ENERGY CONSERVATION

ORNL/Sub/78-7229/4

Research and Development of Energy-Efficient Appliance Motor-Compressors

Volume IV—Production Demonstration and Field Test

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Work performed for

OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the

U. S. DEPARTMENT OF ENERGY

OFFICE OF BUILDINGS ENERGY
RESEARCH AND DEVELOPMENT

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A05 Microfiche A01

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ORNL/Sub/78-7229/4
Dist. Category UC-95d

RESEARCH AND DEVELOPMENT OF ENERGY-EFFICIENT APPLIANCE MOTOR-COMPRESSORS

VOLUME IV - PRODUCTION DEMONSTRATION AND FIELD TEST

SEPTEMBER 1983

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Report prepared by
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under
Subcontract 7229
for
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, TN 37830

operated by
UNION CARBIDE CORPORATION
for the
U. S. DEPARTMENT OF ENERGY
under Contract No. W-7405-eng-26

ABSTRACT

Two models of a high-efficiency compressor were manufactured in a pilot production run. These compressors were for low back-pressure applications. While based on a production compressor, there were many changes that required production process changes. Some changes were performed within our company and others were made by outside vendors.

The compressors were used in top mount refrigerator-freezers and sold in normal distribution channels. Forty units were placed in residences for a one-year field test. Additional compressors were built so that a life test program could be performed. The results of the field test reveal a 27.0% improvement in energy consumption for the 18 ft^3 high-efficiency model and a 15.6% improvement in the 21 ft^3 high-efficiency model as compared to the standard production unit.

PREFACE

This report describes the work performed in a compressor demonstration program conducted by Columbus Products Company and Kelvinator Compressor Company, both of which are divisions of White Consolidated Industries, Incorporated. This work was performed for Oak Ridge National Laboratory which is operated by Union Carbide Corporation for the U.S. Department of Energy. This program was concerned with the development of high-efficiency compressors for low back-pressure applications. The primary application was refrigerator-freezers.

Columbus Products Company performed the initial pilot compressor run. A manufacturing defect was discovered at Columbus which required reworking of the compressors. Due to relocation of the compressor manufacturing facility to Kelvinator Compressor Company, the rework was performed at that plant. Both the reworked units and those that were acceptable were assembled into refrigerator-freezers in the Columbus plant.

ACKNOWLEDGEMENTS

This work was conducted with the support of the Office of Building and Community Systems of the U.S. Department of Energy through Oak Ridge National Laboratory. The program monitor at Oak Ridge was Mr. Edward A. Vineyard.

Work performed at Columbus Products Company, to initiate production of the product, was done by the following: H.A. Almy and P.P. Hilligoss of Manufacturing Tooling; J.A. Pawlowski and E.E. Bryant of Quality Control; C.L. Trump of Drafting and Records; and D.L. Matyac and R.J. Harris of the Engineering Laboratory.

Work performed at Kelvinator Compressor Company, to rework the compressors for the product, was done by the following: R. Peuler, V.P. & General Manager; H. DeVrough of Manufacturing Engineering; C. Frazine of Manufacturing Tooling; W. Rednar of Quality Control; and R. Houser of Purchasing.

Engineers involved in this contract at Kelvinator Compressor Company were Mr. Robert W. Earley and Mr. Marc G. Middleton. Mr. Robert D. Spalink contributed his time and energy in acquiring parts and services needed for the performance of this work. Mr. Ralph E. Niven supervised the construction and testing of the compressor. Mr. R. Stuart Sauber was the program manager. Mrs. Kathleen L. Warren typed this report.

TABLE OF CONTENTS

	PAGE
ABSTRACT	iii
PREFACE	v
ACKNOWLEDGEMENTS	vii
1. INTRODUCTION	1
2. COMPRESSOR PRODUCTION	2
2.1. Engineering Drawings	2
2.2. Special Vendor Parts	2
2.3. Special Internal Parts	5
2.4. Combination Parts	8
2.5. Assembly	10
2.6. Quality Audit	11
3. REWORK	14
3.1. Engineering Investigation	14
3.2. The Rework Plan	16
3.3. Rework Compressor Components	16
4. REFRIGERATOR-FREEZER PRODUCTION	20
4.1. Engineering Drawings	20
4.2. Special Vendor Parts	20
4.3. Distribution	20
5. FIELD TEST	22
5.1. Distribution	22
5.2. Instrumentation	23
5.3. Data Collection	27
5.4. Field Test Results	27
5.5. Field Test Conclusions	42
6. LIFE TEST	45
6.1. Description	45
6.2. Results WA-080	46
6.3. Results WA-100	54
6.4. Conclusions	57
7. TEST PROCEDURES	59
7.1. Calorimeter Test	59
7.2. Pullout Test	63
7.3. Sound Test	64

1. INTRODUCTION

The purpose of this second phase was to produce two models of a high-efficiency compressor and evaluate their performance through life tests and field evaluation tests. The first phase of the project involved the development and market evaluation of the high-efficiency design.

The two high-efficiency models manufactured were the WA-080 and the WA-100. The WA-080 compressor has a capacity of 800 Btu/hr while the WA-100 has a 1000 Btu/hr capacity. The design of these high-efficiency, or W-line, compressors was accomplished through a modification of standard production, or T-line, units.

The report is organized into sections describing the production of the compressors and refrigerators along with results of the field and life tests.

2. COMPRESSOR PRODUCTION

The process of implementing the prototype design began with a series of meetings between engineering, purchasing, quality control, scheduling, manufacturing engineering, and production personnel at Columbus Products Company (CPC). Out of these meetings evolved decisions on which parts would be purchased from vendors and which would be manufactured by CPC. For those parts that were purchased outside the company, our regular vendors were used as much as possible. Work which these suppliers could not perform was sent to machine shops in the local area so that personal contact could be maintained.

Concurrent with these meetings engineering drawings were prepared. As the high-efficiency compressors, denoted as the W-line, used many production parts, inventories had to be checked to ensure adequate supplies. Some W-line parts were made with obsolete tooling. In these cases, it was necessary to check what tooling remained and to order replacement tooling if necessary.

2.1. ENGINEERING DRAWINGS

In order to perform the pilot production run, engineering drawings had to be created which covered all sources of compressor components from internal machining to subassemblies purchased from vendors. When the drawings were satisfactory to the engineering department, a release was prepared to let everyone interested become aware of a new drawing. The drawings were then taken to the Columbus Manufacturing Committee (CMC) for discussion. Following the release of a drawing, changes could still be made by the manufacturing information change authorization (MICA).

2.2. SPECIAL VENDOR PARTS

The following sections describe the compresssor components that were produced by outside companies for the production of the high-efficiency compressors. Various degrees of difficulty were required. A

limited discussion of each part is given to give a better appreciation of the change. The compressor on which the part is used is also identified.

2.2.1. CYLINDER GASKET

This cylinder gasket was used on the WA-100. Even though the 1.218 inch diameter bore had been previously used in production, it never had been produced in a low back-pressure version. Since the low back-pressure machines used a different valve stop and valve relief than the room air-conditioner (RAC) machines, a new gasket was a necessity. In order to ensure the assembly of the WA-100 compressor, we purchased over 9,000 gaskets. The reason for this was the probable tolerance distribution. T-line compressors, in one-inch bores, have historically been assembled with 0.008 inch to 0.030 inch thick gaskets. This wide range occurs, however, over a very long time. On any given compressor run about three gaskets will receive heavy usage. A large inventory assured that there would never be a shortage. The same situation was true of the WA-100 compressors. Most of the compressors built in that run would vary only a few thousandths of an inch in their gasket requirements. Our problem was that we did not have enough time between the machining of the parts and the assembling of the compressor to know where that range would fall. Our intention was to get about 375 pieces per thickness but the run yielded about 420 pieces per thickness. It should be noted that it was necessary to measure each gasket individually for thickness. The entire run of gaskets cost less than $500.00.

2.2.2. VALVE SUCTION

This suction valve was used on the WA-100. It is very similar to the valve used on our regular production low back-pressure compressors. An extended tip to accommodate the larger 1.218 inch bore is the only change. The tip is the part of the suction valve that impacts the valve stop machined in the cylinder housing.

In order to produce this valve, a die had to be made. This die stamped out the inside or reed of the suction valve after a production operation had punched the bolt holes and outer dimensions. Following the stamping work the reeds were deburred.

Upon receipt of the reeds at CPC, an incoming inspection was performed. The sample report showed that the reeds were good except for a high degree of variance in the alignment of the two punches. Normally, we would have rejected the valves and corrected the vendor set up. Due to the short time until the assembly of the compressor, this was not possible. Instead, we set up a fixture and hand sorted the entire lot of 1095 reeds. It took an inspector about one and one-half days to do the sorting, but we received enough good pieces to build the pilot production run.

2.2.3. ROTOR ASSEMBLY COMPLETE

This rotor was used by both the WA-080 and WA-100. It is completely different from the two pole rotor that was in production. The rotor in combination with the stator comprises the motor.

2.2.4. STATOR ASSEMBLY

The stators for the WA-080 and WA-100 are significantly different from each other. In order to produce the stators, dies had to be obtained to produce the laminations because the laminations had different slot configurations than the regular production motors. The laminations were then welded into stator cores and mylar slot insulation put into every slot. Next, insertion winding machinery, which had been specially set up for this motor run, installed the windings. The stator is finished by adding lead, blocking the winding end turns and tieing the windings.

2.2.5. DISCHARGE TUBE AND SLEEVE

This piece, used on both the WA-080 and WA-100, is a furnace-brazed assembly consisting of the sleeve and the discharge tube. A production sleeve used in our low back-pressure compressors was very similar to the sleeve used in this assembly. The only difference was the removal of a neck-down used on the production version. The neck-down was used to accommodate a smaller diameter discharge tube. These pilot production, high-efficiency compressors used a heavier tube. Because of the double-loop design, both the regular diameter production and the heavier diameter "W" tubes were hand bent. The sleeve was made of copper while the discharge tube was made of steel.

2.2.6. HOUSING - CYLINDER CAST

This die casting is used to make cylinder housings for the WA-100. It is identical to our regular production cylinder housing except for the sleeve. It uses a larger diameter sleeve because of the larger (1.218 inch) diameter bore.

2.2.7. SLEEVE CYLINDER

This sleeve is used on the WA-100. Cylinder sleeves are die cast into cylinder housing castings. Cylinder sleeves are cast iron. These sleeves are later bored to produce a cylinder bore that the piston will run in. The WA-100 uses a 1.218 inch bore as compared to the usual 1.000 bore. Our standard sleeve would not accept a 1.218 bore so it was necessary to make a larger diameter sleeve.

2.3. SPECIAL INTERNAL PARTS

Many assemblies required special attention from CPC manufacturing personnel. Fixtures had to be reworked in some cases to make these assemblies. In other cases, processes had to be modified in order to produce a part. Punches were changed and tooling had to be reset. In a few cases new tooling had to be ordered. The following subsections contain a discussion of the new parts and subassemblies that required

a change to produce. No discussion is given to obsolete parts that had to be retooled as there was no change involved. In these cases old tool drawings were sent out to procure the part.

2.3.1. NAMEPLATE

This nameplate is for both compressors. Production of the nameplate was a very simple process. All that was required was the purchase of a single type piece, the letter "W". The regular stamping press was set for the desired style and the nameplates were run.

2.3.2. SHELL - COMPRESSOR

The same shell was used on both the WA-080 and WA-100 compressors. It is very similar to our regular production low back-pressure shells. In order to improve return gas flow into the suction muffler, we raised the suction tube location. In the prototype compressors of Phase I, the tube had been relocated upwards by 0.250 inch. We were not able to raise it this high in the pilot production due to interference with the end head welder. The best we could obtain was 0.125 inch and still clear the welders.

In order to produce the shell, it was necessary to make two passes through the piercing dies. In the first pass the suction tube die insert was removed. Process and discharge tubes, along with the fusite locations, were then pierced into the drawn shell. In the second pass the fusite, suction tube, and discharge tube insert were removed. The suction insert was replaced and a 0.125 inch thick shim was inserted to relocate the suction tube pierce.

Tooling costs were extremely inexpensive using this system. Only a shim was required. An entirely new pierce insert would have probably cost about $2,500.00. Personnel utilization, however, could have turned into a major problem. This procedure required two set-ups instead of one, doubling those manpower requirements. The piercing operation ran at only 50% of its normal rate since it required two passes instead of the usual one.

2.3.3. SHELL ASSEMBLY

Both the WA-080 and the WA-100 used this shell assembly. Standard suction and process tubes were used. The electrical terminal and fence were standard. A regular low back-pressure mounting arrangement was used.

2.3.4. DISCHARGE MUFFLER ASSEMBLY

This assembly is used on both the WA-080 and WA-100 compressors. There are no new parts contained in the assembly. The assembly is a recombination of existing production parts. A larger diameter hole was needed in the muffler outlet shell to accept the larger discharge tube. Basically this muffler assembly is a marriage of the high back-pressure outlet shell and the low back-pressure baffle and inlet shell.

2.3.5. DISCHARGE MUFFLER AND HEAD ASSEMBLY

A standard low back-pressure head assembly is silver soldered to the special discharge muffler assembly to create this assembly. It is used on both of the high-efficiency compressors produced. Regular production fixtures were used to produce the assembly.

2.3.6. DISCHARGE MUFFLER TUBE AND HEAD ASSEMBLY

This assembly is the result of joining the discharge muffler and head assembly and the discharge tube and sleeve assembly. A fixture is used to position the discharge tube and discharge muffler. Silver solder is used to make the joint. Both the WA-080 and the WA-100 use this assembly.

2.3.7. DISCHARGE MUFFLER, HEAD ASSEMBLY, AND DAMPENER

Following the soldering operation to create the above assembly, two rubber dampeners are secured to the discharge tube by two metal clips. One dampener is located on the discharge tube just after it comes out

of the suction muffler, the other is positioned about three inches from the shell. The purpose of these dampeners is to reduce the vibration of the discharge tube, resulting in a quieter compressor. These dampeners have been used on all the low back-pressure compressors built at CPC. They are also used on both models of the high-efficiency design.

2.4. COMBINATION PARTS

In preparing to produce the WA-080 and WA-100, we needed two basic parts which we could neither produce ourselves or purchase easily. These were the crankshafts for both compressors and the WA-100 cylinder housings. Production tooling was similar to what was needed, but the modifications were still quite expensive. After several discussions about possibilities involving the CPC production tool room, engineering model shop, and off-line manufacturing floor operations, it became apparent that we had to take this portion of the production to an outside machine shop. Originally we had contemplated procuring these parts through vendors. The realization that a vendor would have to completely tool these parts led us to the solution of CPC doing partial machining and having an outside machine shop do partial tooling. As it turned out, for both the crankshafts and cylinder housings, we did some rough machining, sent the parts outside for some detail finishing and returned the parts to CPC for final grinding, honing, deburring, and other operations. The two sections below describe the necessary operation for these parts.

2.4.1. HOUSING - CYLINDER MACHINED

This housing is used on the WA-100. There are five major differences between it and our production cylinder housing. They are: (1) the bore diameter has been increased from 1.000 to 1.218 inches; (2) the tip of valve stop radius has been relocated from 0.620 inch from the centerline of the bore to 0.770 from the centerline; (3) valve stop radius has been increased from 0.140 to 0.150; (4) the centerline of

the valve relief radius has been changed from 0.495 to 0.605 inch from the bore centerline; and (5) the chamfer on the bore was reduced from 30° to 15°.

Two of these requirements presented major problems in our tooling situation. These were the relocation of the valve relief and valve stop in relation to the bore center. While we could easily modify the diameter of the valve radius or valve relief, we could not change the location relative to the centerline of the bore. After much discussion, it was decided that the most sensible course to take would be to have an outside machine shop perform these operations.

The course of events then started with CPC heat treating the raw castings to stabilize them for machining. This is normal for all our die cast work. Within CPC we called this heat treating operation "processing". The processed cylinder housings were rough machined. This put in the locators, rough bore, and rabbet fit that would be necessary to mount it to the motor housing. We then sent the housings to have the valve relief and valve stop machined. We then machined the deck, spring locations, and honed the bore completing the cylinder housing.

Since the valve stop and relief must have a very flat surface to ensure long life of the suction reed, we have always used specially ground end mills rather than the regularly available mills. We supplied the mill for the valve relief and ordered a 0.160 inch radius mill for the valve stop as we used 0.150 inch radius in production.

2.4.2. CRANKSHAFT MACHINED

The basic four pole crankshaft is used on the WA-080 and WA-100 compressor. The only difference between these two styles is the throw of the crankshaft. A combination of internal and external machining was necessary to produce these crankshafts.

Initially, the crankshaft castings were rough machined on the production crankshaft line at CPC. The rough machined parts were sent outside to put in the oil groove all the drill operations that included the radial holes, eccentric hole, cross fed hole, and crankpin hole. Upon their return to CPC, we performed the grind operations on the crankpin, main bearing, lower bearing, and thrust face. We also performed the ream of the crankpin hole to the necessary dimensions to accept the plug. These operations were the final steps to completing the crankshafts.

2.5. ASSEMBLY

Due to all the preparation work, the pump assembly went very smoothly. The pumps were produced at the normal production rate. The pump and shell assembly, as well as the operations completing the compressor went as well as regular production. From the start of the first pump assembly to the final skidding of the last compressor took about three days. The actual time at any operation was about one and one-half days, but it takes about that long for any single compressor to work its way from the beginning of the assembly line to the skidding area.

2.5.1. PUMP ASSEMBLY COMPLETE

This assembly is the compressor without the shell. It is the complete mechanism as it comes off the assembly line before it is put into a shell. There were some fixture changes needed to assemble the pumps. One of the changes was in the automatic head gasket selection. At this station, a servo mechanism rotated the crankshaft while a transducer measured the height of the piston above the deck. The computer then selected the proper gasket. A problem occurred because the servo mechanism rotated the crankshaft by a spiral tube which extended from the crankpin. On the 'W' compressors we removed the tube and replaced it with a plug. A new fixture was made so that the mechanism would rotate on the top portion of the crankpin.

Another problem occurred in assembling the piston ring to the piston on the 1.218 inch bore of the WA-100. The piston rings are lined up

on a spring loaded mandrel. The piston is then pushed against the mandrel expanding the piston ring and slipping it onto the piston and seating in the piston groove. In order to assemble this larger piston assembly, we had to make a new mandrel. The piston ring assembly operation is performed by hand.

2.5.2. PUMP AND SHELL ASSEMBLY

The pump is put into the shell by feeding the discharge tube through the shell at the proper opening. Next, the electrical cluster is connected to the electrical terminal. Springs are then mounted on the spring brackets. Finally, the extension piece on the discharge tube is silver soldered to the shell. The pump and shell assembly are then put on pallets and run through the dehydration oven for about two hours.

2.5.3. COMPRESSOR COMPLETE

Immediately following the dehydration ovens an end head, or top shell, is positioned on the compressor. Each compressor is put on an individual pallet on a conveyor line. This line feeds the end head welder. While still hot from the dehydration process, the weld is made. Compressors are then sent to the leak tank where compressors are submerged, pressurized, and checked for leaks. Those compressors which are found to leak are set aside for repair. Units which are acceptable are then sent to the paint line where the compressors are masked and then painted by being submerged into a tank of paint. Painted compressors then proceed through a drying oven. As the units come out of the oven, a date code is stamped onto each compressor. The compressors are then skidded for storage until needed for production.

2.6. QUALITY AUDIT

All through the demonstration project we had been performing usual quality audit operations. Following the completion of welding of the

shell, it was normal to perform a calorimeter test and teardown operation. A teardown compressor showed signs of melting of the plastic muffler, Figure 2-1. The muffler had been released to production for another compressor but never used. Only slight melting was seen in the QA teardown machine. A readjustment of the end head welders was found to reduce the problem. At this time a decision was made to finish the pilot production run as it was more than two-thirds complete.

In the week following the production period, it became obvious that the melting problem was far more common than had been thought. Every compressor torndown showed some signs of melting; quite a few were extremely severe. With this knowledge, we began to seek some way to determine good units from bad units. After a series of calorimeter tests, it was judged that a small partial melt was acceptable. No muffler melting has ever resulted in a piece of plastic becoming detached from the main body of the part.

Using the guidelines we developed, all of the pilot production compressors were sorted. Sorting was done by visual inspection using a flexible fiberoptic lense. This visual inspection was performed by engineering personnel and took three days to complete. It was about three months after the pilot production that the sorting took place. Results of the sorting were quite disappointing with approximately two-thirds of the compressors judged unacceptable.

