NATIONAL BUREAU OF STANDARDS REPORT

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CONVERSION OF THE THERMO-KING GASOLINE ENGINE DRIVEN ONE-TON WAREHOUSE REFRIGERATING UNIT TO ELECTRIC DRIVE

by

C. W. Phillips
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Report to

Mechanical Engineering Division
Headquarters, Quartermaster Research & Development Command
Natick, Mass.

U. S. DEPARTMENT OF COMMERCE
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NBS PROJECT **NBS REPORT**

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NBS

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Abstract

An important item of Army refrigerating equipment, the nominal 1-ton warehouse refrigerating unit, was investigated to determine the relative net refrigerating capacity when operated with an electric motor as compared to operation with a gasoline engine. The ease with which the conversion from gasoline engine drive to electric motor could be made in the field was studied. Pertinent previous tests of similar 1-ton gasoline engine driven warehouse refrigerating units are referenced to substantiate recommendations for modification of relative fan speeds. As designed, the conversion kit from gasoline engine drive to electric motor drive, except for one error in machining size, was able to be installed by two mechanics, without previous experience in making this conversion, in less than eight hours, including an operational check. The net refrigerating capacity with electric motor drive was 5980 Btu/hr as compared to 9720 Btu/hr with gasoline engine drive, under conditions of 110 F ambient temperature and 0 F warehouse temperature. Decreasing the evaporator and condenser fan speeds by reducing the drive pulley furnished with the electric motor conversion kit to the same size as used with the gasoline engine drive is recommended for an estimated gain of 30% in net refrigerating capacity.

1. INTRODUCTION

Among the items of Army refrigerating equipment the 600 cubic foot warehouse with a nominal 1-ton refrigerating unit has become one of the most important units. Where electric power is not readily available these refrigerating units are powered by gasoline engines which start and run as required under control of the thermostat sensing the warehouse temperature. Such cycling of a gasoline engine requires complicated control equipment including heavy duty batteries, relays,

automatic choke, cranking limit devices, cranking motor, generator, and other controls. Failure of any one of these devices will render the unit inoperable. Units can be operated on cyclic basis by an electric motor with much simpler control and partly because of this, conversion of the unit to electric motor operation is desirable where electric power is available. In the development of this item of Army refrigerating equipment various prototypes have included combination power plants with both gasoline engine and electric motor drives. Some of these combinations were equipped with over-riding clutches so that either type of drive could be employed without any mechanical changes, others required belt changes or mechanical clutch adjustments.

A 1-ton warehouse refrigerating unit, Thermo-King Model MQ-51, equipped with a Crosley liquid-cooled gasoline engine was supplied for the performance tests and was converted to electric motor drive, using a kit manufactured by U. S. Thermo Control Co., who were also the manufacturers of the Thermo-King unit involved.

A purpose of the tests was to determine the relative capacity of the 1-ton unit driven by the two prime movers. Another purpose of converting a unit as a part of the investigation was to see how practical the actual conversion was as a field operation.

2. DESCRIPTION OF THE TEST ITEMS

The Electric Motor Conversion Kit, manufactured by U. S. Thermo Control Co., which was further identified as N. B. S. Specimen No. 107-54, contained all items required for the conversion. The items supplied were:

Part No.	Nomenclature	Quantity
1310	Belt, drive, oil pump	1
9AA2	Belt, fan	2
#10	Cable, power, rubber covered, 4 wire conductor - 15 ft. long	1
C4980A-10	Clamp, oil line	1
MQE-D503C	Coupling, drive assy.	1
MQE-S517B	Cover, relay box	1
Q15-R721B	Grommet, rubber	1
MQE-E503C	Motor and base assembly, electric	1
MQE-519B	Plate, identification	1

Part No.	Nomenclature	Quantity
MQE-520C	Plate, instruction	1
T-205B	Puller, drive pulley	1
MQE-D502A	Pulley, drive, oil pump	1
MQE-S510C	Pump assembly, oil	1
MQE-E508D	Relay box assembly	1
MQE-S522A	Strip, nut, oil pump mounting	1
T-206A	Wrench, (hx. bar) Compressor pulley)	1

The electric motor, part of Part No. MQE-E503C above, can be further identified as:

Westinghouse Life-Line Motor
Type CSP Design B
Frame 284
7.5 H.P.
3 Ph - 60 cycle 220/440 volts
20/10 amps/line
Locked KVA Code G
1750 rpm
Ser. #5308
S #1442202

The unit used for the conversion was a Model MQ51 Thermo King 1-ton warehouse refrigerating unit, originally equipped with a Crosley liquid-cooled engine. This unit was identified as N.B.S. Specimen 101-53, and bore manufacturer's Serial No. QS-200.

