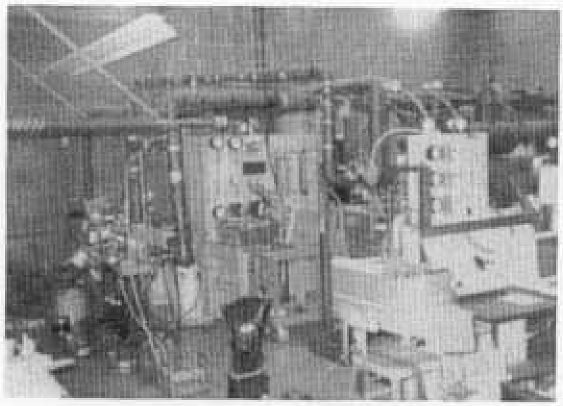

Figure 7. BR-105R.2 heat pump

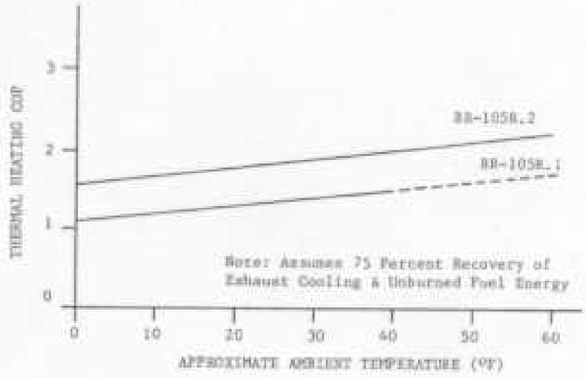

Figure 8. BR-105R.1 and BR-105.2 heat pump COP vs. ambient temperature

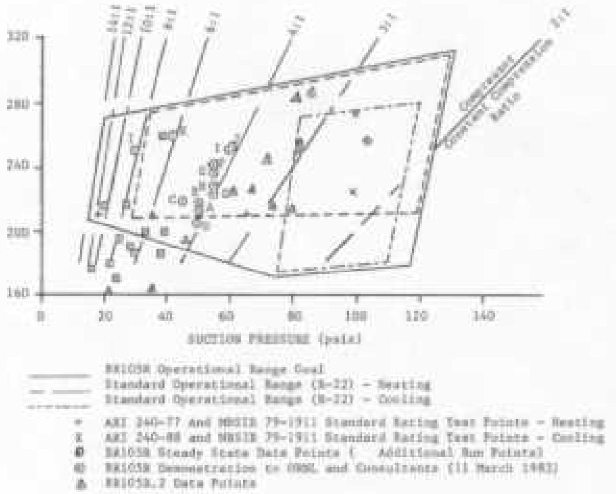

Figure 9. Operating conditions envelope

Figure 10. Data-acquisition system

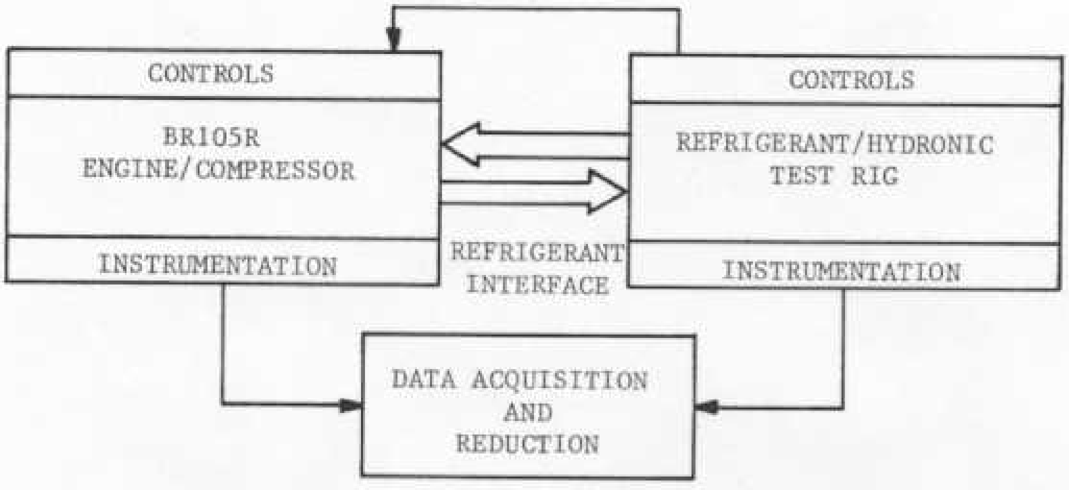

Figure 11. Basic elements of breadboard heat pump system

Discussion

J.J. FROST, Columbia Gas, Columbus, OH: Comment on first cost.

A.T. BRAUN: Considering the exceptional simplicity of the design, the small number of parts and absence of requirements for exotic materials, and unusually open tolerances, the first cost of the Braun engine should be substantially less than its conventional counterparts.

K.J. KOUNTZ, Institute of Gas Technology, Chicago: What are the projected residential air-air heat pump COPs for the Braun engine considering the higher discharge pressure and lower suction pressures in the systems, relative to the water-cooled evaporators and condensors reported on in the paper?

BRAUN: The COPs reported in the paper are based on conditions corresponding to those of conventional residential air-air type equipment. Note that the Braun engine/compressor is expected to perform better than "conventional" equipment due to the absence of lubricant in the refrigerant accomplished with the non-lube design of the Braun compressor.

G. HEBER, Frigoscandia, Bellevue, WA: How noisy are the compressors?

BRAUN: As our machines are completely vibration-free structural noise transmission is eliminated and noise control depends mainly on housing around engine/compressors. The cost of the housing is minimized because of the small size of the machine and acceptable noise levels can therefore be attained with substantially less effort than in the case of conventional units.