As the relocation of the compressor manufacturing facilities to Kelvinator Compressor Company (KCC) had begun before the sorting of the pilot production run, nothing was done for several months with the compressors. During this time, cost estimates were established, part availability checked, and a rework plan established. Discussions with ORNL lead to a discussion to undergo the rework process described in Section 3.

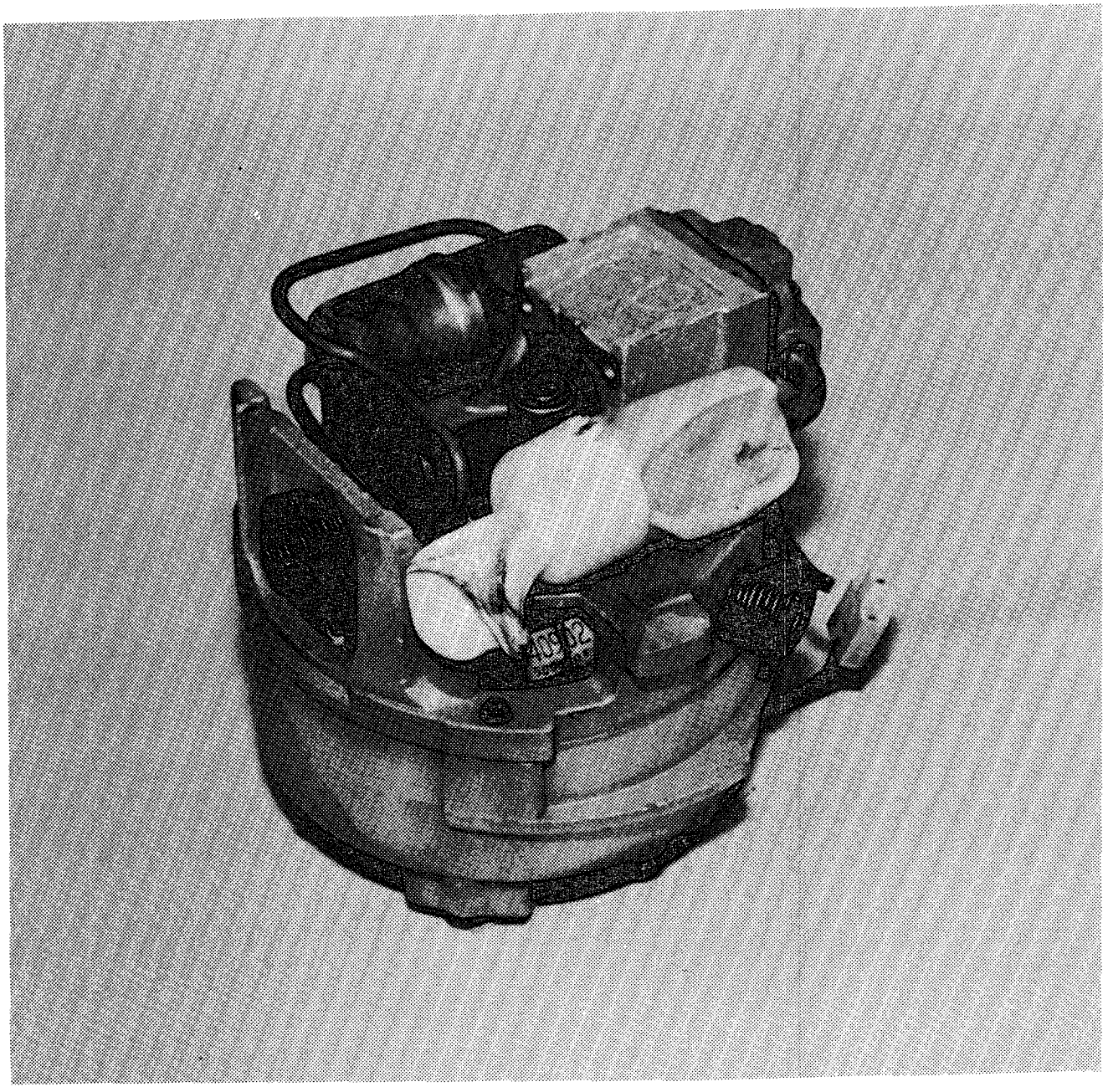

Figure 2-1. Torndown Compressor With Melted Muffler

3. REWORK

The rework was performed at KCC in January 1982. Some of the procedures that were described for the pilot production at CPC also occurred at Kelvinator. There was a series of planning meetings much like CPC, but they were far less involved. Outside parts were bought while others were internally made. The rework process was based on an engineering investigation.

3.1. ENGINEERING INVESTIGATION

Approximately three weeks after the conclusion of the pilot production, we began an engineering investigation into the muffler melting problem. Our initial effort centered around the weld seam. We thought that by controlling the starting and stopping position of the weld, we might prevent the suction muffler melting. Test compressors were prepared which had suction mufflers with a temperature indicating wax applied to their surfaces. In addition, thermocouples were inserted into the compressor shell at the area of the suction muffler inlet.

Test welds were then made on the compressors. The thermocouple results were very close to those obtained by the temperature-indicating wax. No matter where we started the weld seam, we were unable to prevent the melting. These tests did show, however, that a reduction in temperature of about 100°F would result in minimal melting if any.

Based on this, we began to evaluate our thermoplastic resin selection. Previous testing had shown that glass reinforced Valox could withstand higher temperatures. In operations, the glass in the plastic ate away at the aluminum cylinder housing where they came into physical contact. These findings were based upon a thirty percent glass filling of the polyester resin.

A review of the data sheets on the resin showed that a 15% glass filled resin would melt only about 20°F below the 30% filled resin. The 15% glass filled resin is designated DR-51. We immediately ordered

new samples of the suction muffler molded out of DR-51 resin. Repeating our welding tests with the DR-51 mufflers yielded only trace amounts of melting around the inlet to the suction muffler. To avoid this melting, we modified the suction muffler inlet to move it about a quarter of an inch from the compressor shell. Repeating again, the weld test yielded no signs of suction muffler melting, Figure 3-1.

As a further guarantee, a change in the manufacturing process at KCC reduced the compressor temperature at the time of welding. This process change involved performing the dehydration of the compressor after welding rather than before. This process change reduced the compressor temperature during welding from about 180°F to the factory ambient temperature. This change ensured the success of the rework operation.

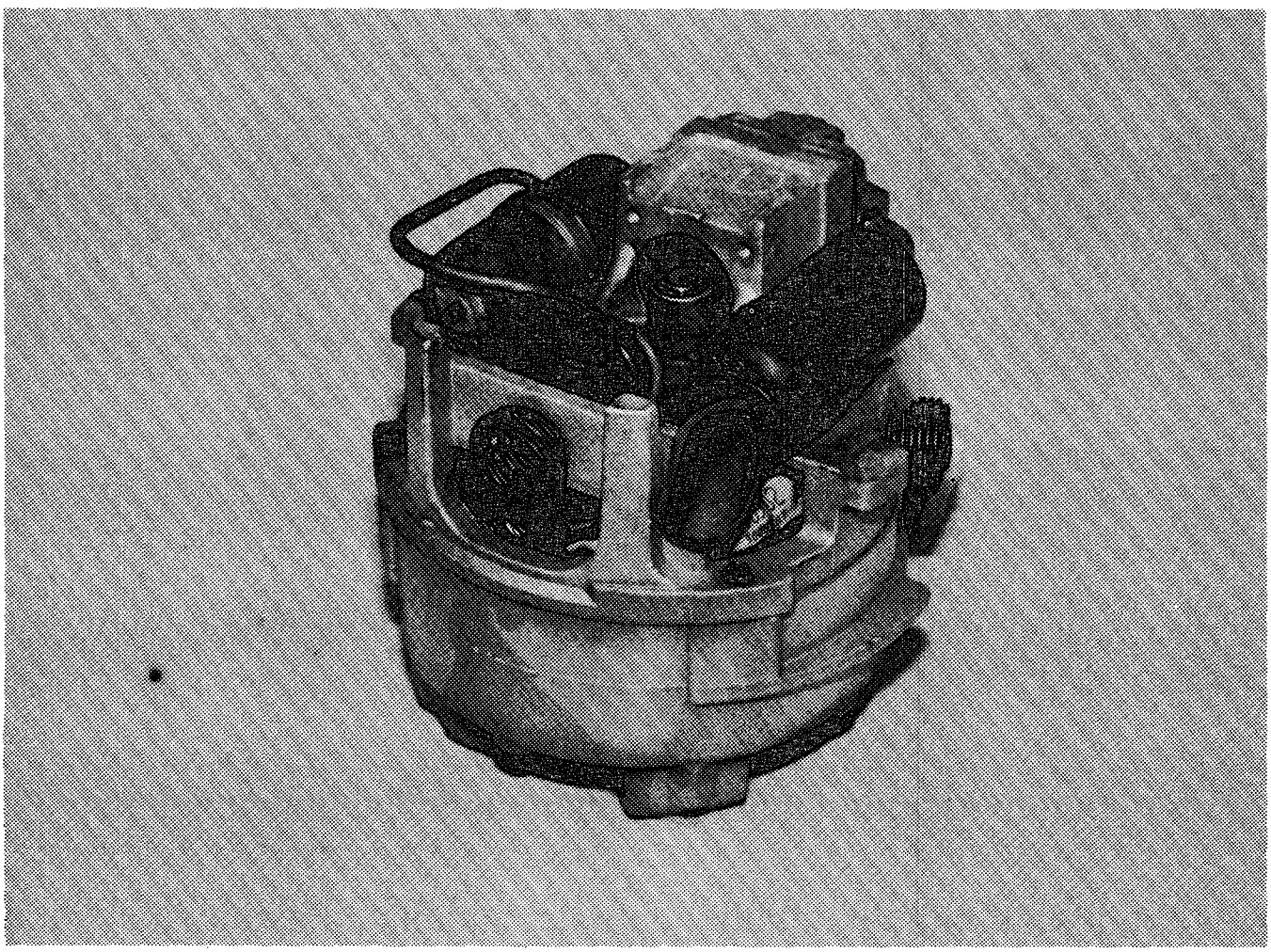

Figure 3-1. Modified Suction Muffler

3.2 THE REWORK PLAN

Basically the rework plan was quite simple. Rather than try to repair all the compressors at once, we decided to process them in batches. Our goal was to process about 120 compressors a day. The first step was to cut off the end head or top shell, Figure 3-2. Next, a pair of diagonals would be used to cut the discharge tube. The electrical cluster would be removed from the terminal. Mounting springs could then be removed from the spring holders filling the pump assembly.

Once the pump assembly was free, it was put into a fixture. The screw was removed that held the melted muffler in place. A torch was used to melt the silver solder joint that held the remains of the discharge tube. A new discharge tube was soldered to the discharge muffler. A new plastic suction muffler was installed. At this point the pump assembly was put into a new shell assembly, Figure 3-3. The top shell was welded in place. Reworked compressors were then leak checked. Following the leak check, the units were painted and then dehydrated. An electrical high voltage test was performed. Finally the units were put on skids for shipment to CPC.

3.3. REWORK COMPRESSOR COMPONENTS

The following sections contain a description of new parts which were needed for the rework operation. It is not a long list due to the fact that most of the original compressor was salvaged.

3.3.1. SUCTION MUFFLER REAR

This is physically the same part as was previously used. The only difference is the grade of plastic was changed from Valox 310 to Valox DR-51. This change boosted the deformation temperature by 100°F.

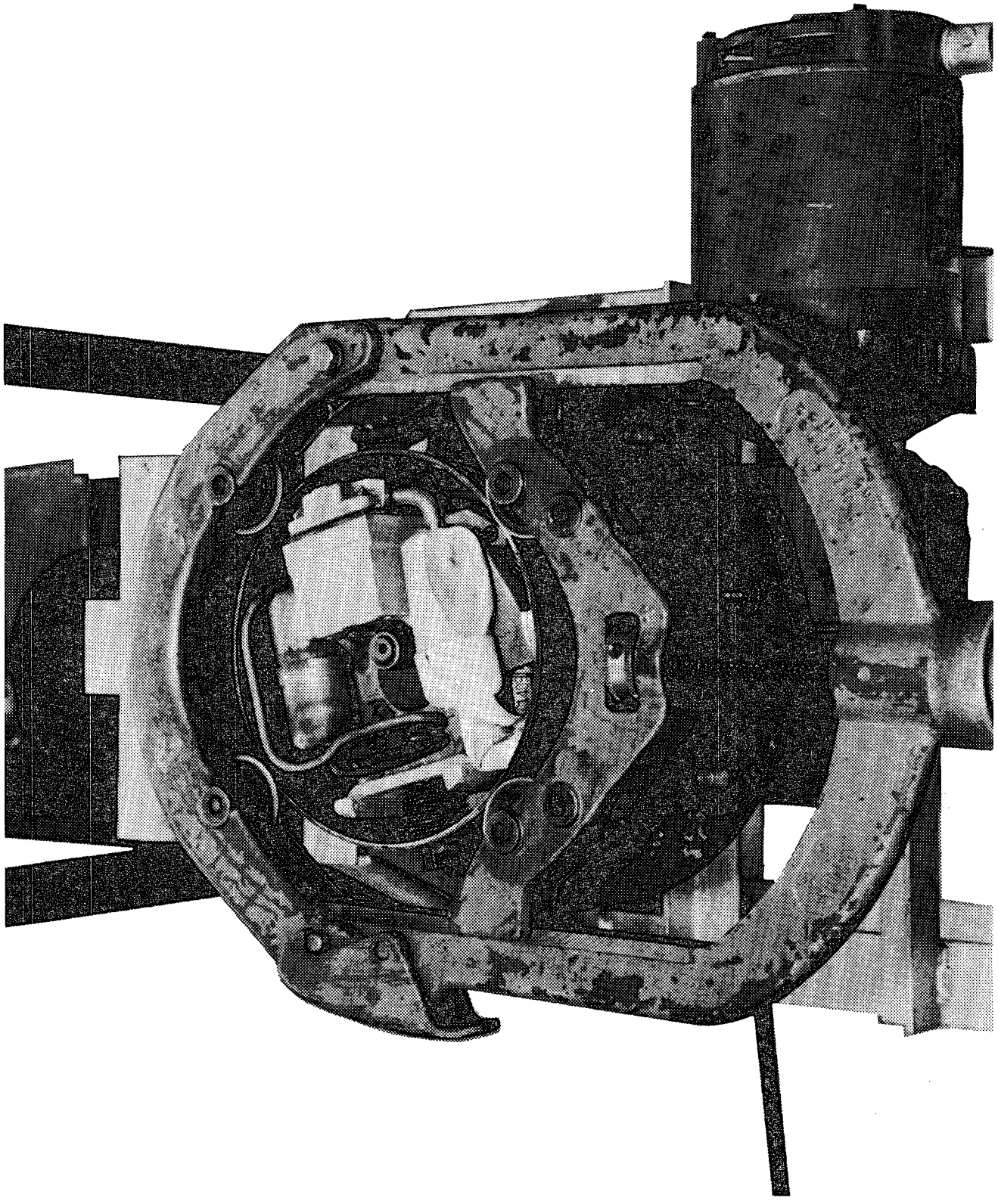

Figure 3-2. Cutting Off End Head of Compressor

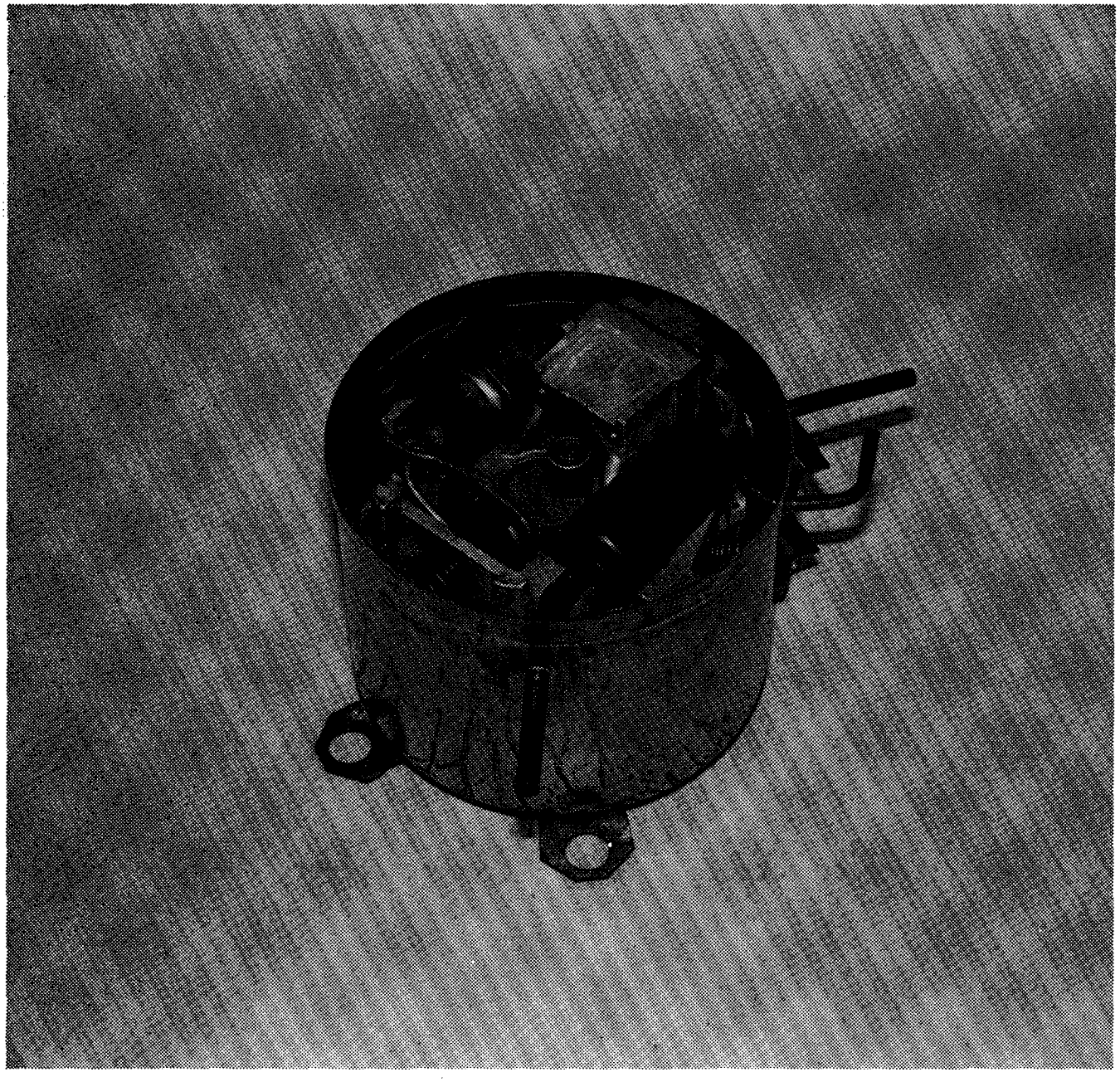

Figure 3-3. Reworked Compressor

3.3.2. SUCTION MUFFLER FRONT

A change in the grade of plastic was also made in this part. Additionally, the muffler inlet was modified to move it farther away from the weld seam on the shell. Testing has shown very little if any reduction in compressor performance as a result of this design change. It should be noted that we changed the color to black from the original natural colored Valox 310 to avoid any possibility of confusion during the rework process.

3.3.3. LOWER SHELL ASSEMBLY

This shell assembly has four mounting feet. The original shell assembly made at CPC used only three which had been the standard for the T-line compressor. The foot pattern was changed because the machine compartment of the White-Westinghouse refrigerator had been changed to accommodate a K-line compressor. It was necessary for CPC to use K-lines during the relocation of the T-line manufacturing facility.

Another change to the shell assembly was in the tubing. The process tube is used to charge and evaluate the compressor and system. The original shell assembly has a tube which was present and swaged out at the end. Our four foot version utilized a straight piece of tubing that had the same diameter as the swage on the original tube. This change was made to standardize parts as much as possible between the models of compressors built at KCC.

3.3.4. NAMEPLATE

A discussion of the nameplate is only significant because it carries the part number of the reworked compressor. KCC does not use letters in their part numbers as had CPC. In order to differentiate the reworked compressors from those that were judged acceptable, yet maintain a continuity, changes in the part numbers were necessary.

4. REFRIGERATOR-FREEZER PRODUCTION

The process of implementing the compressor design into refrigerator cabinets began with a series of meetings with engineering, purchasing, quality control, scheduling, manufacturing engineering, and production personnel at CPC. These meetings produced the schedules for parts purchase and manufacturing schedule to produce the refrigerators containing the new compressor design.

Concurrently with these meetings engineering drawings were prepared.