Figure 1 shows the Model MQ51 Thermo King warehouse refrigerating unit used in these tests. It is mounted in operating position in a demountable insulated warehouse. The wires across the front of the condenser guard are for thermocouples and the hole in the front machine compartment door was made for test purposes. When used with a gasoline engine a muffler was attached to the exhaust pipe extending vertically from the front left top corner.

Figure 2 shows the evaporator side of the test unit mounted in a warehouse wall. The wire crossing the front of the evaporator guard is a support for thermocouples.

Figure 3 is a front view of a Thermo King 1-ton unit of the same model as N.B.S. 101, showing the Crosley liquid-cooled gasoline engine, generator-starter assembly and drive coupling. The two belts from the drive coupling operate the evaporator and condenser fans.

Figure 4 is a side view of the condensing unit section of the same unit.

Figures 5 and 6 are front and side views, respectively, of the primary items involved in the conversion to electric motor drive. In Figure 5 the square enclosure over the electric motor contains the transformer-rectifier for the normal direct-current controls, throttling valve relay, defrost holding relay and defrost timer. The belt-driven apparatus to the left of the rectifier enclosure is an oil pump which operates the evaporator air damper. The small wire attached to the front surface of the motor is a thermocouple. In Figure 6 the rectangular enclosure above the motor contains the magnetically-operated motor relay.

3. TEST PROCEDURE

The Model MQ51 Thermo King unit, as originally equipped with the Crosely liquid-cooled gasoline engine was tested to determine its net refrigerating capacity. The unit was installed in operating position in one wall of a 600 cu. ft. insulated warehouse which was then calibrated for heat loss. A test of the unit at conditions of 110 F ambient temperature and 0 F warehouse temperature to determine the net refrigerating capacity was then made. This capacity is the sum of the calibrated heat gain of the warehouse and the heat equivalent of the electrical energy required to maintain the interior warehouse temperature at 0 F. during steady operation of the unit. A Model 4 R Thermo King compressor whose capacity had been measured previously on an N.B.S. calorimeter was substituted for the original compressor in the unit under test because its capacity was known. The original Model 4 R Thermo King compressor had been employed in a series of tests of long duration to determine drfrosting characteristics of this unit under various methods of control and its condition was not suitable to simulate new compressor performance.

Following the test under the gasoline engine drive, the gasoline engine was removed and the electric motor drive conversion kit was installed for a comparison test. The instructions in a manual entitled "Thermo-King (Model MQ51-E) Instruction Manual and Parts List With Instructions for Conversion from Model MQ-51 Gasoline to Model MQ-51 Electric" were followed in making the conversion. The steps listed in the manual were as follows:

1. Disconnect battery cables from batteries. Leave negative cable attached to engine. Leave positive cable attached to unit.

2. Remove batteries from compartment in bottom of unit. Clean the battery compartment.

3. Open petcock under water pump and drain coolant into a container.

4. Disconnect radiator hoses at end of extension tubes fastened to bulkhead. Leave hoses connected to engine.

5. Disconnect engine exhaust hose at pipe under condenser coil. Leave exhaust hose connected to engine.

6. Disconnect engine terminal board with wire harness.

7. Disconnect all wires connecting engine to bulkhead terminal board, at board.

8. Disconnect two flexible oil lines at engine.

9. Disconnect positive lead to starter-generator. Disconnect this cable at both ends, otherwise it will be "hot" and may cause a short circuit.