4.1. ENGINEERING DRAWINGS

In order to run a production lot of refrigerators containing the 'W' compressor design, engineering drawings had to be created. When the drawings were satisfactory to engineering, a release was prepared. This is the mechanism that lets everyone become aware of a new drawing. The release and drawing were then taken to a meeting of CMC. Following this release, it is then scheduled into production.

4.2. SPECIAL VENDOR PARTS

In order to use the 'W' compressors in the refrigerator cabinets, it was necessary to use some electrical components not normally used in production of the standard refrigeration units. Components, such as the capacitor with its attaching wire harness, clamp, and cover, had to be scheduled and purchased in order to run a production lot of refrigerators.

4.3. DISTRIBUTION

Distribution of these cabinets was done through the normal marketing network. The high-efficiency compressors were installed into standard production refrigerators. These cabinets were not segregated as being different in energy consumption, therefore, they entered the consumer

market on a random basis. The compressors in these cabinets are marked so that if a failure occurs in the field, the compressor will be torn down to determine the nature of the failure.

5. FIELD TEST

The field test consisted of forty refrigerators which were placed in residential applications. There were four refrigerator models which made up the field test group. Those models are: RT180EC, RT210EC, RT185DC, and RT215DC. Originally the field test demonstration was envisioned to last six months during which intensive monitoring of the refrigerators would be conducted. Following this six month period an extended thirteen month surveillance would be conducted but on a reduced basis. It had been thought that certain instrumentation would be removed between the intensive and reduced emphasis test.

Additional engineering efforts brought the realization that significant monitoring of the field test units would be extremely difficult. The areas which would be considered included: the number of door openings, the length of those door openings and hourly analysis of ambient temperature, the thermostatic setting of the refrigerator, the setting of the anti-sweat heater switch, and the relative humidity at the user's location. In the end it was decided to only monitor the power consumption for approximately one year, due to the enormous problems of data collection and the physical size of the instrumentation.

5.1. DISTRIBUTION

The refrigerators in the field test are primarily located in the state of Michigan. There are some units, however, located in Alabama, Tennessee, Vermont, Ohio, and Washington, D.C. The units are in urban, suburban, small towns or villages, and rural areas. Participants in the program range from single-member households to family units consisting of five members. Ages of household members in the field test group have been newborn to early seventies. Employment status among adults were basically working people with a few retirees.

5.2 INSTRUMENTATION

In our search for suitable kilowatthour meters, we came across a rather novel device. This device is a solid-state kilowatthour pulse initiator, Figure 5-1. The pulse initiators filled one of our most basic requirements. That being that the instrumentation package should not be obvious to the field test participants, Figure 5-2. This then helped remove any biasing of the test data.

After testing two pulse initiators at CPC, we placed a purchase order to acquire forty units for the field test. It is possible to obtain the pulse initiator with a variety of pulse rates. Owing to some accuracy consideration, we acquired pulse initiators that would send a signal out for every ten watt-hours consumed. In our actual application we took the center tap and wrapped it with ten turns of wire thereby reducing the initiators output to one pulse for every 100 watt-hours. The pulse is fed to an electro-mechanical counter, Figure 5-3. Consequently, this counter records every 100 watt-hours of power consumed.

After having done this we took several units and checked them against a standard rotating appliance kilowatthour meter. We discovered that, despite the manufacturer's claim, wrapping the center tap did not improve accuracy. Therefore, the field test units which had not been shipped to participants were all individually checked. The units checked ranged from 63.7% to 115.9% of the actual power consumed. With this data we then established correction factors for each of these field test cabinets. Only five refrigerators have pulse initiators which do not contain a correction factor.

An additional problem with the pulse initiators developed. Of the forty that we received, approximately six or seven would not function at all. Numerous calls and letters to the vendor produced only a minimal response. As a result we sent a member of our engineering department to the vendor along with the defective units.

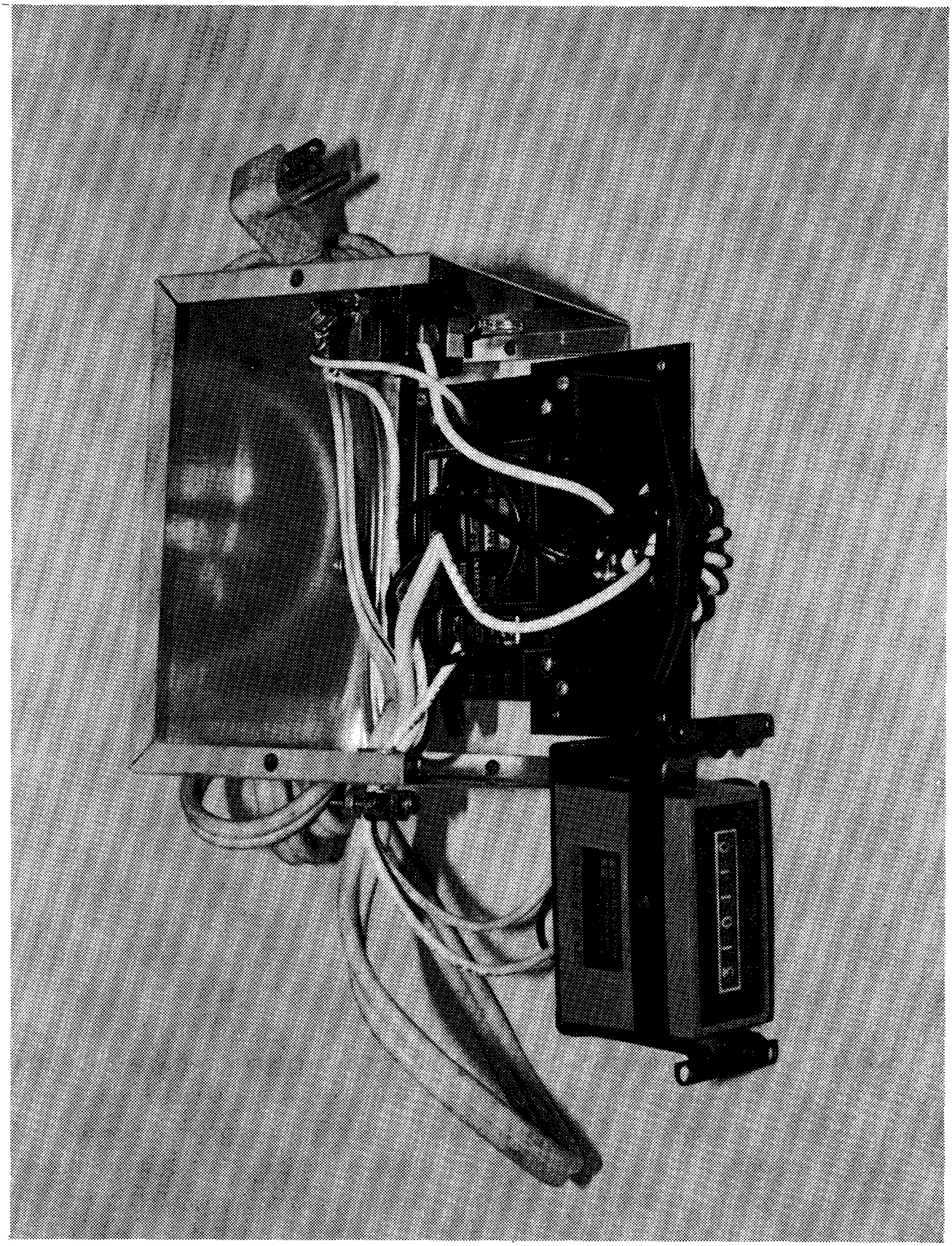

Figure 5-1. Pulse Initiator Package

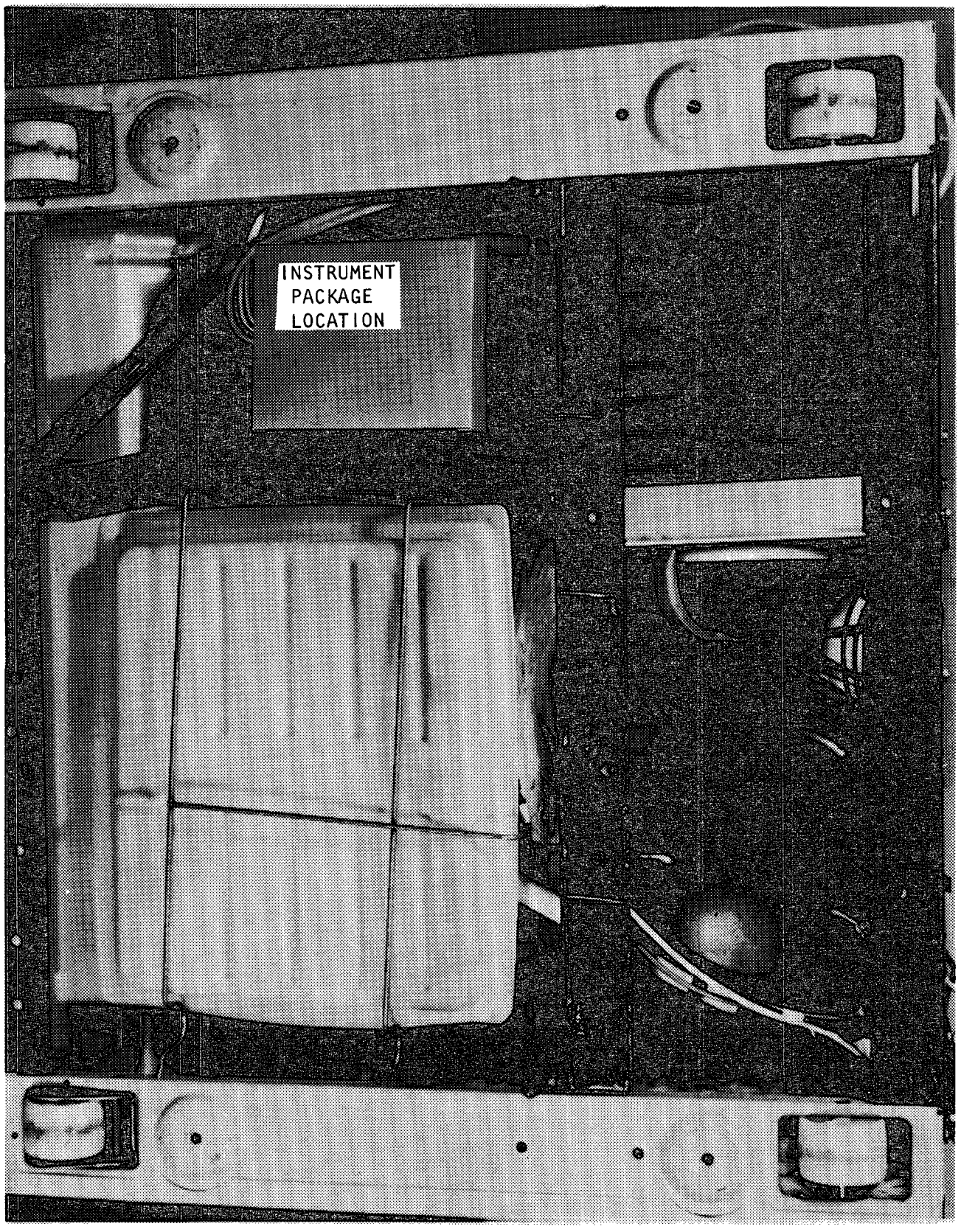

Figure 5-2. Instrumentation Package Location

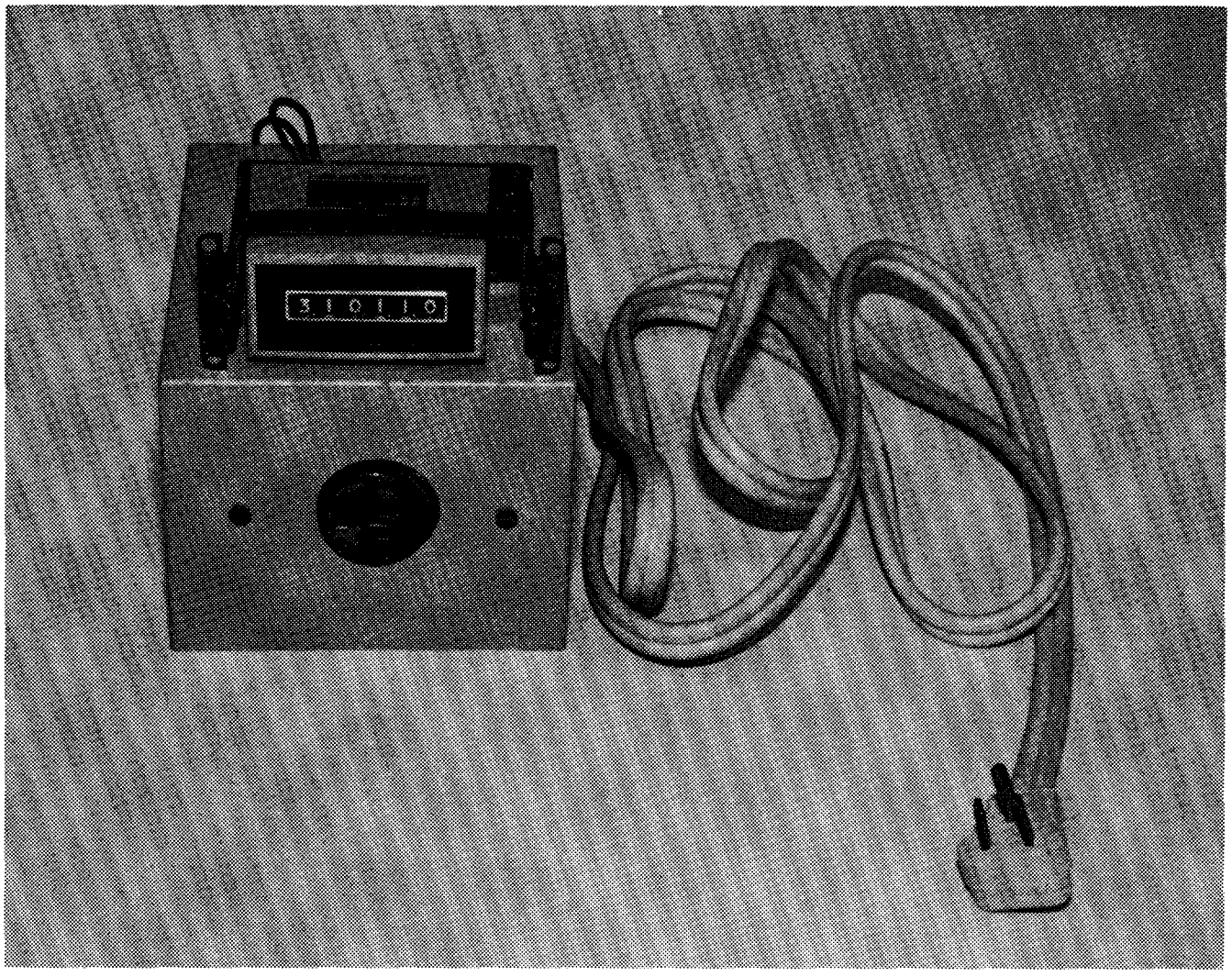

Figure 5-3. Electro-Mechanical Counter

This trip was quite successful with all but two of our pulse initiators being put into operating order. It appears that if a pulse initiator operates for about three or four days that its reliability indeed becomes quite high. We had two or three pulse initiators fail while undergoing correction factor testing at Kelvinator. No units, however, to date have failed in the field test. Additionally, our testing has confirmed that the accuracy problems are linear. That is, if an initiator indicates one percent high at a low power consumption level, it will also indicate one percent high at a high power consumption level.

5.3. DATA COLLECTION

All field test participants were required to fill out a questionnaire prior to receiving their field test cabinet. While participants were generally consulted on the color of their unit, they were not given free choice regarding the compressor utilized in those refrigerators. A copy of the questionnaire, that was filled out by all the participants, is shown in Figure 5-4.

Power consumption readings are taken on a monthly basis by field test participants and mailed to KCC. In addition, the date is recorded so that kilowatthour per day figures may be developed for each refrigerator.

Additionally, the ambient temperature that the field test cabinets are placed in is recorded. An example of this field test data collection postcard can be seen in Figure 5-5. These postcards are stamped and preaddressed so that every incentive is given to the field test participant to respond.

5.4. FIELD TEST RESULTS

The application of the 'W' compressors to the cabinets for production is illustrated in this section. Performance of the RT18 cabinets, which used the WA-080 compressors, is represented by Figures 5-6 through 5-9. Figure 5-6 is of a cabinet with a standard production compressor. Figure 5-7 is a composite of the data obtained from two sample cabinets with 'W' compressors, Figures 5-8 and 5-9. Performance of the RT21 cabinets, which used the WA-100 compressors, is represented by Figures 5-10 through 5-14. Figure 5-10 is of a cabinet with a standard production compressor. Figure 5-11 is a composite of three sample cabinets with the WA-100 compressors, Figures 5-12, 5-13, and 5-14.

Kelvinator
COMPRESSOR COMPANY
1545 CLYDE PARK, S.W. • GRAND RAPIDS, MICHIGAN 49509

One of the White Consolidated Industries
WCI

FIELD TEST QUESTIONNAIRE

Name _____

Address _____

City _____ State _____ Zip _____

1.) Will the refrigerator be located at the above address? _____
If not, please write address here. _____
_____

2.) In what room of the residence will the refrigerator be located?
(kitchen, utility room, etc.) _____

3.) Is this room heated? _____ What is its average temperature? _____

4.) Is this room air conditioned? _____ What is its average temperature? ___

5.) Please write in the number of permanent household members that are in each age category.

MALES				FEMALES			
0-5	_____	26-35	_____	0-5	_____	26-35	_____
6-10	_____	36-45	_____	6-10	_____	36-45	_____
11-15	_____	46-55	_____	11-15	_____	46-55	_____
16-20	_____	56-65	_____	16-20	_____	56-65	_____
21-25	_____	Over 65	_____	21-25	_____	Over 65	_____

6.) Will this refrigerator be the only one in use at this household? _____
(If answer is yes, skip to question #8)

7.) Will this refrigerator be the primary unit at this household? _____

8.) Will this refrigerator be an additional unit or a replacement unit in your household? _____

9.) If this refrigerator is a replacement unit, please write in the make (Kelvinator, G.E., Frigidaire, etc.), size in cubic feet if known, and approximately age. _____

10.) If this refrigerator will be used for other purposes than the freezing and refrigeration of household food, please indicate that use._____
_____

Thank you for your cooperation!

Figure 5-4. Field Test Questionaire

BELDING PRODUCTS COMPANY
115 EAST MAIN STREET
BELDING, MICHIGAN 48809

ATTN: D.O.E. COORDINATOR

ENGINEERING

READ METER AT BOTTOM-FRONT OF

REFRIGERATOR – FILL OUT CARD

BELOW AND DROP IN THE MAIL:

METER READING ☐ ☐ ☐ ☐ ☐ ☐

DATE READ _____ ROOM TEMP _____ °F

NAME _____

Figure 5-5. Field Test Postcard

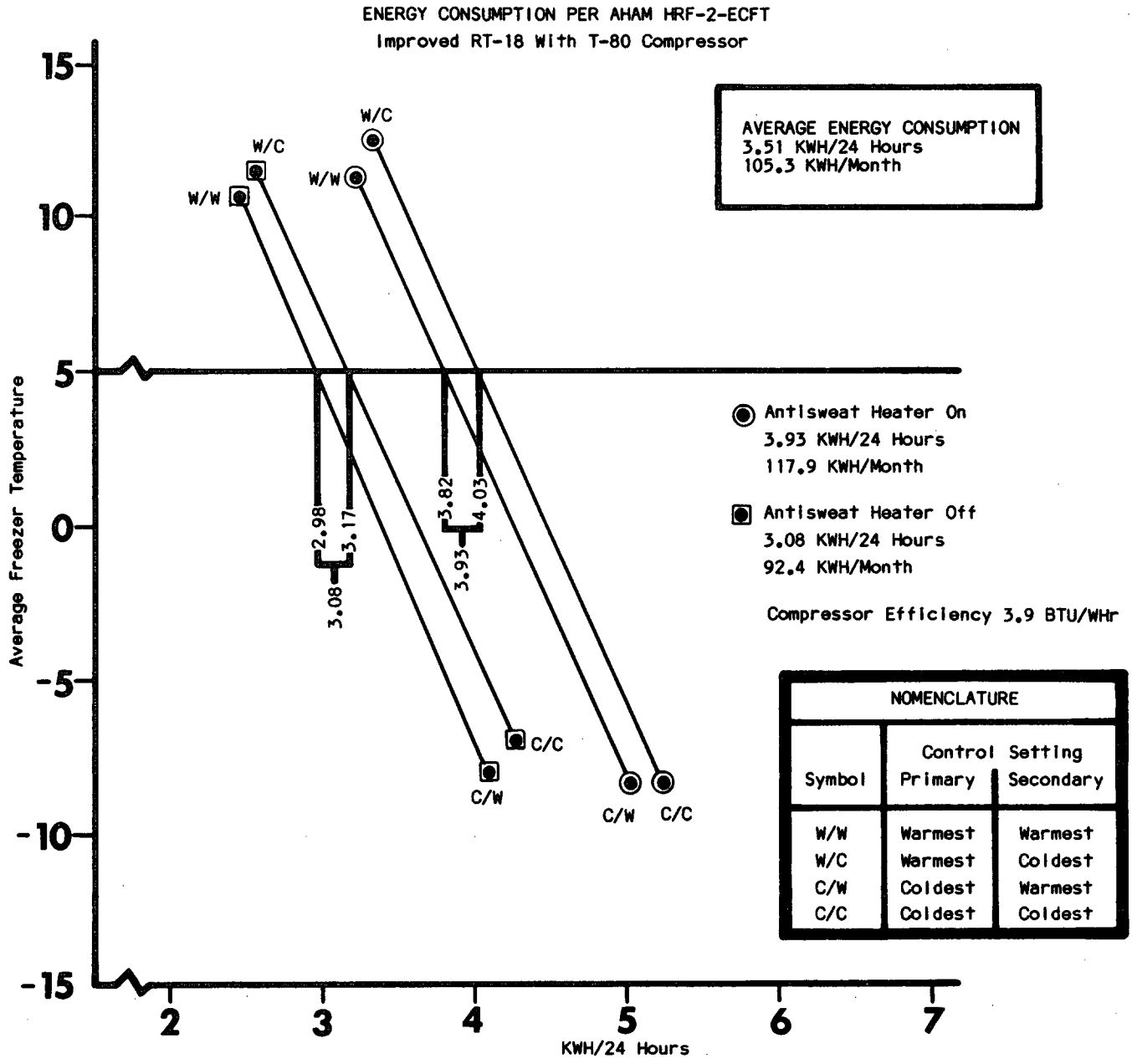

Figure 5-6. Production RT18-T80 Compressor

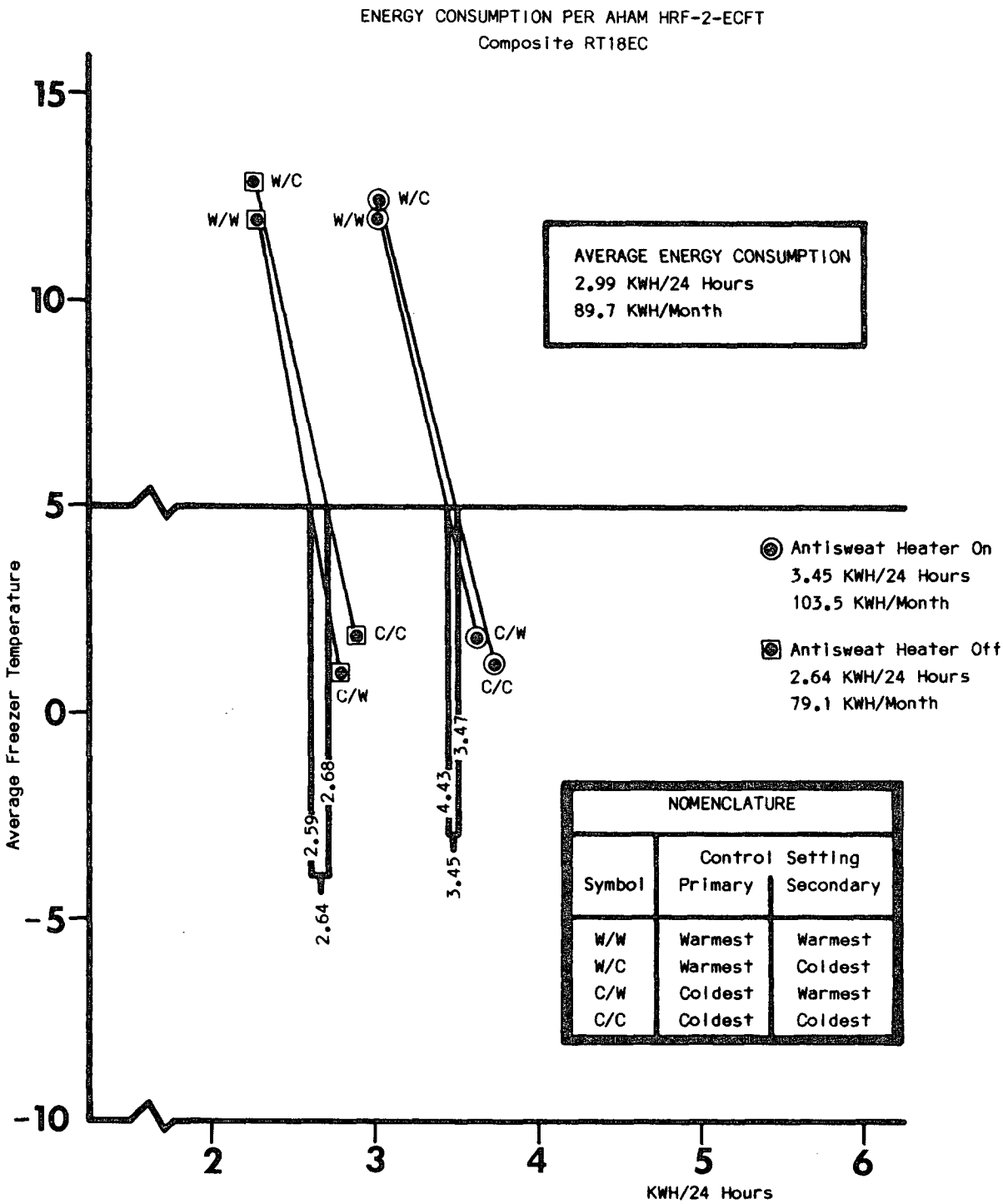

Figure 5-7. Composite of Two RT18 Cabinets With 'W' Compressors

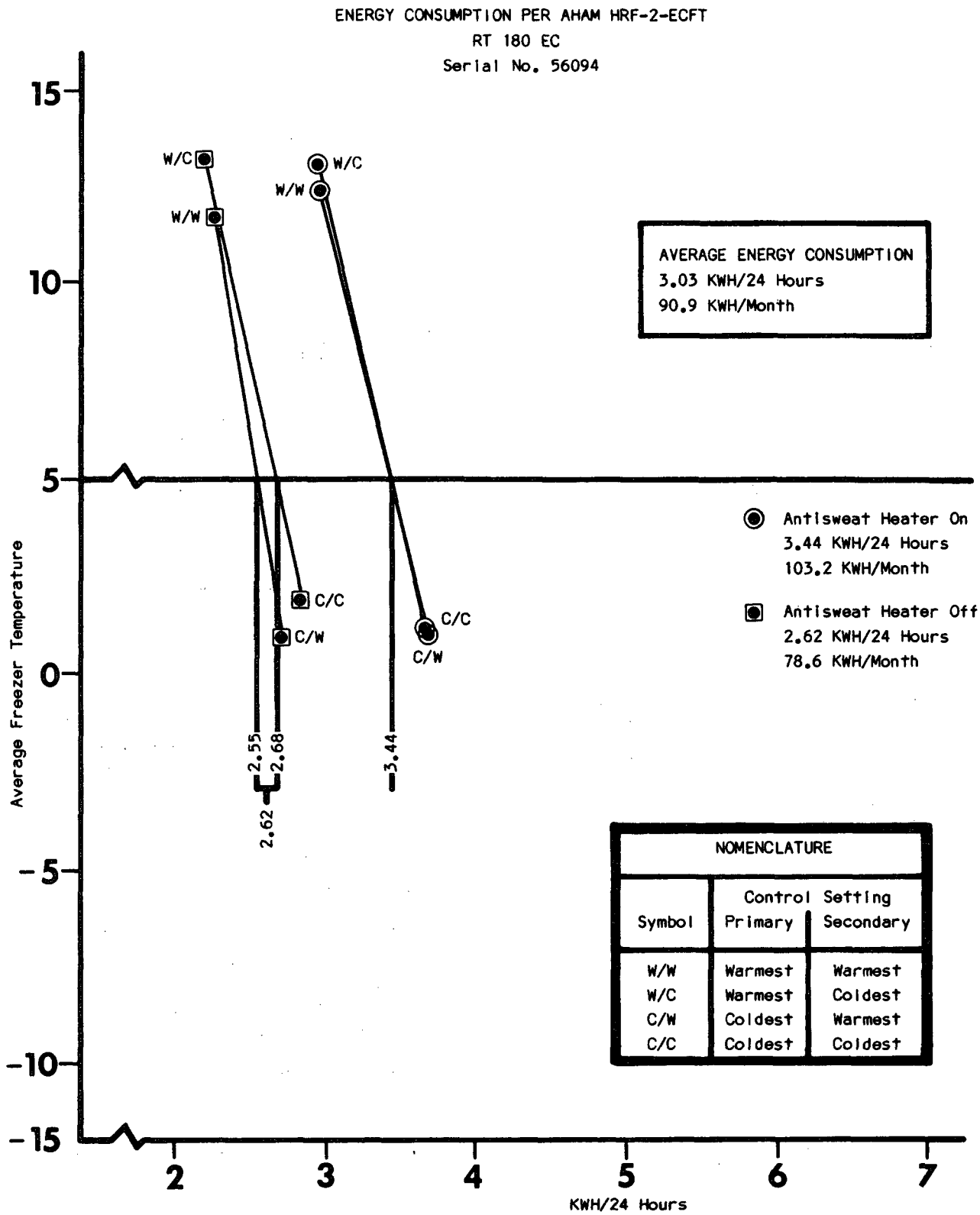

Figure 5-8. Sample 1 - RT18 - 'W' Compressor (56094)

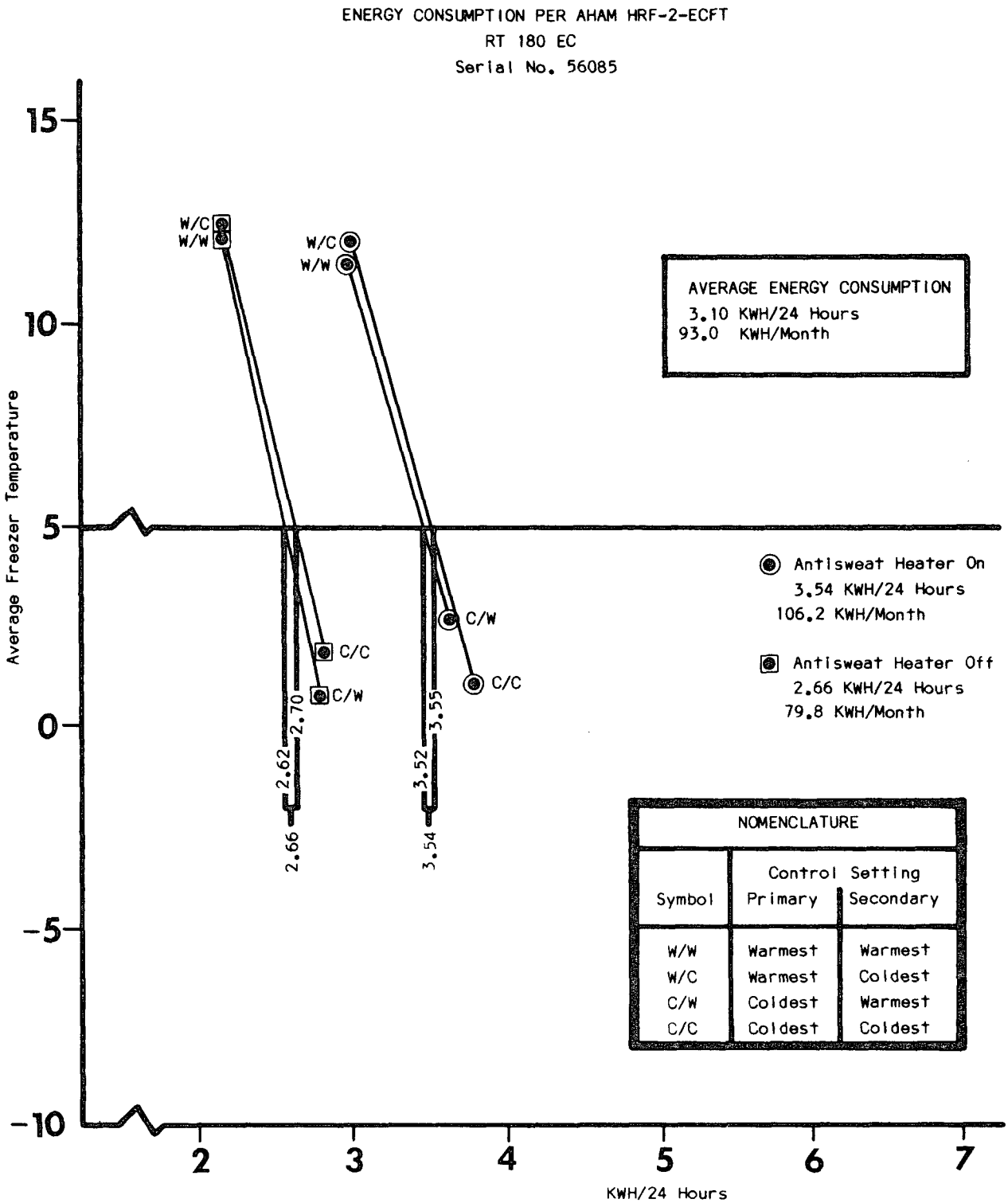

Figure 5-9. Sample 2 - RT18 - 'W' Compressor (56085)