10. Disconnect fuel line at fuel pump.

11. Loosen clamps and remove carburetor air cleaner. Store air cleaner with engine for possible future use.

12. Remove center post from between two front doors.

13. Remove four bolts fastening engine to side flanges of power tray. Remove two bolts at open end of tray.

14. Remove engine from unit, carefully sliding splined shaft out of splined hole in drive coupling.

15. Loosen bolts holding condenser fan housing and bracket assembly to flanges on condenser coil. Slide fan and bracket assembly downward in adjustment slots.

16. Remove fan belts from unit and store with engine for possible future use.

17. Remove socket head cap screw holding coupling to tapered end of compressor shaft. Save this screw for later use in making the conversion.

18. Using special puller supplied with conversion kit, remove drive coupling from compressor shaft.

19. Install electric motor assembly in power tray through front opening of unit. Slide assembly to right as far as possible to allow clearance for installation of new drive coupling on compressor shaft. Be sure that keyway in coupling fits over key in shaft.

20. Place socket head cap screw (referred to in para.1) on end of special extension wrench and insert in coupling to fasten drive coupling to compressor shaft.

21. Place oil pump drive belt over shaft of electric motor, and new set of longer fan belts over drive pulley and fan pulley.

22. Slide electric motor toward compressor, carefully inserting motor shaft into drive coupling. See that shaft key is in place. Move motor to the left until holes in motor base line up with matching holes in power tray. Install and tighten four bolts and two bolts.

23. Tighten two socket head screws in split collar on motor shaft.

24. Loosen bolts holding oil pump assembly. Remove assembly and connect two flexible hydraulic oil lines. Fasten oil line clamp under corner screw of oil pump cover.

25. Install oil pump assembly on bracket and place belt over pulleys. Loosen set screw in oil pump drive pulley and align the two pulleys. To adjust belt tension: raise oil pump assembly and tighten two bolts. Allow 3/4" slack in belt midway between two pulleys. Tighten set screw in drive pulley.

26. Remove oil filler plug and fill oil pump reservoir with one quart of SAE 10-W oil. Install and tighten oil filler plug.

27. Remove relay housing cover. Slip rubber grommet over wire harness. Fit grommet into slot in relay housing. Connect terminal board to terminal board on transformer. Install a brass nut on each active binding post. Install housing cover.

28. Connect positive battery cable to brass post on line-starter box. It may be necessary to spread the cable clamp before installing.

29. Adjust tension of fan belts: move condenser fan housing upward in slotted holes and tighten adjustment screws. Allow 3/4" to 1" slack in belts midway between pulleys.

30. Install center post between doors.

31. Remove wiring diagram-instruction plate, and identification plate from unit. Replace with new plates covering electric motor operation. Store old plates with engine for possible future use.

32. Connect motor lead cable to source of 220 volt, 60 cycle, 3 phase electric current. Connect lead so that compressor rotates in a clockwise direction when viewed from the motor end. Turn unit on momentarily to check direction of rotation. If compressor turns counter-clockwise, reverse the position of any two power leads in the connector cable.

Two laboratory mechanics without previous experience in making this conversion were assigned the job of making the actual conversion. No difficulty was experienced until Step 22. At this point is was discovered that the bore of the drive coupling (Part No. MQE-D503C) on the motor end was 1 1/8" while the motor shaft was 1 1/4". The coupling assembly was sent to U. S. Thermo Control Co. for exchange or modification and was returned in about a week. No further complications in making the conversion were encountered, and, with correction for the time lost because of the incorrect sizing of the drive coupling components, the installation was easily made by two mechanics in less than eight hours, including a check for operation. All parts, including clamps and other miscellaneous hardware, necessary for the job were provided in the kit.

After installation of the electric motor drive and accessories, the unit was again operated in the calibrated warehouse and the net refrigerating capacity determined. The power input to the motor, nominally rated at 7 1/2 h.p, was measured.

In each of the comparative capacity tests, the unit was operated for more than twenty four hours and the data reported is that observed during a stable period of six hours at or near the end of the operating period.

4. TEST RESULTS

The results of the two comparative tests of net refrigerating capacity, first with the unit powered by a Crosley liquid-cooled gasoline engine, and second, with a Westinghouse electric motor are presented under Tests 1 and 2 in Table 1.