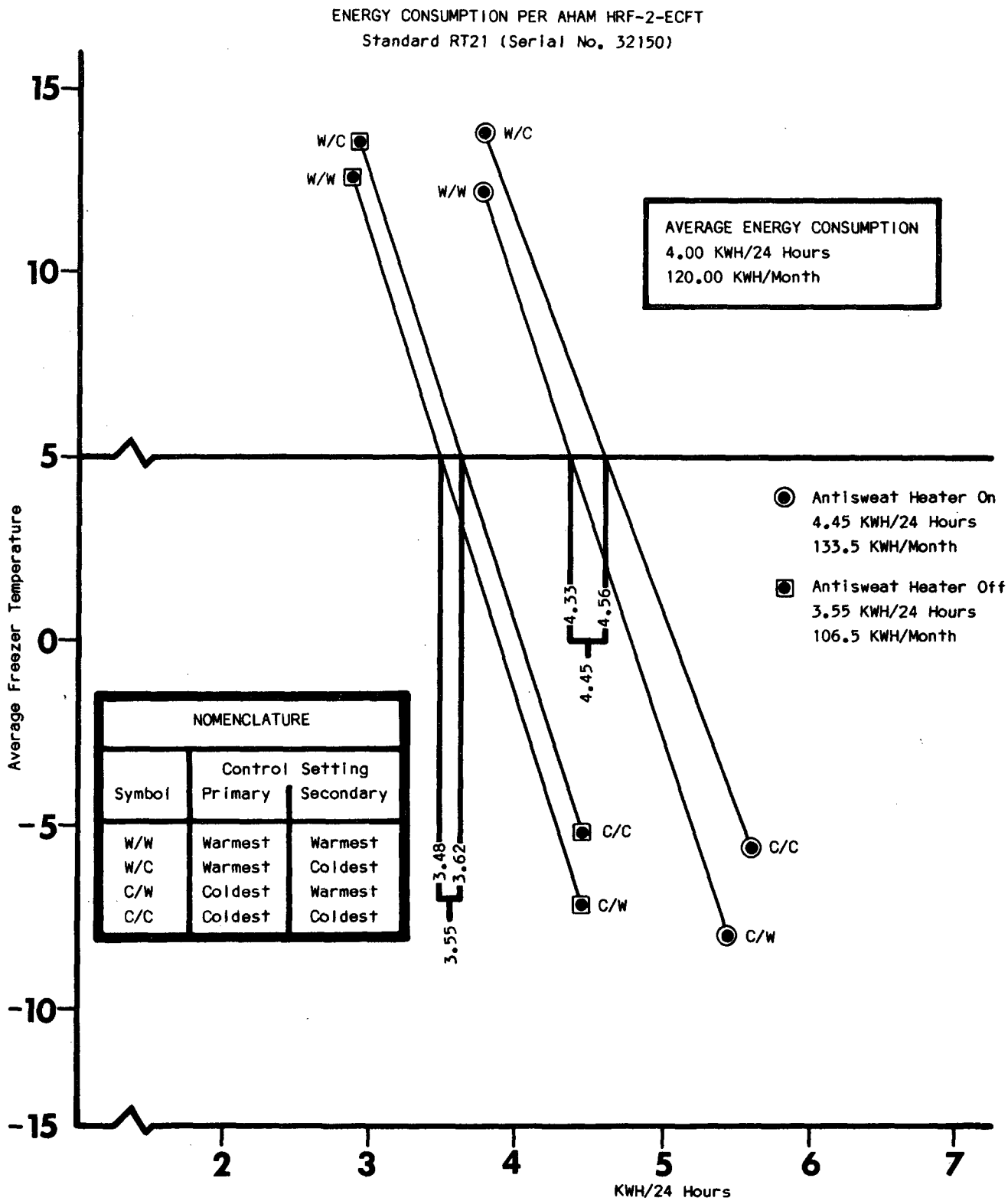

Figure 5-10. Production RT21-T105 Compressor

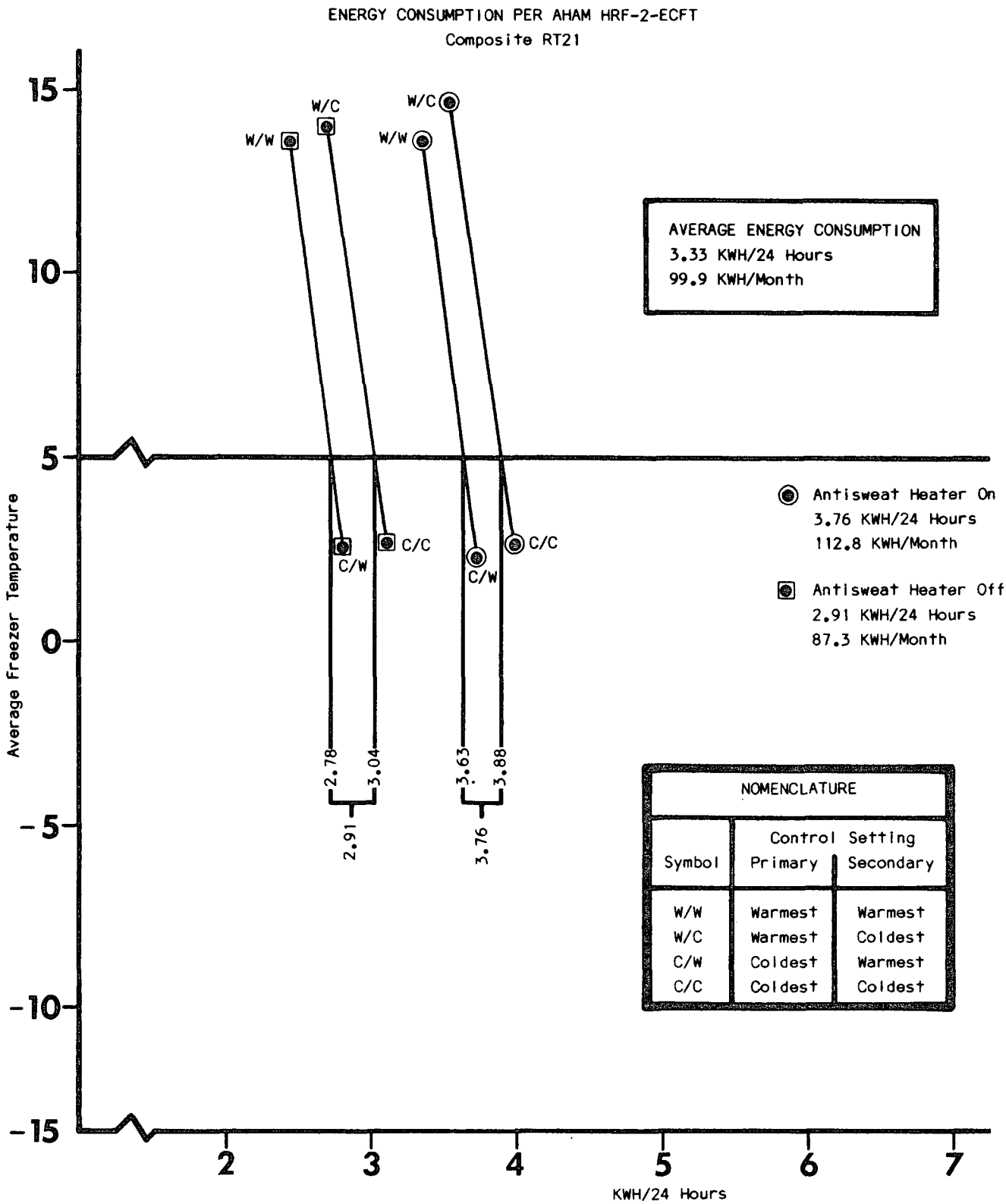

Figure 5-11. Composite of Three RT21 Cabinets With 'W' Compressors

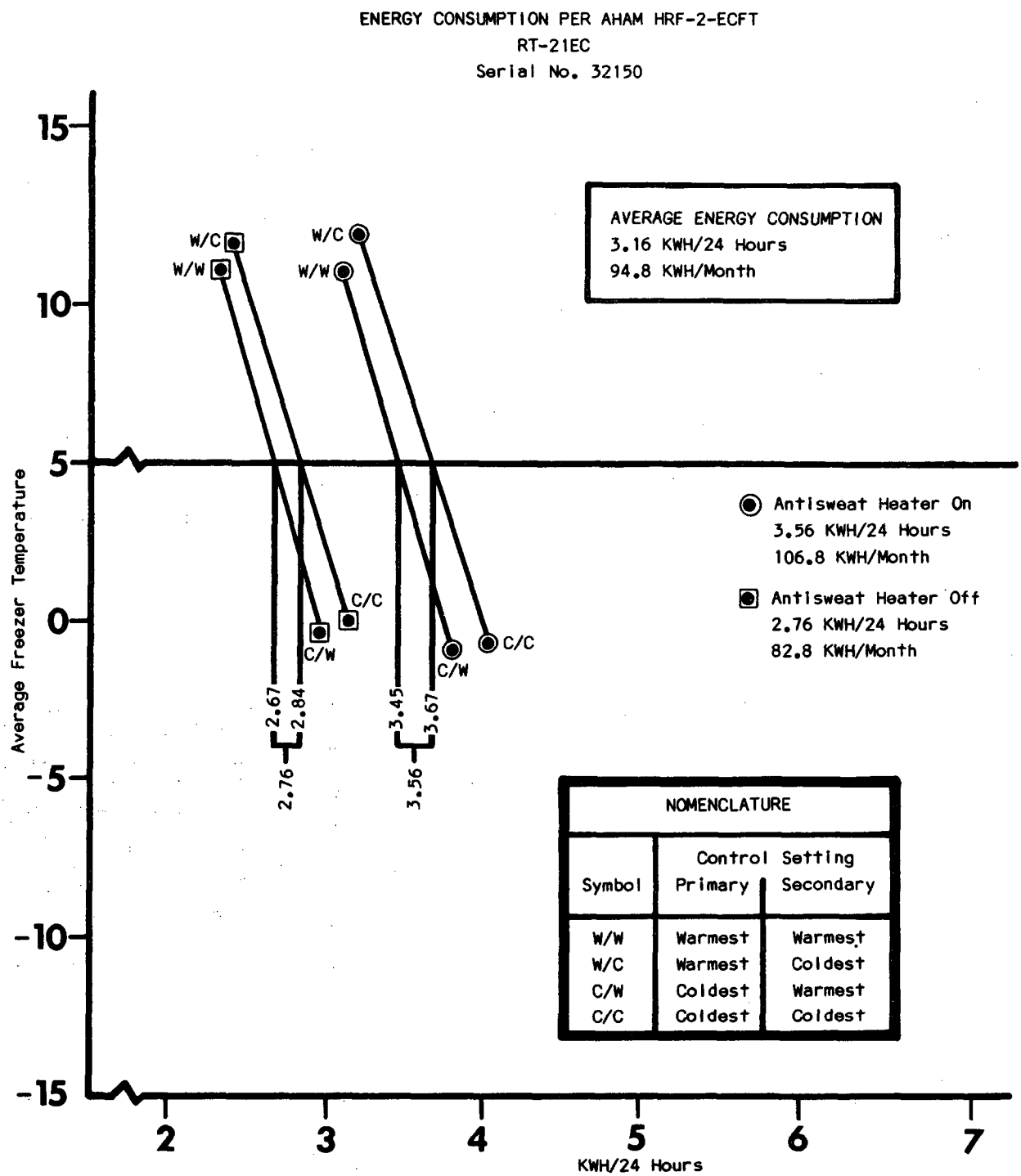

Figure 5-12. Sample 1 - RT21 - 'W' Compressor (32150)

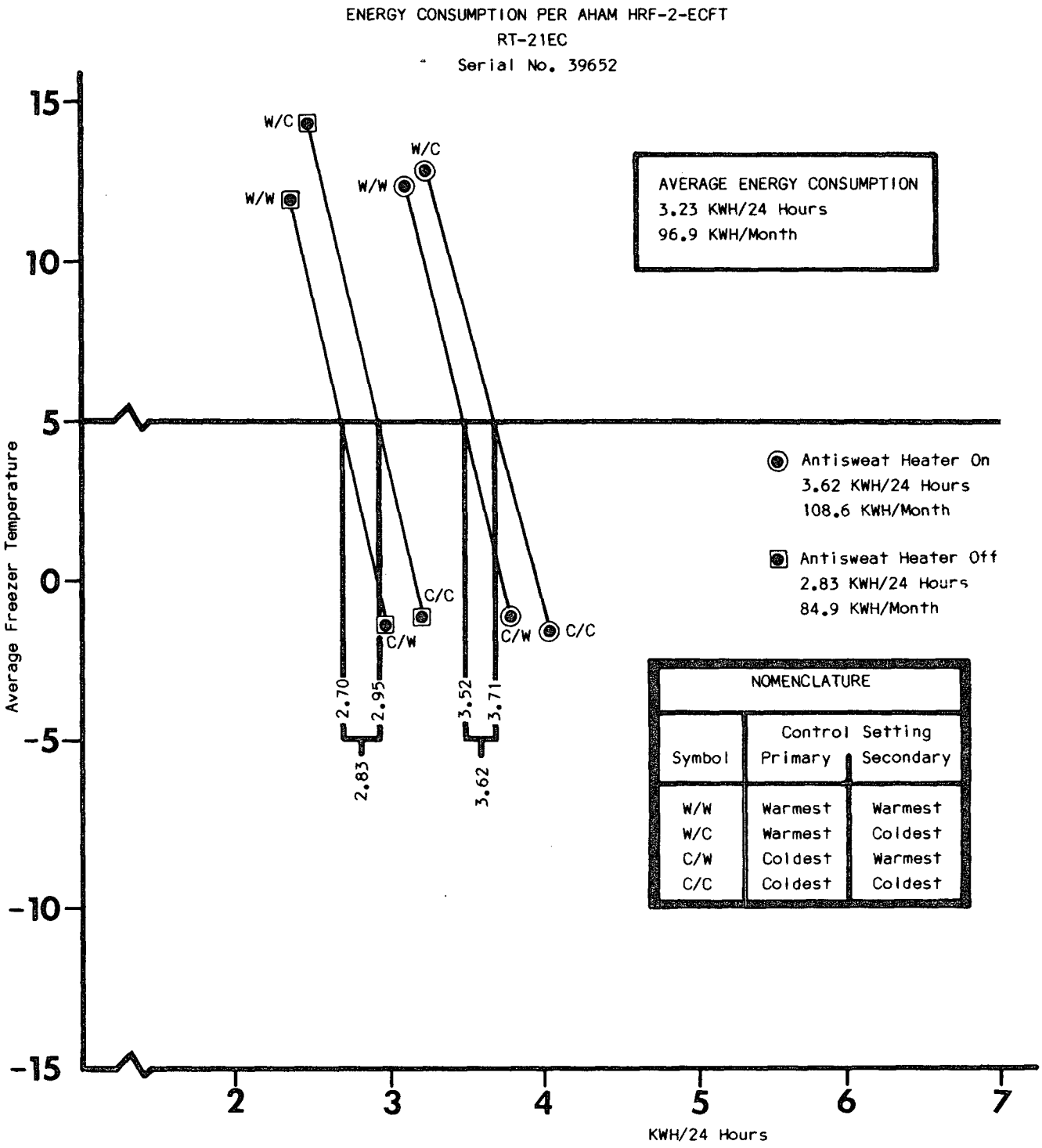

Figure 5-13. Sample 2 - RT21 - 'W' Compressor (39652)

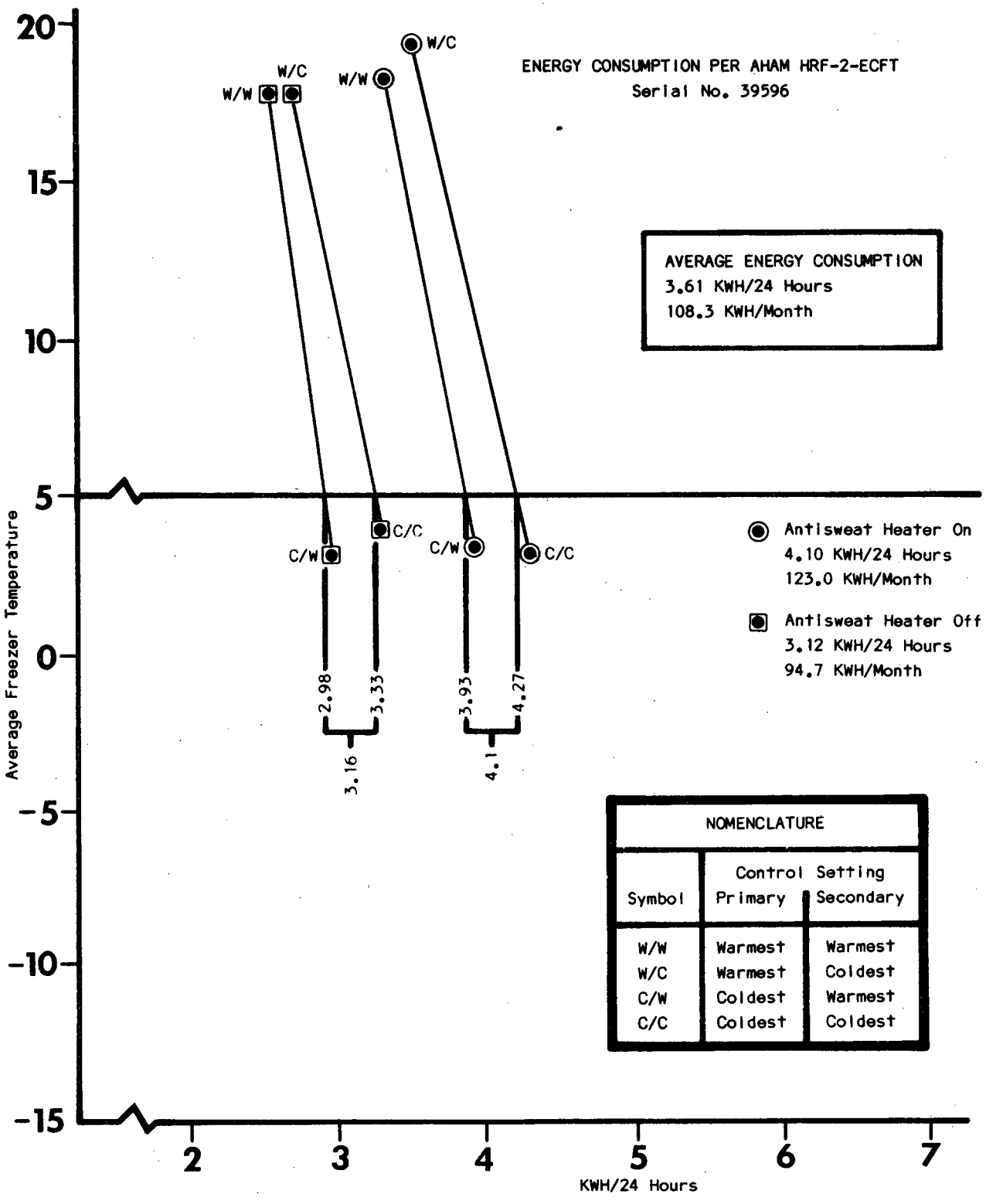

Figure 5-14. Sample 3 - RT21 - 'W' Compressor (39596)

After completing thirteen months of data collection on the field test refrigerators, efficiency gains have resulted with the use of both the WA-080 and WA-100 compressors. The WA-080 compressor, when applied to the 18 ft^3 unit, yielded power consumption reduction on an average of 27.0%. An energy consumption reduction was also recorded on the 21 ft^3 unit refrigerator which used the WA-100 compressor. The magnitude of this reduction was 15.6%. As can be seen in Tables 5-A through 5-D, a 21 ft^3 refrigerator-freezer equipped with a W-line compressor uses about the same power as an 18 ft^3 refrigerator-freezer equipped with the standard production model.

The differences between the 27.0% improvement that was recorded on the 18 ft^3 unit and the 15.6% improvement obtained with the 21 ft^3 unit can be explained by a comparison of the relative compressor efficiency improvements. The WA-080 replaced a TEA-090 in the RT18's. The TEA-090 had a standard baseline efficiency rating of 4.2 BTU/WHr. The WA-080 had an efficiency of 4.89 BTU/WHr. This then resulted in a compressor efficiency improvement of 16.4%. The rating was obtained by calorimeter testing the W80's after life test. This data can be found in Section 6.2. The WA-100's yielded an EER rating of 4.57 BTU/WHr following their life test. They replaced the TEA-105 in the RT21 which had an EER value of 4.2 BTU/WHr. This resulted in an improvement of 8.8% in compressor efficiency. On the RT21 refrigerators, every percent of compressor efficiency improvement yielded 1.8% refrigerator efficiency improvement. The RT18's yielded 1.6% efficiency improvement for every 1% compressor improvement.

Analyzing the monthly average power consumption, it can be seen that all of the field test refrigerators had the lowest power consumption in the colder winter months. Highest energy consumption in all groups occurred in the month of July. In analyzing the monthly data collection cards, we observed the same trend within the four subgroups. Households, which were reporting generally cooler temperatures, were generally also reporting lower power consumption. Large shifts in individual cabinet meter readings are sometimes attributable to the utilization of the anti-sweat heater. In cabinet 35167, which is a 21 ft^3 high-efficiency test unit, a dramatic increase is recorded between

TABLE 5-A 18 FT^3 HIGH-EFFICIENCY UNIT PERFORMANCE TEST DATA (KWH/24 HR)

Serial No.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Cumulative
36823	2.16	1.93	2.05	2.02	1.88	1.98	2.09	2.07	2.32	2.46	4.30	2.78	2.40	2.05	2.33
36830	1.88	1.30	1.11	1.26	.92	1.06	1.05	1.98	2.65	2.46	2.78	2.82	2.25	1.82	1.81
36829	2.21	1.79	1.73	1.60	1.57	1.63	1.73	1.62	2.05	2.30+	2.30	2.16	2.45	2.60	1.99
36850	3.32#	3.19#	1.74	1.74	1.68	1.66	1.79	1.75	2.16	1.94	3.09	2.86	1.97	1.84	2.28
37341	2.01	1.77	1.61	1.50	1.40	1.42	1.47	1.52	1.87	1.82	2.21	2.05	1.81	1.69	1.73
37340	1.73	1.51	1.72	2.13	1.15	1.21	1.21	1.81	2.17	2.32	2.36	2.23	2.18	2.13	1.85
36819	--	2.36	2.45	2.85	2.69	2.70	2.90	2.26	1.76	1.82	1.78	1.79	1.83	1.90	2.23
36832	--	--	--	1.85	1.61	1.49	1.68	1.59	1.83	1.74	1.78+	1.78	1.74	1.60	1.69
36763	--	--	--	1.77	1.78	1.76	1.73	1.78	2.00	1.84	2.28	2.13	1.99	1.86	1.90
36831	--	--	--	3.23	2.72	2.07	2.15	2.28	3.29	3.47	4.51	4.15	3.44	2.37	3.02
Averages	2.00	1.78	1.77	2.00	1.74	1.70	1.78	1.87	2.23	2.21	2.74	2.47	2.21	1.99	2.08

TABLE 5-B 18 FT^3 STANDARD UNIT PERFORMANCE TEST DATA (KWH/24 HR)

Serial No.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Cumulative
36834	2.82	2.18	2.17	2.06	2.03	1.98	1.54	2.10	2.35	2.27	3.18	3.17	2.34	2.50	2.33
36825	1.65	1.18	1.09	1.40	1.43	1.48	1.28	3.00	2.62	2.17	2.23	2.26	1.75	1.50	1.79
36833	--	2.40	2.31	2.09	2.15	2.36	2.19	2.47	2.44	2.71	2.91	2.69	2.35	2.34	2.41
36960	2.67	2.15	2.00+	2.00+	2.00	1.95	1.93	2.03	2.06	2.20	2.81	3.22	3.04	*	2.36
39199	3.47	2.37	2.30	2.44	2.32	2.29	2.34	2.29	3.17	3.87+	2.87	3.83	3.52	3.27	2.96
36940	3.55	3.40	3.55	3.52	3.53	3.17	3.74	3.51	3.93	4.53	3.49	4.05	3.92	4.00	3.68
37370	3.63	3.23	2.86	2.38	2.44	2.37	2.38	2.57	3.43	3.99	4.40	3.78	3.96	3.55	3.22
36958	3.35	3.37+	3.37	3.15	3.57	3.29	3.36	3.62	3.95	3.43	3.93	3.72	3.33	*	3.50
37374	--	--	2.84	2.87	2.74	2.70	2.87	2.85	3.35	3.47	3.68	3.57	3.23	3.05	3.11
37361	--	--	--	3.89	2.67	2.98	3.00	2.97	3.45	3.06	3.19	3.17	3.35	3.04	3.13
Averages	3.02	2.54	2.50	2.58	2.49	2.46	2.46	2.74	3.08	3.17	3.58	3.35	3.08	2.91	2.85

-- Indicates unit not under test.
+ Indicates assumed usage, same as subsequent month. Card not received.
* Indicates unit under test. Card not received.
# Indicates data not included in cumulative or average.

TABLE 5-C 21 FT^3 HIGH-EFFICIENCY UNIT PERFORMANCE TEST DATA (KWH/24 HR)

Serial No.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Cumulative
35179	3.26	3.17	2.50	2.18	2.19	2.13	2.31	2.40	3.20	2.96	2.98	2.56	2.92	2.61	2.64
35167	--	2.27	2.02	2.04	1.98	1.91	1.93	2.08	2.53	2.34	2.83	2.66	2.22	2.15	2.23
35182	3.01	2.94	2.89	2.24	2.54	1.95	2.22	2.14	2.48	2.31	2.83	2.47	2.19	1.92	2.42
35160	3.23	3.43+	3.43	3.77	3.81	3.89	3.77	3.87	4.12	3.88+	3.88	4.09+	4.09	3.78	3.80
35650	2.89	2.89	2.39	2.46	2.37	2.70	2.25	2.80	3.35	3.38	3.92	3.66	3.67	3.67	3.04
35159	--	1.84	1.79	1.88	1.78	1.77	1.85	1.94	2.39	2.29	3.03	2.74	2.52	2.18	2.16
35180	--	--	--	--	--	3.80	3.80	4.05	*	*	*	*	*	*	3.83
Averages	3.10	2.76	2.50	2.43	2.45	2.59	2.59	2.75	3.01	2.86	3.25	3.03	3.03	2.72	2.87

TABLE 5-D 21 FT^3 STANDARD UNIT PERFORMANCE TEST DATA (KWH/24 HR)

Serial No.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Cumulative
35705	3.39	3.63	3.75	3.59	3.57	3.46	3.60	3.93	3.97	4.38	3.77	4.01	3.80+	3.80	3.78
35648	--	3.49	2.69	3.26	3.19	3.29	3.34	3.35	3.71	3.38	4.12	3.82	3.68	3.36	3.41
35708	2.88	2.88	2.26	2.13	2.22	2.15	2.07	2.10	2.66	3.43	3.82	3.61	3.65	2.73	2.75
35645	3.46	2.70	2.35	2.43	2.23	2.42	2.46	2.48	3.60	3.86	4.22	4.18	3.60	3.19	3.05
35647	3.75	3.59	3.57	2.92	2.55	2.47	2.62	2.74	3.65	3.94	4.46	3.86+	3.86+	3.86	3.41
35663	3.50	3.32	3.59	3.74	3.60	3.09	3.16	3.25	3.86	4.41	4.82	3.52	3.52	3.28	3.59
35703	--	1.97	2.42	2.23	2.40	2.20	2.16	2.07	2.09	2.09	2.38	.92#	*	*	2.19
35671	--	--	--	3.26	3.02	3.10	3.16	3.16	3.75	3.49	4.04	3.71	4.05+	4.05	3.52
35649	--	--	--	--	3.32	3.44	3.78	3.65	4.04	3.89	4.44	4.20	3.95	3.89	3.92
35178	--	--	--	--	--	--	2.55	2.55	2.58	1.94	2.73	2.78	2.65	2.70	2.56
Averages	3.40	3.08	2.95	2.95	2.90	2.85	2.89	2.93	3.39	3.48	3.88	3.74	3.64	3.43	3.22

-- Indicates unit not under test.
* Indicates unit under test. Card not received.
+ Indicates assumed usage, same as subsequent month. Card not received.
# Indicates data not included in cumulative or average.

the months of June and July due to the anti-sweat heater. The reduction in power, which occurred between the August and September readings of this unit, is influenced by the switching off of this heater. Household member size, which undoubtedly had some influence, could not be correlated in this test.

5.5 CONCLUSIONS

Clearly this field test has shown that the use of high-efficiency compressors significantly reduced energy consumption in residential refrigerator-freezer applications (Figures 5-15 and 5-16). The power consumption is directly attributable to the increases in compressor efficiency as there were no other changes made to the refrigerators. The average field test energy values obtained for the refrigerators are substantially lower than those obtained by the AHAM energy consumption test HRF-2-ECFT. The rating test is performed with no openings of either the refrigerator or freezer door. It is conducted in a 90°F ambient with a loaded freezer compartment. The ambient temperatures that were recorded in the field test application sites were significantly lower than the AHAM test. Door openings without doubt occurred on a fairly frequent basis. Loading comparisons are impossible to calculate as the amount of individual household usage is most likely quite variable. Still, the AHAM tests do provide a relative indicator of refrigerator-freezer energy consumption. Those units which tested out with higher AHAM power consumption values also consumed more power in actual application.

While we had always debated the trade off of family size, ambient temperature, and door openings in analyzing the AHAM test, it became quite interesting to note that the ambient temperature had such a pronounced effect on energy consumption. The shifts in ambient temperature from summer to winter were generally about 10° - 12°F. The resulting decrease in power consumption comes from two major sources. First, with the lower external temperatures, the amount of heat gain through the walls, doors, and seals of the refrigerator unit is reduced. In addition, the reduction of the refrigerant condensing temperature lowers the compressor work.

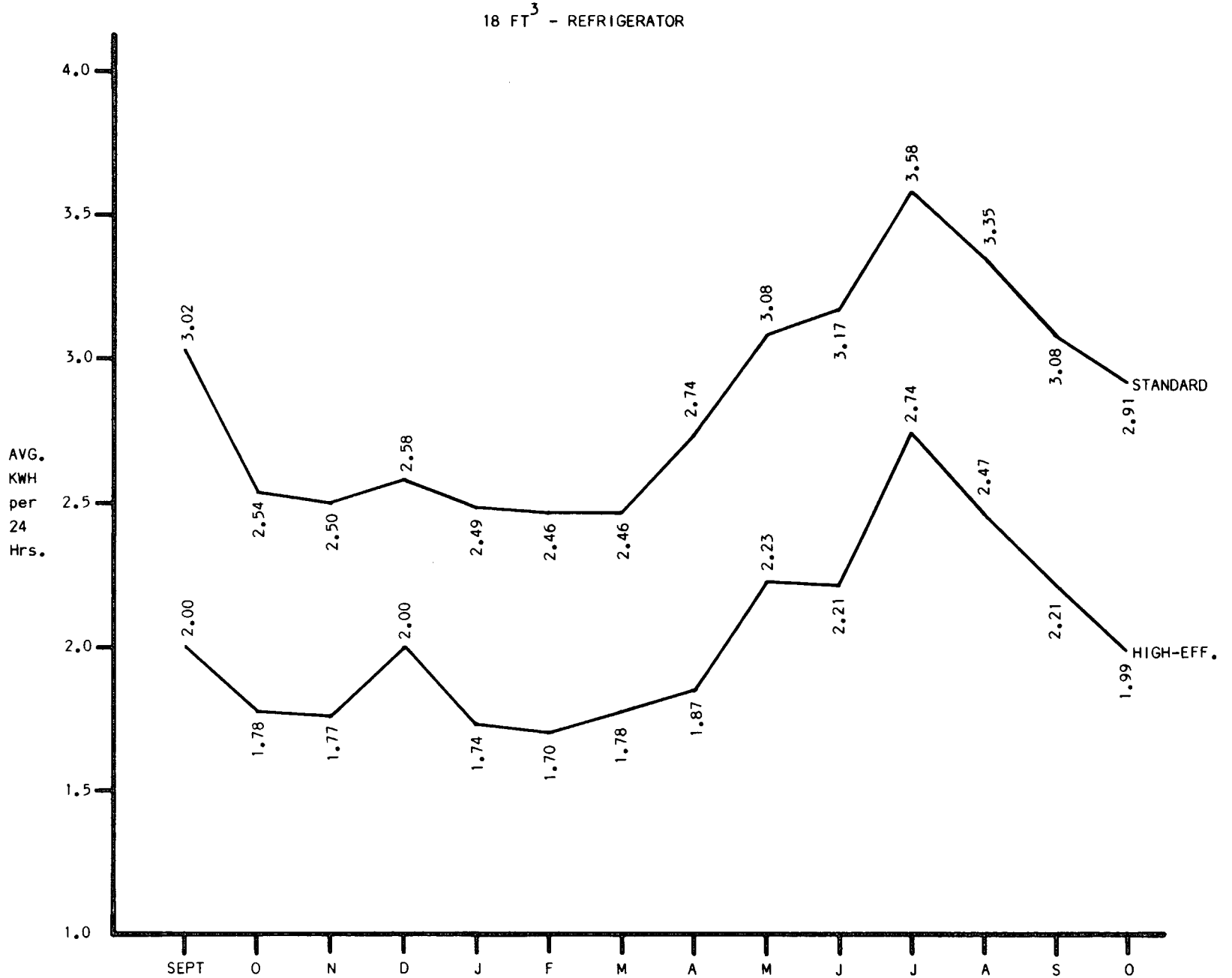

Figure 5-15. Field Test Results - 18 ft^3 Units

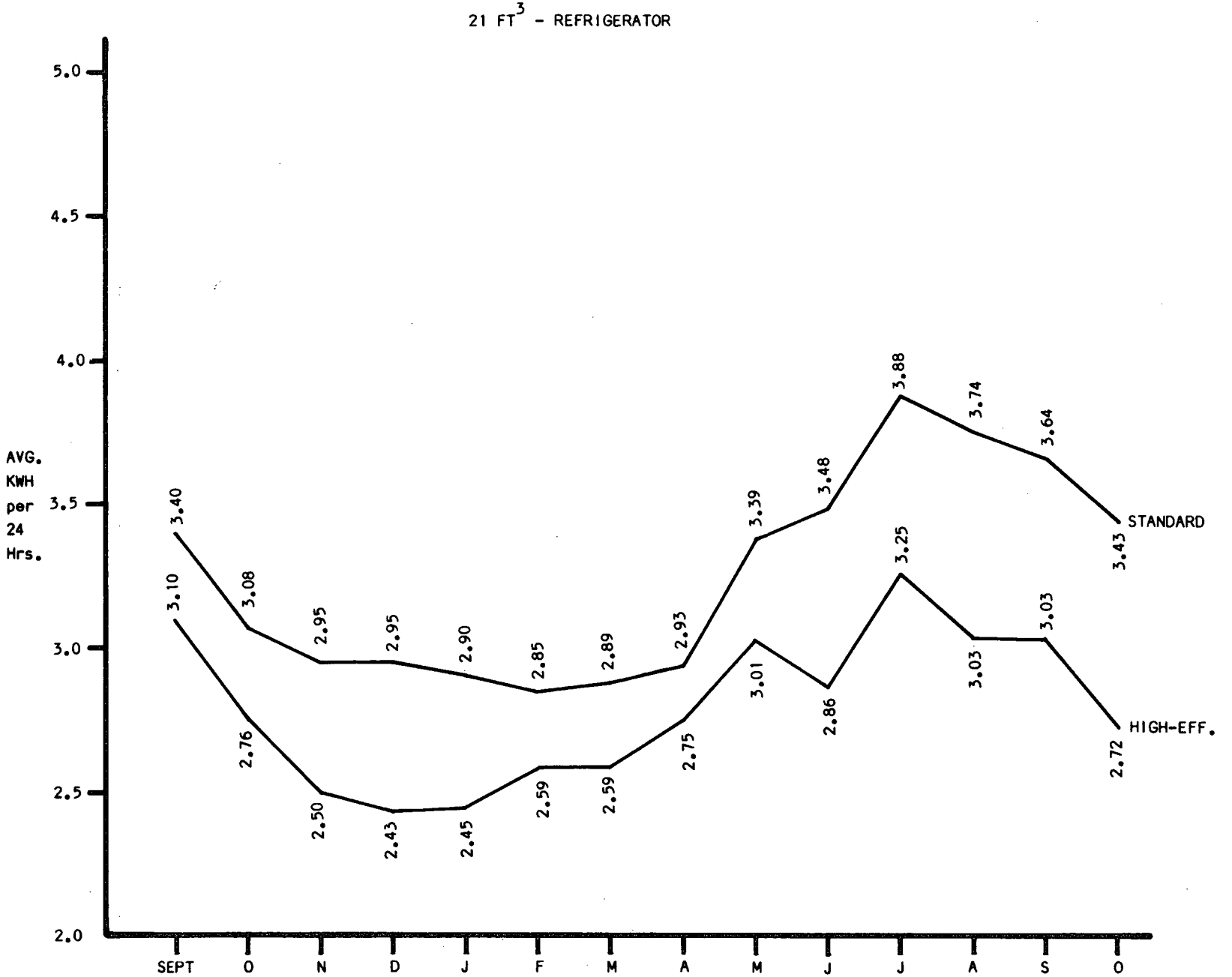

Figure 5-16. Field Test Results - 21 ft^3 Units

6. LIFE TEST

Fifty compressors were put on life test. Prior to being put on the life-test stands, the compressors were calorimeter and sound tested. Our original intention was to conduct the test on twenty-five pieces each of the WA-080 and WA-100 compressors. Due to a minor counting error, we tested twenty-six WA-080 compressors and twenty-four WA-100 compressors. This change in the mixture of the life test group is not significant.

6.1. DESCRIPTION

Life tests are conducted to evaluate the reliability and durability of complete compressors, subassemblies, or components. Tests are often made to evaluate chemical stability as well as mechanical endurance. The tests are made on life-test stands designed to give accelerated and/or intensified results. Compressors may be tested in either continuous operation or under cycling conditions.

Since we had conducted cycling life tests as part of the Phase I design and development project, we elected to conduct only continuous-run life tests. The primary purpose of the cycling life tests is to evaluate the initial lubricating properties and characteristics of the compressor during start up. The major concern was the quality of manufacture of the compressor components rather than their design. A continuous operation of the compressor bearings, valves, and the piston ring would show any manufacturing process flaw more rapidly than a cycling test.

The life-test stands consist of the electrical wiring necessary to start and run the compressor and to power the forced-air cooling fan. The refrigeration system consists of the compressor and expansion valve and a length of interconnecting copper tubing which acts as a reservoir. Gauges are utilized to measure the compressor suction and discharge pressures. Winding temperature measurements may be taken as required during the test by the use of a portable resistance bridge. In addition a clock is used to record the total running time.

In order to obtain the proper test conditions, the amount of refrigerant used and the setting of the expansion valve are adjusted. The suction pressure normally is set to 10 ± 1 psig, while the discharge pressure is set to 385 + 10 psig. Under normal conditions shell bottom temperatures of 200°F to 225°F are to be expected. This was not the case with the high-efficiency W-line compressors which ran significantly cooler. The major reason for this reduced temperature operation was the compressor's overall efficiency resulting in decreased power consumption. This decrease in power consumption then led to decreased power loss and the resulting temperature drop on life tests. The normal duration of a continuous life test is 3,000 hours. Figure 6-1 shows a typical compressor on a life-test stand. Figure 6-2 shows several life-test stands in their test cells.

6.2. RESULTS WA-080

Of the twenty-six WA-080 compressors which were put on life test, eight were built at CPC and the remaining were reworked at KCC. All compressors were given a sound and calorimeter test before being put on the life-test stands. Following the 3,000 hour test, calorimeter pullout and sound tests were performed. The data from these tests can be seen in Tables 6-A and 6-B.

An analysis of the average capacity, power consumption and energy-efficiency ratios shows a favorable trend. While the power consumption increased following the life test, the capacity rose at a faster rate resulting in an improvement in EER. An improvement can also be seen in comparing the average dBA readings.

These readings are taken after pressures had been stabilized and the unit had operated for 30 minutes. The decrease in dBA levels can probably be attributed to the compressor being fully run-in after the life test.

An additional indicator of the condition of the compressor following the life test is the average pullout voltage. As can be seen from the table, the average pullout voltage was 97.9 volts. This compares very

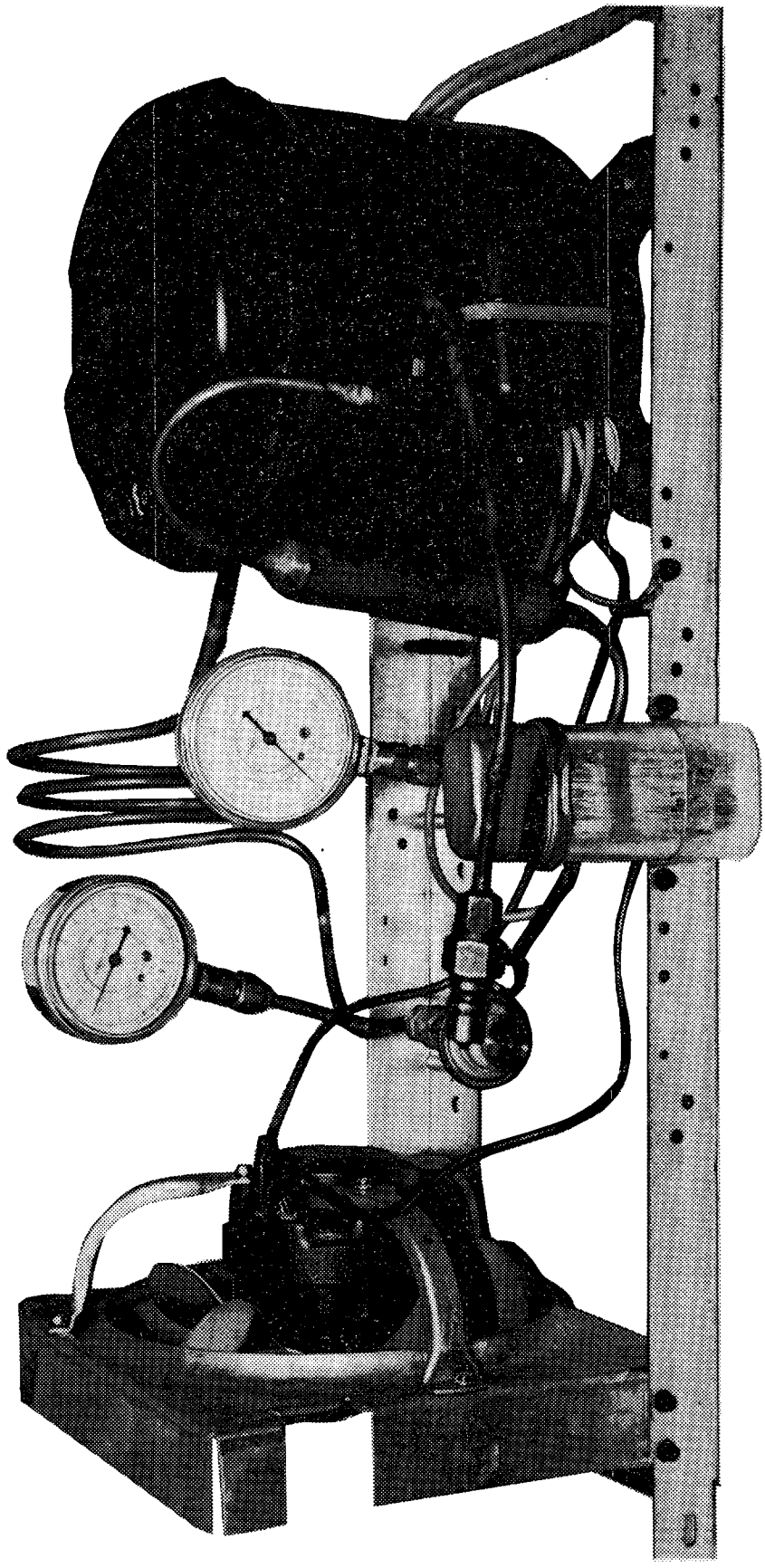

Figure 6-1. Typical Compressor on a Life-Test Stand

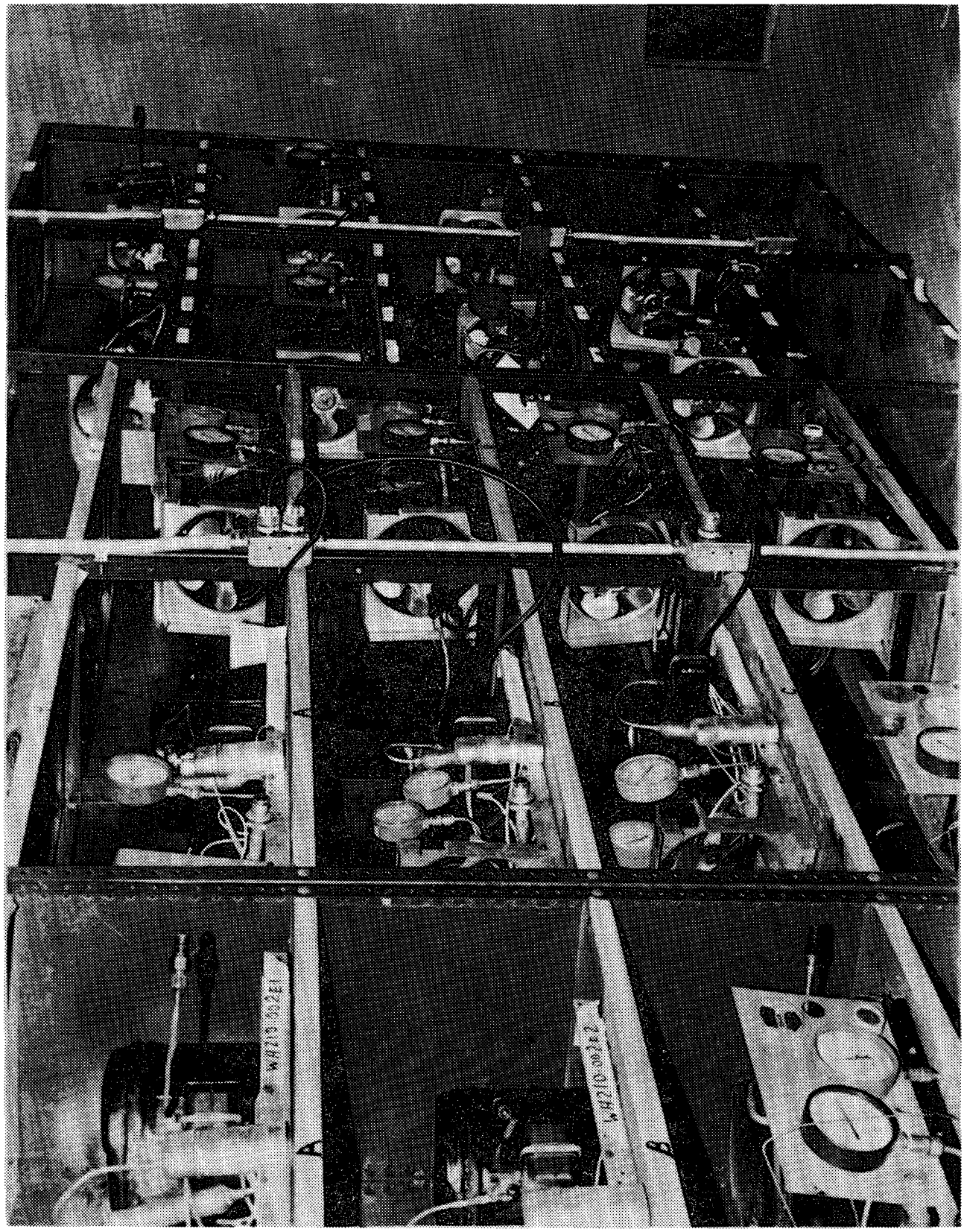

Figure 6-2. Life-Test Stands in Test Cells

TABLE 6-A

WA-080 COMPRESSORS

BEFORE LIFE TEST

COMPRESSOR	BTU/HR	WATTS	BTU/WHr	dBA
W80-002P-1	777	155.7	4.99	48.5
W80-002P-2	775	151.4	5.12	49.0
W80-006P-2	784	161.6	4.85	48.0
W80-006P-3	802	168.9	4.75	46.5
W80-006P-5	791	159.2	4.97	45.5
W80-006P-6	770	152.9	5.03	48.5
W80-006P-7	746	150.3	4.96	48.5
W80-006P-9	786	160.9	4.89	49.5
W80-008P-2	798	164.4	4.85	47.5
W80-008P-3	797	163.6	4.87	47.0
W80-008P-4	798	161.6	4.94	49.0
W80-008P-5	788	169.4	4.65	50.0
W80-008P-6	767	168.5	4.55	49.0
W80-008P-7	766	157.6	4.86	48.0
W80-008P-9	775	159.1	4.87	47.0
W80-008P-10	778	161.2	4.83	47.5
W80-008P-11	790	159.7	4.94	47.0
W80-008P-12	784	163.6	4.79	46.5
W80-008P-13	759	156.8	4.84	48.0
W80-008P-14	756	159.6	4.73	48.0
W80-008P-16	698	165.2	4.22	50.0
W80-008P-17	736	158.0	4.66	50.0
W80-008P-18	737	151.5	4.86	47.5
W80-008P-19	784	164.1	4.78	46.5
W80-008P-20	729	158.1	4.61	48.0
W80-008P-21	725	159.7	4.54	47.0
AVERAGES	769	160.1	4.80	48.0