This table shows a net refrigerating capacity of 9720 Btu/hr with the gasoline engine drive in Test 1 and 5980 Btu/hr with the electric motor drive in Test 2.

The primary difference in operating characteristics between the two tests was the speed of the compressor. In both cases it was direct-driven with the gasoline engine driving the compressor at a speed of 2418 rpm whereas the electric motor drove the compressor at 1703 rpm. The belt-drive assembly for the condenser and evaporator fans furnished with the electric motor conversion was sized to operate the fans at a speed about 150 rpm lower than that observed when the gasoline engine was driving the compressor at 2400 rpm. For example, when the compressor was driven at 2418 rpm by the gasoline engine, the condenser and evaporator fans operated at 1601 rpm and 1379 rpm, respectively. When the compressor was driven at 1703 rpm by the electric motor, the fan speeds were 1450 rpm and 1243 rpm, respectively. That is, in Table 1 the net refrigerating capacity with the electric motor drive was 61.5% of that observed with the gasoline engine drive whereas the speed of the compressor with electric drive was 70.4% of the that observed with the gasoline engine drive. Correspondingly, the evaporator and condenser fan speeds with electric drive were about 90% of those observed with gasoline engine drive.

Also given in Table 1 are the results of capacity tests of two other 1-ton Thermo King gasoline engine driven warehouse refrigerating units. In Test 3 another 1-ton unit of the same model number was operated with a compressor speed of 1330 rpm with fan speeds in proportion as determined by the pulley ratios. In this test the net refrigerating capacity was 79.2% of that observed in Test 1 whereas the compressor and fan speeds were about 55% of those in Test 1.

In Test 4 the same compressor as that used in Tests 1 and 2 produced a net refrigerating capacity of 10,100 Btu/hr at a speed of 2291 rpm when used in a third 1-ton warehouse refrigerating of the same model. A calorimeter test of compressor A, the one used for Tests 1, 2 and 4, showed that its gross refrigerating capacity was 13,700 Btu/hr under the same operating conditions as those shown in Test 4.

Tests 3 and 4 in Table 1 were not a part of the present comparison, but they provide data which will be used to help explain under Discussion and Conclusions the disproportionate decrease in capacity in Test 2 as compared to Test 1 when the compressor speed was decreased as a result of conversion to electric drive.

The small variations in the ratio between fan speed and compressor speed observed in Tests 1, 3 and 4 in Table 1 are thought to be due to belt slippage.

All components of the electric conversion kit functioned as intended. The oil pump developed sufficient pressure to operate the evaporator air damper. All controls normally operated by 24 volts DC functioned satisfactorily with the transformer-rectifier furnished.

5. DISCUSSION AND CONCLUSIONS

As stated in the introduction the comparison tests of the two methods of driving a 1-ton Thermo-King warehouse refrigerating unit were made to determine:

1. Ability to make the conversion from gasoline engine drive to electric motor drive as a field operation.

2. Net refrigerating capacity for each method of drive.

Two laboratory mechanics, neglecting the time delay caused by the improper size of the drive coupling assembly, were able to make the conversion including operation of the unit for purposes of check within eight hours. Since neither of the mechanics had previously performed this conversion it appears practical as a field operation. No opening of refrigerant lines was required, therefore, a knowledge of the assembly of refrigeration circuits was not a prerequisite. The step by step instructions provided in the manual adequately described each required operation and the kit contained every item required to make the complete conversion.

The net refrigerating capacity of the 1-ton warehouse refrigerating unit was reduced 38.5% by virtue of the conversion to electric drive whereas the speed reduction of the compressor was only 29.6% and the speed reduction of the condenser and evaporator fans was only 10%.

In previous tests made of a 1/3-ton gasoline engine driven warehouse refrigerating unit, it was observed that the heating effect of the evaporator fan was a primary contributing factor to the reduction of the net refrigerating capacity of the unit as the speed was increased. In that series of tests, it was shown that when the speed of compressor and fans were increased proportionally a balance point was reached where the increase in compressor capacity was exactly offset by the increase in evaporator fan power because the compressor capacity increased proportionally with speed whereas the evaporator fan power increased as the cube of its speed. At speeds above that corresponding to this balance point the net refrigerating capacity decreased.