TABLE 6-B

WA-080 COMPRESSORS

AFTER LIFE TEST

COMPRESSOR	BTU/HR	WATTS	BTU/WHr	PULLOUT VOLTAGE	dBA
W80-002P-1	790	160.9	4.91	96	48.0
W80-002P-2	819	163.1	5.02	100	46.0
W80-006P-2	785	159.6	4.92	96	47.0
W80-006P-3	854	160.4	5.32	98	48.0
W80-006P-5	813	159.3	5.10	98	46.0
W80-006P-6	766	156.9	4.88	94	48.0
W80-006P-7	764	156.5	4.88	94	47.0
W80-006P-9	783	161.9	4.84	96	47.5
W80-008P-2	807	163.6	4.94	99	47.0
W80-008P-3	824	168.4	4.89	99	47.5
W80-008P-4	782	159.9	4.89	96	48.5
W80-008P-5	803	167.4	4.80	99	48.5
W80-008P-6	820	166.8	4.92	99	48.0
W80-008P-7	755	162.0	4.66	96	46.0
W80-008P-9	800	163.4	4.90	97	46.0
W80-008P-10	808	167.2	4.83	99	46.5
W80-008P-11	806	166.8	4.83	99	47.5
W80-008P-12	815	165.4	4.92	99	46.0
W80-008P-13	825	166.4	4.96	99	47.0
W80-008P-14	793	162.0	4.89	99	46.0
W80-008P-16	773	164.6	4.69	101	49.0
W80-008P-17	802	165.2	4.85	99	47.0
W80-008P-18	773	166.8	4.63	99	48.0
W80-008P-19	813	164.0	4.96	97	50.0
W80-008P-20	831	167.0	4.97	99	49.0
W80-008P-21	767	164.4	4.66	99	46.0
AVERAGES	799.0	163.5	4.89	97.9	47.3

favorably with the original 99.1 volts we received when testing prototype W80's. Those prototypes were built and tested as part of the Phase I work and are covered in that report.

Following the completion of testing, the compressors were cut open and torn down. Compressor components were then placed on trays so that comparative analysis between compressors could be made, Figures 6-3 and 6-4. All compressor parts were thoroughly examined for unusual wear. Special attention was paid to all the bearing surfaces. In addition, the cylinder bore and piston ring were closely examined. No evidence of unusually high wear was discovered.

Also of great interest was the condition of the suction muffler and the muffler mounting areas on the cylinder housing. All of the CPC built compressors, which utilized the original Valox resin, showed signs of melting. None of the reworked compressors, which had used a redesigned muffler molded of DR-51 resin, evidenced any melting. While we expected no wear on the cylinder housings of the CPC units, we were interested in the reworked compressors. These life-test units confirmed our earlier findings that the 15% glass-filled DR-51 molded mufflers did not abrade the cylinder housing.

From the analysis of life-test compressors, some general comments can be made. The valve system performed exceptionally well. Only minor traces of coking were found on the valve plate suction reed and discharge reed. This can be primarily attributed to the reduced operating temperature of the high-efficiency compressors. Due to this same factor, the compressor oil appeared to be clearer than normal. Assembly procedures appeared to be properly followed. Head bolt torque values were all within the manufacturing specification. Head gasket selection on all compressors was within the 0.003 inch to 0.005 inch tolerance range. Wristpin wear appeared about average for the basic T-line compressor. All remaining compressor components were judged to have survived the life test as well or better than the equivalent T-line production models. It should be noted, however, that the reworked compressors contained more foreign material than the CPC

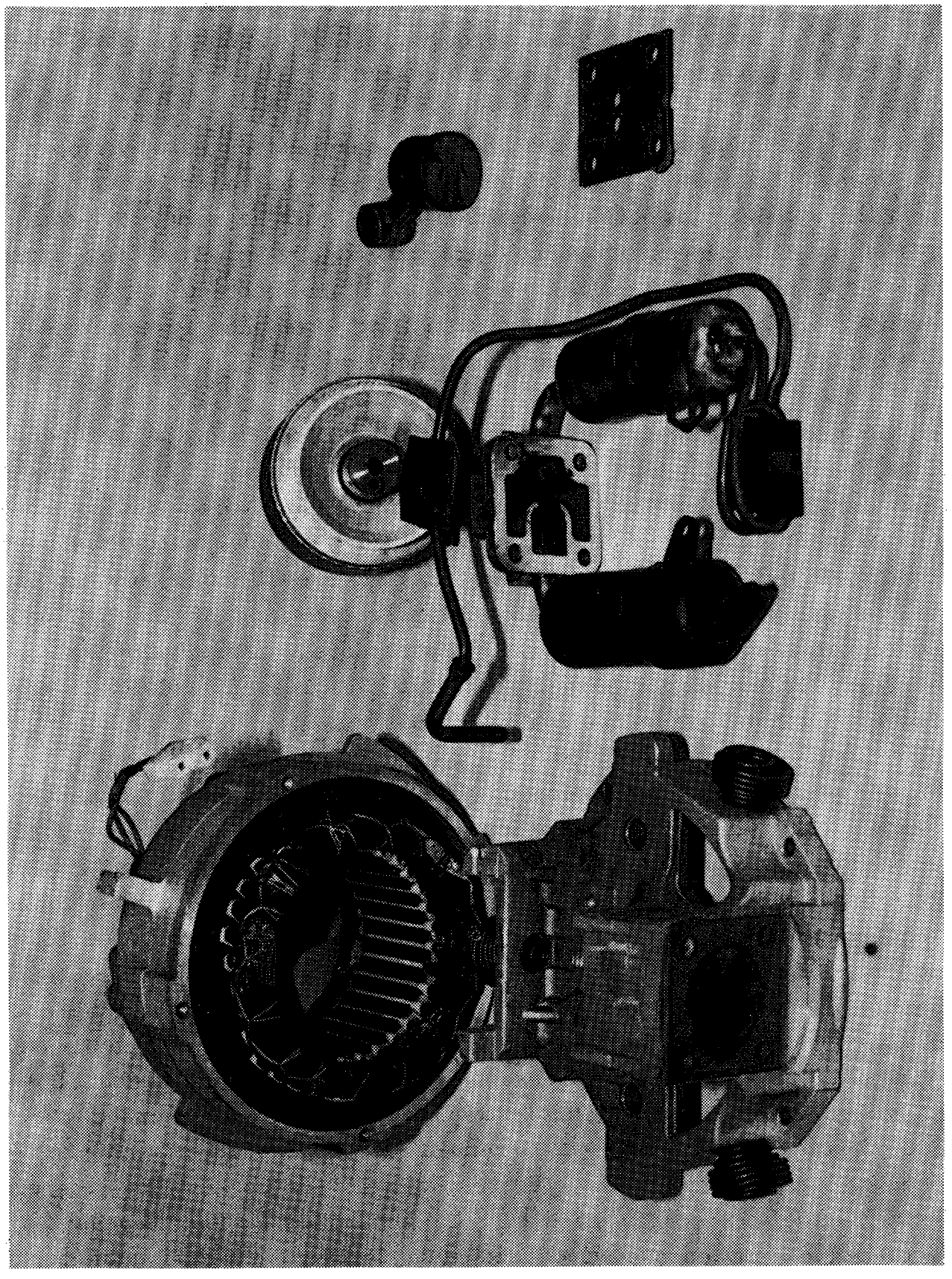

Figure 6-3. Compressor Components

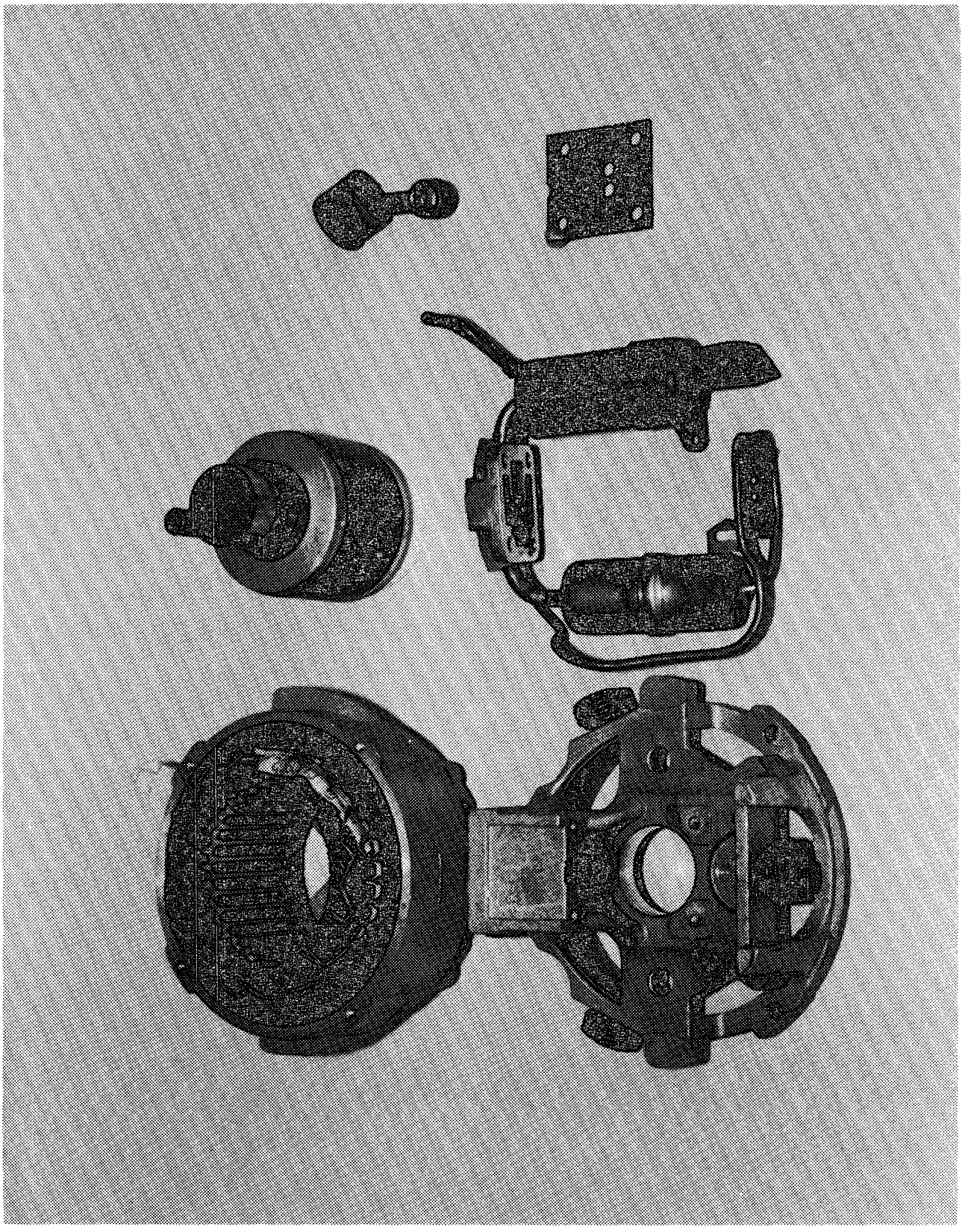

Figure 6-4. Compressor Components

built units. This foreign material was found generally in the compressor sump. No W80's failed due to this foreign matter inclusion or for any other reason. If, however, any of this material had been drawn into the lubricating system, bearing damage would have certainly resulted leading to possible compressor failure. In general, the life-test compressors appeared to have used a very small percentage of their total operating life.

6.3 RESULTS WA-100

Twenty-four WA-100 compressors were put on life test. All of these units were reworked at KCC. These compressors were all given a calorimeter test before being put on the life-test stands. Additionally, most of these compressors were given a sound test. Due to a temporary interruption in the availability of our sound-test facilities, six of the WA-100 compressors were not tested. This interruption was caused by construction of a semi-anechoic sound chamber. Consequently a comparison of the dBA levels obtained before and after the life test must be tempered by the realization that reflected sound power is reduced in the after results.

Analyzing the average capacity, power consumption and energy-efficiency ratio data, contained in Tables 6-C and 6-D shows virtually no change after the life test. Minor reductions were recorded in all areas. The net result was a decline in efficiency of 0.6%. A change of this magnitude is within the test error of our calorimeter operation.

As can also be seen in Tables 6-C and 6-D, there has been a significant reduction in dBA levels from 52.1 to 49.0. These readings are taken with an all-pass band filter. Previous testing has indicated an improvement of approximately two dBA when we changed from our previous sound chamber to the new semi-anechoic chamber. This still leaves, however, an improvement of about one dBA following the 3,000 hour test.

TABLE 6-C

WA-100 COMPRESSORS

BEFORE LIFE TEST

COMPRESSOR	BTU/HR	WATTS	BTU/WHr	dBA
WA-100-006P-1	995	214.4	4.64	50.0
WA-100-006P-2	1021	224.8	4.54	51.5
WA-100-006P-3	1024	219.9	4.66	49.5
WA-100-006P-4	1037	227.0	4.57	50.0
WA-100-006P-5	1001	222.9	4.49	51.0
WA-100-006P-8	1031	222.8	4.63	53.0
WA-100-006P-10	1072	221.3	4.84	52.5
WA-100-006P-11	1046	225.5	4.64	52.0
WA-100-006P-12	1087	230.8	4.71	53.0
WA-100-006P-13	981	217.8	4.50	52.5
WA-100-006P-14	971	210.4	4.62	53.0
WA-100-006P-15	1023	224.9	4.55	51.5
WA-100-006P-16	938	215.6	4.35	52.5
WA-100-006P-17	983	216.8	4.53	52.0
WA-100-006P-18	988	217.2	4.55	52.5
WA-100-006P-19	955	212.6	4.49	53.5
WA-100-006P-20	1009	217.0	4.65	NT
WA-100-006P-21	1021	221.2	4.62	50.5
WA-100-006P-22	996	218.0	4.57	NT
WA-100-006P-23	1063	221.4	4.80	NT
WA-100-006P-24	1084	241.6	4.49	57.0
WA-100-006P-25	1013	224.4	4.51	NT
WA-100-006P-26	1065	223.4	4.77	NT
WA-100-006P-27	1026	219.8	4.67	NT
AVERAGES	1018	221.2	4.60	52.1

NT = Not Tested

TABLE 6-D

WA-100 COMPRESSORS

AFTER LIFE TEST

COMPRESSOR	BTU/HR	WATTS	BTU/WHr	PULLOUT VOLTAGE	dBA
WA-100-006P-1	984	219.0	4.49	95	47.5
WA-100-006P-2	971	219.4	4.43	95	49.5
WA-100-006P-3	1000	235.2	4.25	93	51.0
WA-100-006P-4	981	219.8	4.46	93	46.5
WA-100-006P-5	1012	226.2	4.47	95	48.5
WA-100-006P-8	986	214.8	4.59	93	48.0
WA-100-006P-10	1032	216.2	4.77	95	51.0
WA-100-006P-11	1025	216.2	4.74	95	47.5
WA-100-006P-12	1028	220.0	4.67	95	49.0
WA-100-006P-13	984	219.4	4.48	95	49.0
WA-100-006P-14	983	215.6	4.56	95	49.5
WA-100-006P-15	1030	220.6	4.67	93	49.0
WA-100-006P-16	1008	218.0	4.62	95	49.0
WA-100-006P-17	959	217.6	4.41	95	47.5
WA-100-006P-18	1012	226.2	4.47	95	48.5
WA-100-006P-19	1054	228.6	4.61	95	48.5
WA-100-006P-20	1025	219.6	4.67	95	49.5
WA-100-006P-21	1011	216.4	4.67	95	48.5
WA-100-006P-22	959	216.7	4.43	95	49.0
WA-100-006P-23	1008	219.8	4.59	95	52.0
WA-100-006P-25	1033	227.8	4.53	99	49.0
WA-100-006P-26	1008	219.8	4.59	95	50.5
WA-100-006P-27	1050	224.4	4.68	97	49.0
AVERAGES	1006	220.8	4.57	94.9	49.0

After the completion of all testing, the compressors were cut open and torn down. The compressor parts were then displayed so that we could make a comparative analysis between the units. A complete visual inspection was made of all components. As was the case in the reworked W80's, we found no suction muffler melting with the redesigned DR-51 resin mufflers. Also paralleling the W80 experience, a higher than normal amount of foreign material was found in the compressor sumps. In two of the compressors this material found its way into the motor and caused wearing of the stator teeth and the rotor surface.

All bearing surfaces indicated normal wear. The extended-tip suction reed performed adequately. Examining the piston ring and cylinder bore showed evidence of higher than normal wear. This was significant enough in one compressor to cause its failure following the life test. This compressor, WA-100-006P-24, failed to start for the calorimeter test after completing the normal 3,000 hour life test. Upon cutting this compressor open, we discovered severe wear on the piston ring and cylinder sleeve. This pattern of higher than normal wear, found on all the WA-100 compressors, appears to be caused by soft cylinder sleeves which were specially cast for the pilot production run.

Other assembly analysis showed that head bolt torque specifications were met. The head gaskets were all within the proper tolerance range. The oil was darkened by particles from the high cylinder bore wear area. Unlike oil, which has been exposed to high temperatures, there was no burnt smell. All other assembly details such as tube dampener locations and oil charge quantity appeared to be in order.

6.4. CONCLUSIONS

An overview of the life test project leads to several conclusions. First, the redesigned DR-51 resin muffler is adequate for low back-pressure compressor operation. DBA levels from sound testing are within T-line compressor historical values and the muffler shows no indication of melting when used in a modified manufacturing process. Secondly, the reworked compressors have a higher than desired foreign material level. While not causing compressor failure, this material

in some cases has contributed to wear of some components. Third, as evidence from the sound and calorimeter data, the compressors should maintain adequate life in the refrigerators. Fourth, the cylinder sleeves used in the WA-100 compressor are softer than those used in our regular production and used on the WA-080. This may lead to a somewhat shortened life but the compressor should still have a ten to twelve year useful application. Fifth, the lubrication system of the W-line compressors provided adequate oiling of all bearing surfaces. Finally, the extended-tip suction reed on the WA-100 compressor performed with no difficulties.

In addition to the direct findings of the life test, we have gained relative efficiency levels for the two compressors. In neither case did EER levels reach those that were obtained in the prototype testing of Phase I. Both models, however, were able to exceed the pullout voltage levels.

7. TEST PROCEDURES

The following sections contain data that was originally included in the Phase I report. It has been reedited to reflect changes that have been made as a result of the transfer process from CPC to KCC or due to improvement in technique or equipment.

7.1. CALORIMETER TEST

The calorimeter test is used by KCC for the measurement of compressor capacity and efficiency. The type of calorimeter used at KCC has a water cooled condenser, an automatic expansion valve, and evaporator enclosed in a secondary refrigerant system with electric heaters. The calorimeter is supplied with pressure gauges, electrical meters, and a resistance bridge for winding temperature reading by thermocouple, Figure 7-1. Connected with it is a duct in which the compressor is mounted and in which conditions in an actual installation in an appliance can be simulated. The calorimeter is run on regulated 115 volt 60 hertz power. A functional diagram of a typical calorimeter used at KCC is shown in Figure 7-2.