As stated earlier, a calorimeter test was made of the Model 4-R Thermo-King compressor A, (Serial No. 2138-x) used in test 1, 2 and 4 summarized in Table 1 of this report. The capacity of the compressor itself operating under the same conditions as those summarized in Test 4 was 13,700 Btu/hr at 2299 rpm, while the net refrigerating capacity of the unit was 10,100 Btu/hr at 2291 rpm as shown in Test 4. The heating effect of the evaporator fan was a major part of the difference between the gross compressor capacity and the net refrigerating capacity of the unit. Assuming that the heating effect of the fan contributed all of the difference observed between gross compressor capacity and net unit refrigerating capacity, and a study of the data for the tests involved indicated that this was essentially true, then a value of 3600 Btu/hr is indicated as the energy released by the evaporator fan for a speed of 1234 rpm as shown in Test 4. The energy released by the evaporator fan was computed for Tests 1, 2 and 3 in Table 1 assuming that it varied as the cube of the speed. The gross refrigerating capacity was computed for each test in Table 1 assuming that it was equal to the sum of the net refrigerating capacity and the evaporator fan power, as it was shown by test to be in Test 4.

A comparison of the values for computed gross compressor capacity, computed heating effect of the evaporator fan, and observed net refrigerating effect for the four tests summarized in Table 1 indicate the following conclusions:

1. The gross compressor capacity increased steadily with speed in the range from 1330 rpm to 2418 rpm.

2. The heating effect of the evaporator fan increased rapidly with speed. There was more than a fourfold increase in the heating effect for the range of fan speed from 744 rpm to 1234 rpm and more than a six fold increase in the heating effect for range of fan speed from 744 rpm to 1379 rpm.

3. The relatively high evaporator fan speed and corresponding high heating effect of this fan in Test 2 probably accounted for the disproportionally large decrease in net refrigerating capacity observed as a result of conversion from gasoline engine drive to electric drive.

4. The fourfold difference in the heating effect of the evaporator fan between Tests 2 and 3 probably explains why a higher net refrigerating capacity was observed in Test 3 with a compressor speed of 1330 rpm than was observed in Test 2 with a higher compressor speed.

The results in Table 1 indicate that the minimum fan speed for effective operation, at least for the evaporator fan, should be determined by suitable investigation for the Model MQ-51 Thermo-King unit, either gasoline engine or electric drive, because of the significant effect the heating load of the evaporator fan has on the net cooling capacity of the unit in relation to the gross capacity of the compressor. Pending such an investigation it is recommended that the drive assembly for the evaporator and condenser fans furnished with the electric motor drive conversion kit be made the same size as is normally used with the gasoline engine drive. Based on the relative compressor and fan speeds observed in Test 1, the fan speed for the condenser and evaporator fans, respectively, when the compressor speed is reduced to 1703 rpm would be 1129 rpm and 972 rpm with such a drive assembly. At 972 rpm the heating effect of the evaporator fan would be $\frac{(972)^3}{(1234)^3}$ 3600 = 1760 Btu/hr. Assuming the gross computed compressor capacity at 1703 rpm compressor speed in test 2 would remain constant if the fan speeds were so reduced the net capacity would be approximately 9640 - 1760 = 7880 Btu/hr, an increase of 1900 Btu/hr or 32% as compared with Test 2. It is, of course, recognized that the reduction in fan speed must be considered in the light of proper air circulation within the refrigerated space, but the possibility of more than 30% increase in net refrigerating capacity warrants consideration.

TABLE 1

COMPARISON OF PERFORMANCE OF THREE MQ51 THERMO-KING UNITS WITH ELECTRIC MOTOR OR GASOLINE ENGINE DRIVE

	Test 1	Test 2	Test 3	Test 4
NBS Specimen Number of Unit	NBS #101	NBS #101	NBS #110	NBS #104
Prime Mover	Gasoline Engine	Electric Motor	Gasoline Engine	Gasoline Engine
Thermo King Compressor Used	A	A	B	A
Net Refrigerating Capacity, Btu/hr	9720	5980	7700	10,100
Ambient Temperature, °F	110.9	110.1	110.6	109.6
Warehouse Temperature, °F	0.6	2.8	1.1	-0.8
Compressor Speed, rpm	2418	1703	1330	2291
Condenser Fan Speed, rpm	1601	1450	864	1471
Evaporator Fan Speed, rpm	1379	1243	744	1234
Discharge Pressure, psig	184.5	160	183	177
Suction Pressure, psig	2.1	3.9	-	0.6
Temperature of Air Entering Condenser, °F	116.7	111.0	120.6	-
Temperature of Air Leaving Condenser, °F	127.6	119.0	127.6	-
Temperature of Air Entering Evaporator, °F	2.0	3.3	2.2	-
Temperature of Air Leaving Evaporator, °F	-1.6	0.9	-3.2	-
Entering Evaporator Surface Temperature, °F	-8.3	-3.8	-10.9	-
Evaporator Surface Temperature, Midpoint, °F	-6.7	-2.7	-11.0	-
Evaporator Surface Temperature at T.E.V. Bulb, °F	-5.8	-1.5	-4.2	-
Computed Heating Effect of Evaporator Fan, Btu/hr	5020	3660	810	3600
Computed Compressor Gross Capacity, Btu/hr	14740	9640	8510	13700 a)
Compressor Speed Ratio	1.05	0.74	0.58	1
Gasoline Consumption, lbs/hr	5.0	x	-	-
Electric Power Input, watts	x	5294	x	x

a) This value is a calorimeter measurement for compressor A.