Most calorimeter testing is performed under standard rating point conditions which are chosen to represent typical service conditions on an appliance. The actual test conditions vary depending on the type of compressor to be tested and its application. Conditions given in Table 7-A are for compressors using R-12 refrigerant and intended for low back-pressure applications. These conditions were utilized during the testing of high-efficiency samples for refrigerator-freezer applications.

For a more complete definition of compressor performance than that provided by the standard rating point test, a series of tests may be made at the following evaporator temperatures, in °F: -20.0, -10.0, 0, +20.0. Tests may also be run at condensing temperatures of 110.0°F and 150.0°F in addition to the standard 130.0°F level. It is customary to plot the results of tests of this kind as a family of curves, and the procedure is referred to as "curve testing".

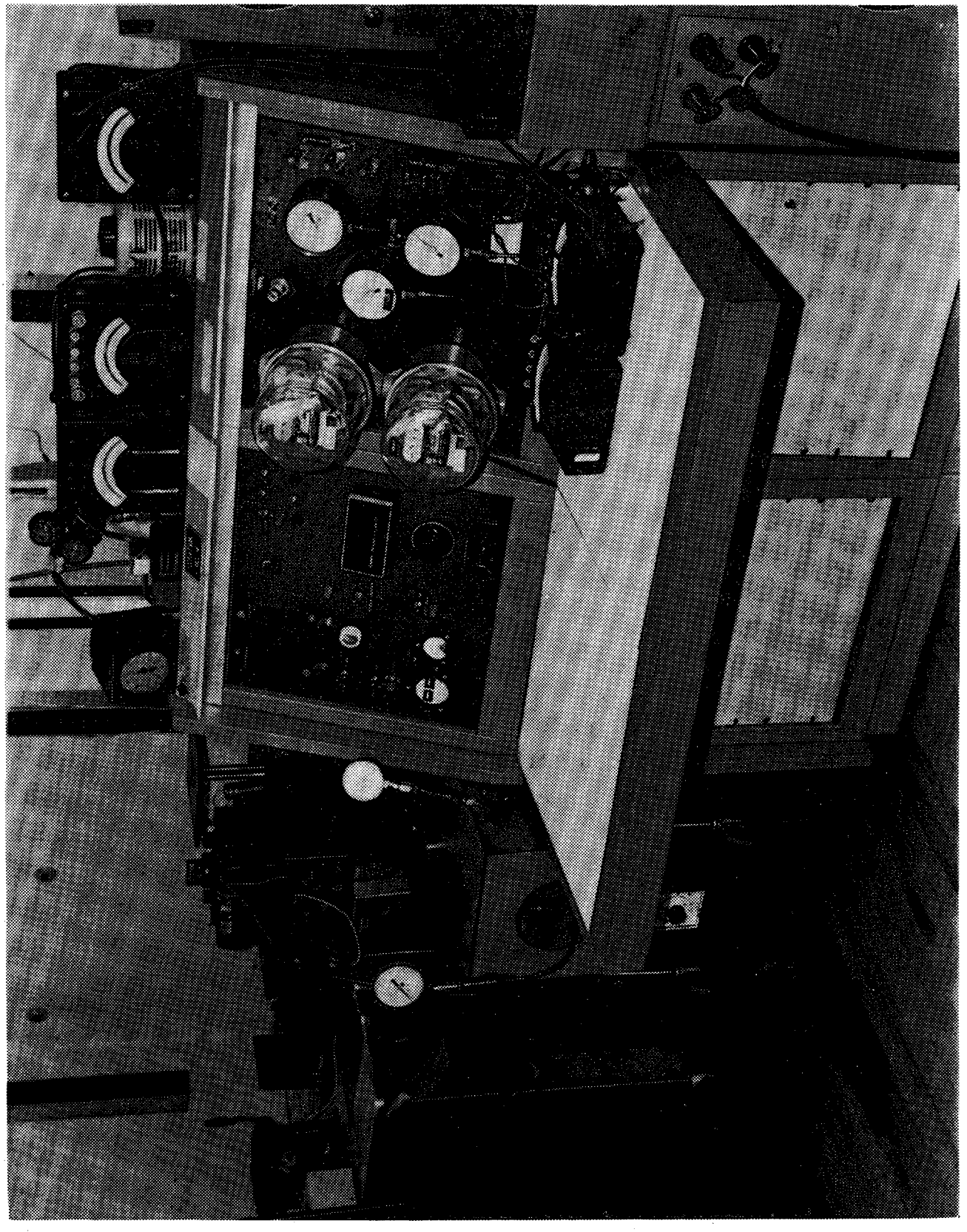

Figure 7-1. Typical Calorimeter with Gauges and Meters

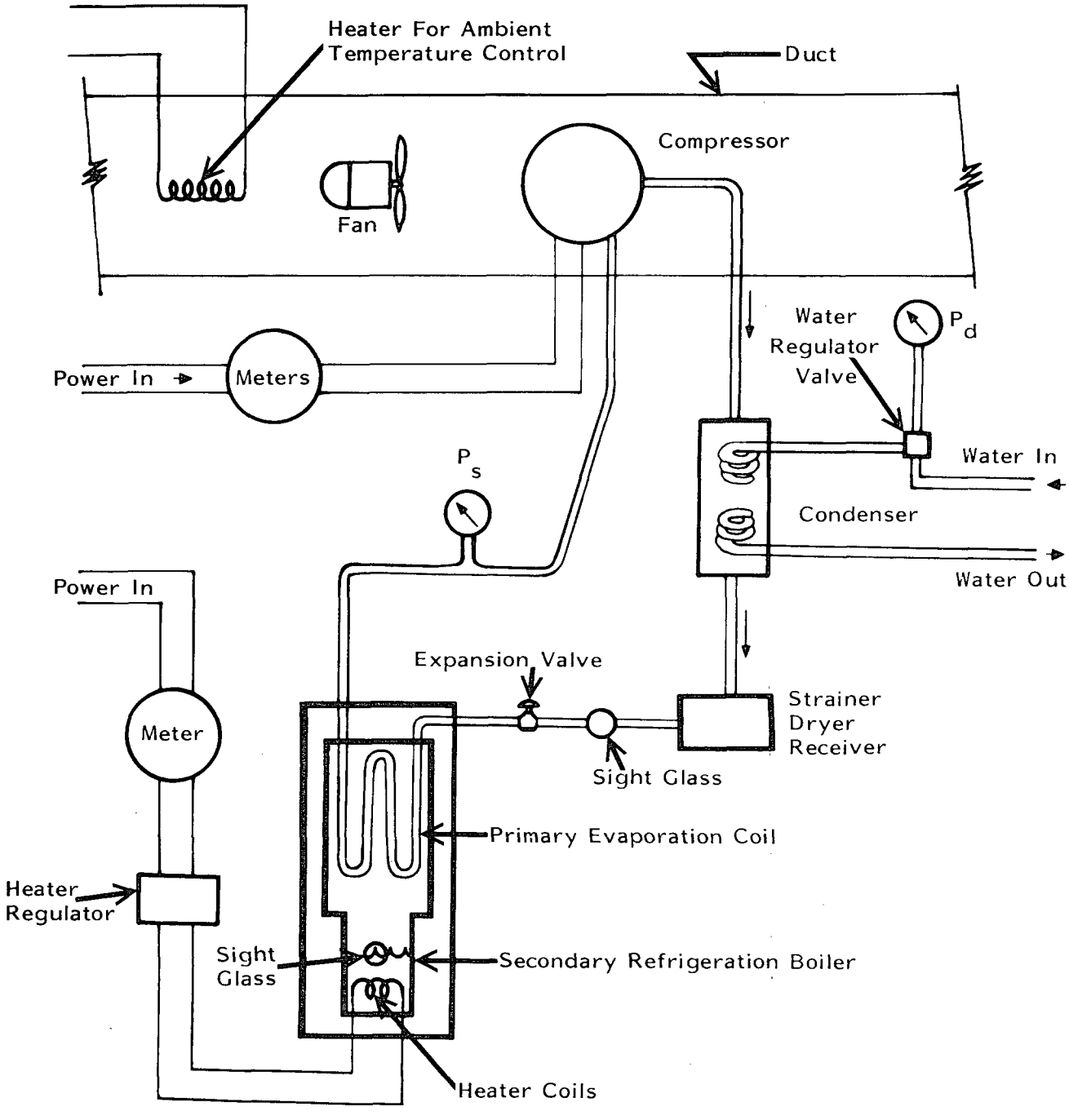

Figure 7-2. Functional Diagram of a Typical Calorimeter

TABLE 7-A

COMPRESSOR STANDARD CALORIMETER RATING POINT CONDITIONS

Evap. Temp. (°F)	-10
Evap. Press. (psig)	4.5
Cond. Temp. (°F)	130
Cond. Press. (psig)	181
Return Gas (°F)	90
Liquid to Exp. (°F)	90

During the calorimeter test the ambient temperature around the compressor, which is in the calorimeter duct, is 90.0°F. Forced air flow is directed at the compressor through the duct. The duct area used for R-12 compressor testing is 144 in^2. Forced air is supplied at a flow rate through the duct of 100 ft^3/min. Thermocouples are supplied and monitored at various locations. Typical thermocouple locations are given in Table 7-B.

TABLE 7-B

TYPICAL THERMOCOUPLE LOCATIONS FOR CALORIMETER TESTING

Suction line 6 in. from compressor
Discharge line 6 in. from compressor
Compressor shell top
Compressor shell under protector
Compressor shell bottom
Condenser inlet
Condenser outlet
Evaporator
Liquid line to expansion valve
Condenser cooling water in
Condenser cooling water out

In operation, cooling water flow to the calorimeter condenser is adjusted to provide the standard discharge or condensing pressure. The expansion valve is set to a standard evaporator or suction pressure, depending on the compressor to be tested, and the heat input to the evaporator is regulated to give standard superheat of the suction gas. The refrigerating effect is then calculated from the measured electric energy supplied to the evaporator during a fixed period of time. Since the observed liquid temperature during the test will not in general equal the standard temperature, the recorded load is adjusted by making a suitable correction based on the enthalpy of the liquid. While the test is in progress, the energy supplied to the compressor is recorded. The EER (energy efficiency ratio) in BTU/WHr is then calculated.

As was noted earlier, calorimeter test conditions differ significantly from the usual conditions in a complete refrigerator system. Calorimeter conditions of operation are stabilized at standard levels, while on a complete system, which runs only part of the time, the conditions vary throughout the running cycle.

7.2. PULLOUT TEST

The pullout test measures the voltage at which a compressor stalls under the conditions described below and is used to determine if it has sufficient torque for heavy load operation. The pullout test is usually performed following a calorimeter test since it is performed while the compressor is mounted on a calorimeter. The test condition for a low back-pressure, R-12, compressor is 200 psig discharge pressure with 30 psig suction pressure. Both the return gas temperature and the ambient temperature are set at 90°F.

Testing consisted of dropping the line voltage in successive steps of five volts. After each drop in voltage, the compressor is allowed to stabilize. At stabilized temperature at each step, volts, amps, and watts are recorded. The result reported is the voltage at which pullout occurs.

CPC uses two other variations of this test. The first is designed for greater accuracy. Instead of reducing the voltage in five volt steps, reductions are limited to two volts. Secondly, for a fast test the voltage may be reduced gradually until the compressor stalls. The only time that is allowed is when it is necessary to record the volts, amps, and watts at five volt intervals. The result reported from the quick test is the voltage at which the compressor pulls out.

7.3. SOUND TEST

The sound test is run with the compressor operating under specified conditions, with readings taken at fixed locations with a sound level meter. In addition, a noise spectrum, or sound level frequency distribution, is recorded. Frequency distribution is analyzed and recorded with the use of 1/10 and 1/3 octave B & K analyzer shown on Figure 7-3.

The test specifications require a test room isolated from outside sources of noise and vibration. The room has non-reflective walls. The CPC test room has a typical background noise level of about 25 dB. A simple calorimeter or water-cooled load stand is used as a refrigeration system when the compressor alone is under test. The calorimeter or load stand usually produces flow noises, therefore it is often isolated from the compressor under test. Compressors under test are mounted on a firm and rigid stand. Rubber mounting grommets, such as those used in refrigerator application, are used to support the compressor on the stand.

Typically, three reading positions are used in the test. Both dBA and dBB readings are taken. One of the microphone positions used at CPC is shown on Figure 7-4. Readings are taken at compressor startup and at 5, 10, and 30 minutes after starting. Before the final 30 minute reading, the compressor must be stabilized at pressures of 181 psig

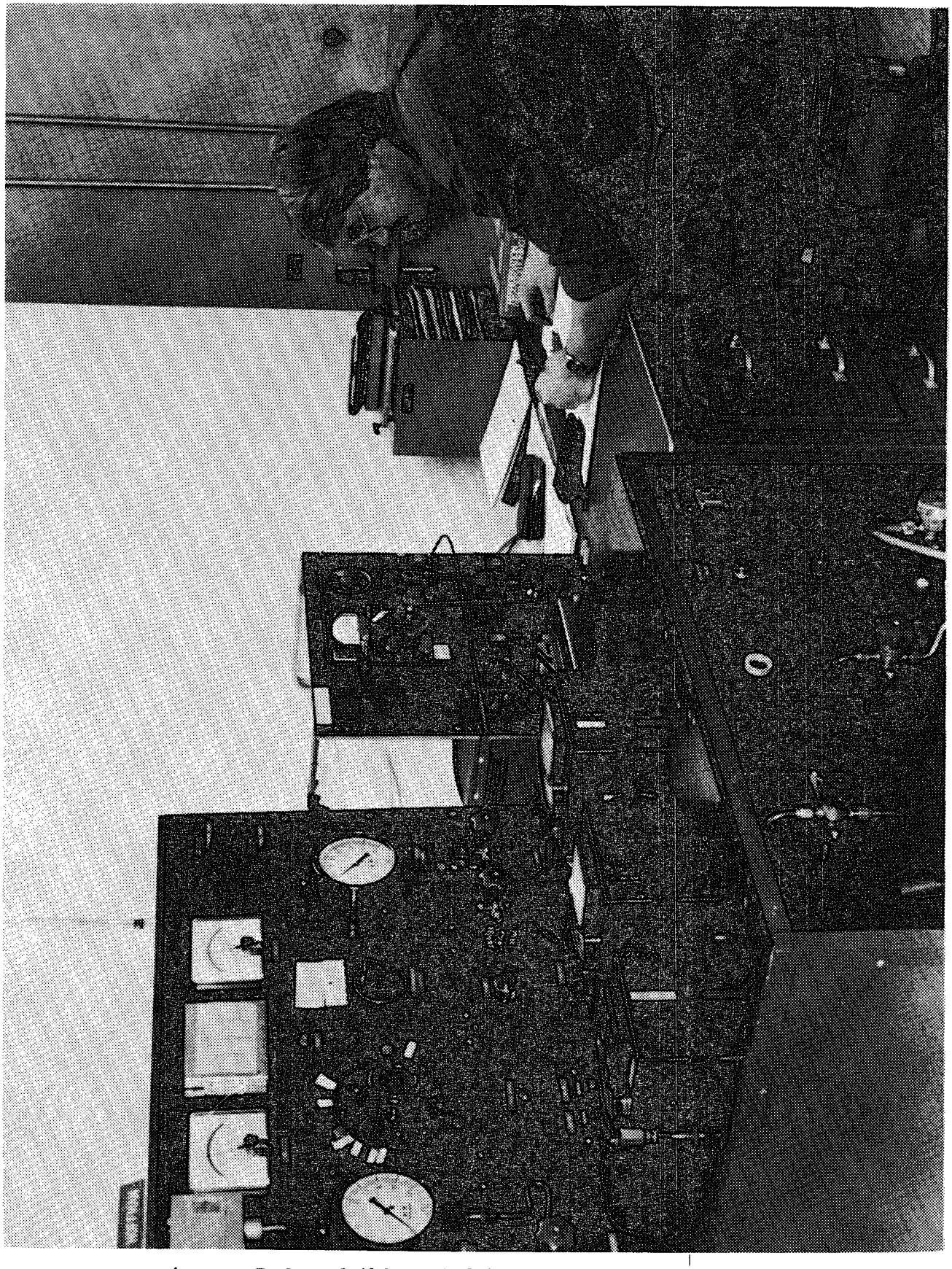

Figure 7-3. 1/10 and 1/3 Octave B & K Analyzer

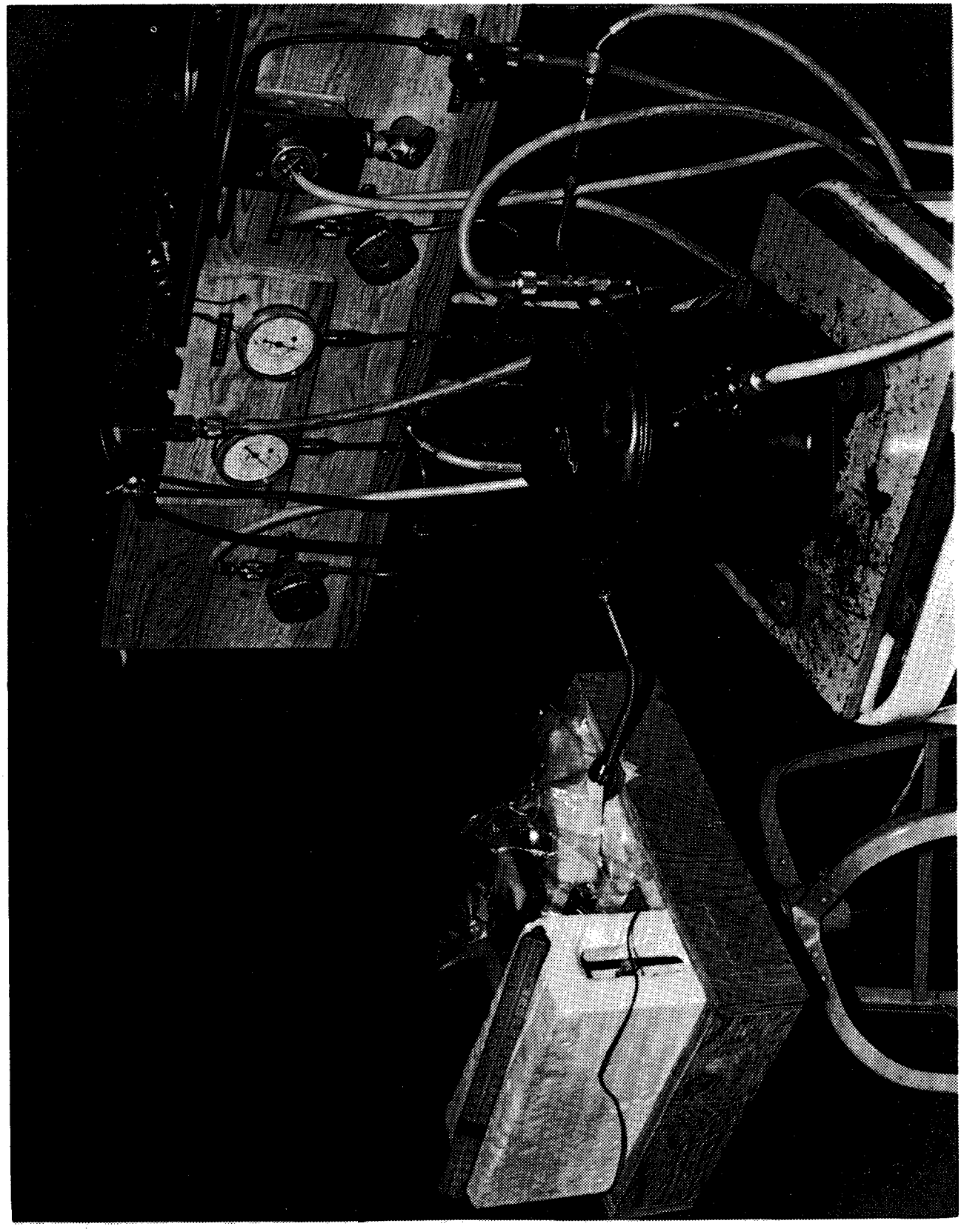

Figure 7-4. Microphone Position

discharge and 4.5 psig suction. In addition, the return gas temperature must be 90°F. If conditions have not stabilized in 30 minutes, the test must continue running until stabilized, and then final readings taken. The microphone of the sound level meter should be in the same horizontal plane as the end head. KCC utilizes a mastic pad on the end head for normal T-line tests, as well as on production compressors. The mastic pad is also utilized on all the efficient compressor samples.