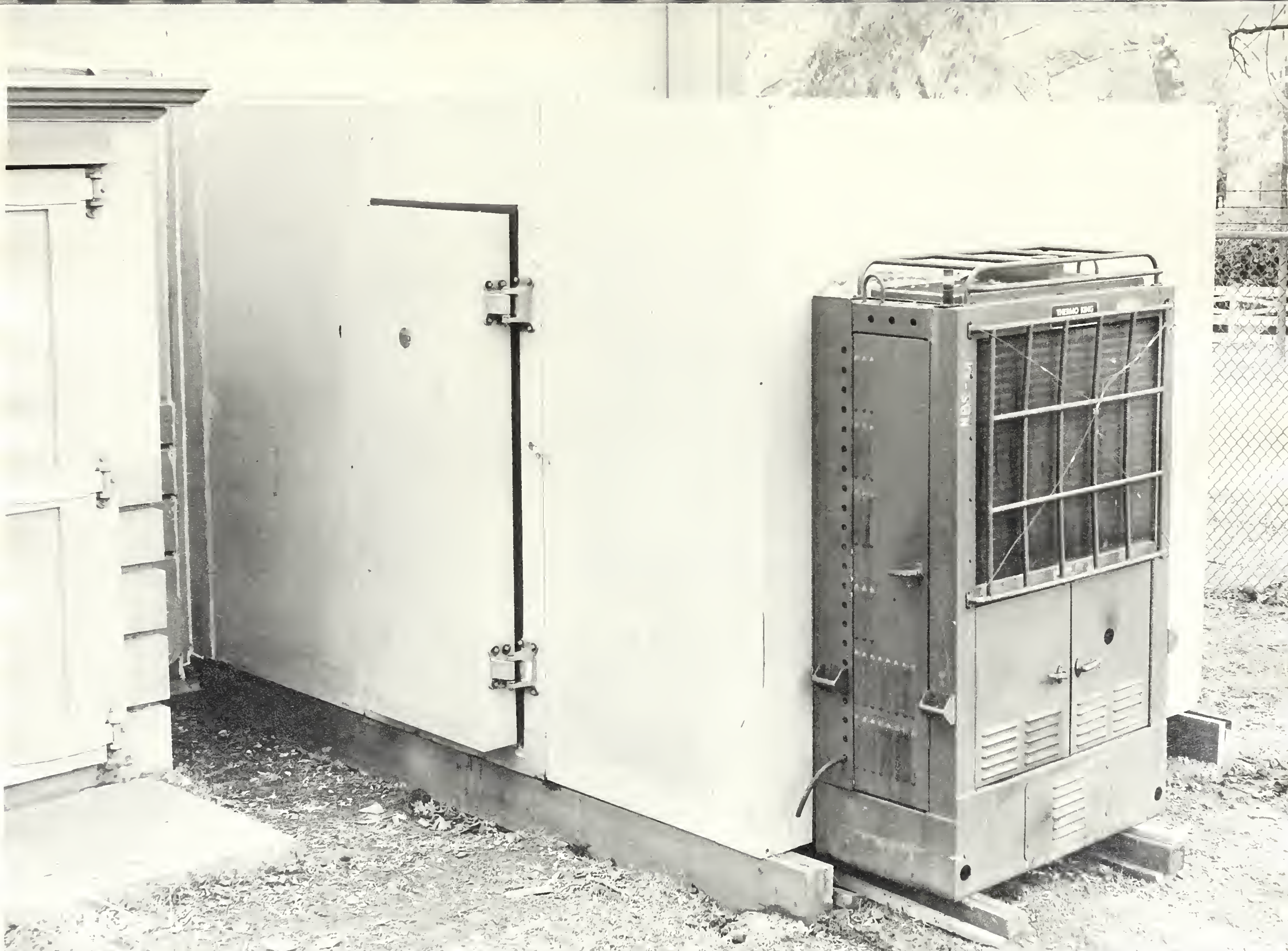

Fig. 1

Fig. 2

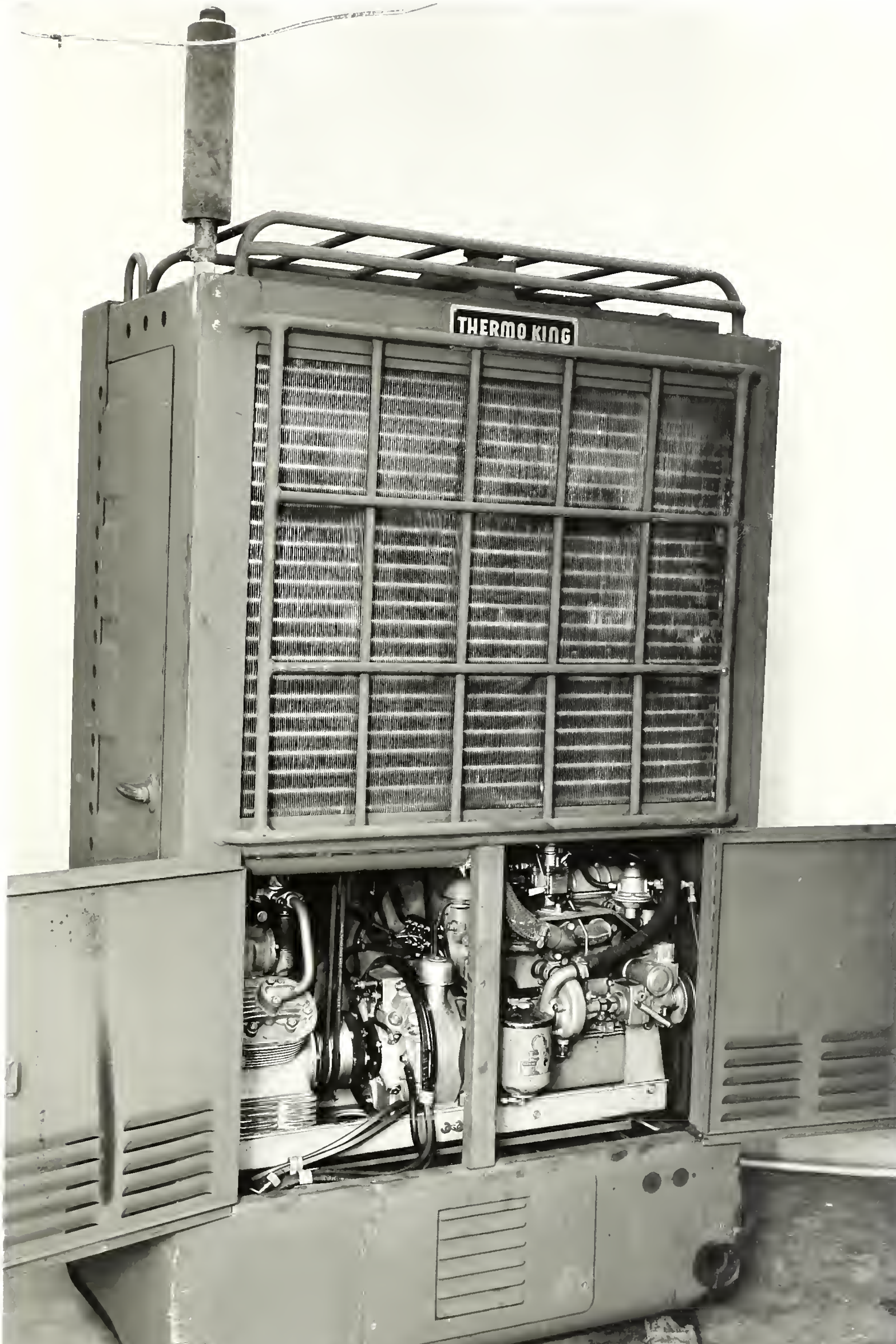

Fig. 3

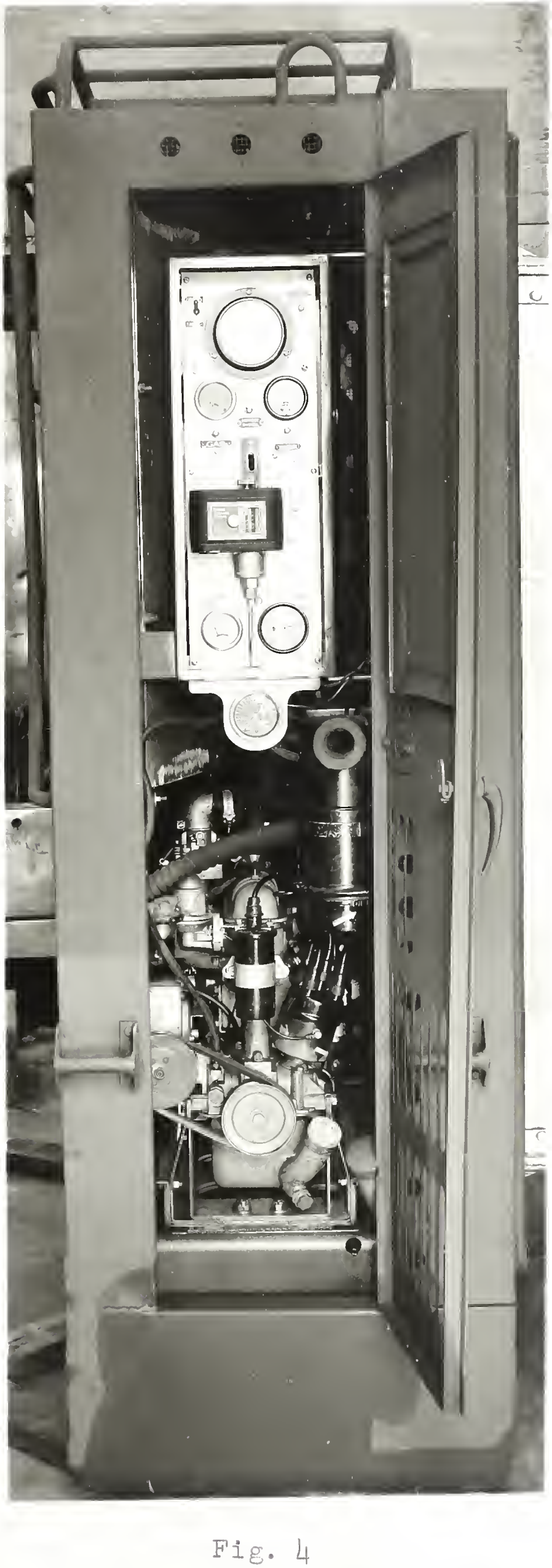

Fig. 4

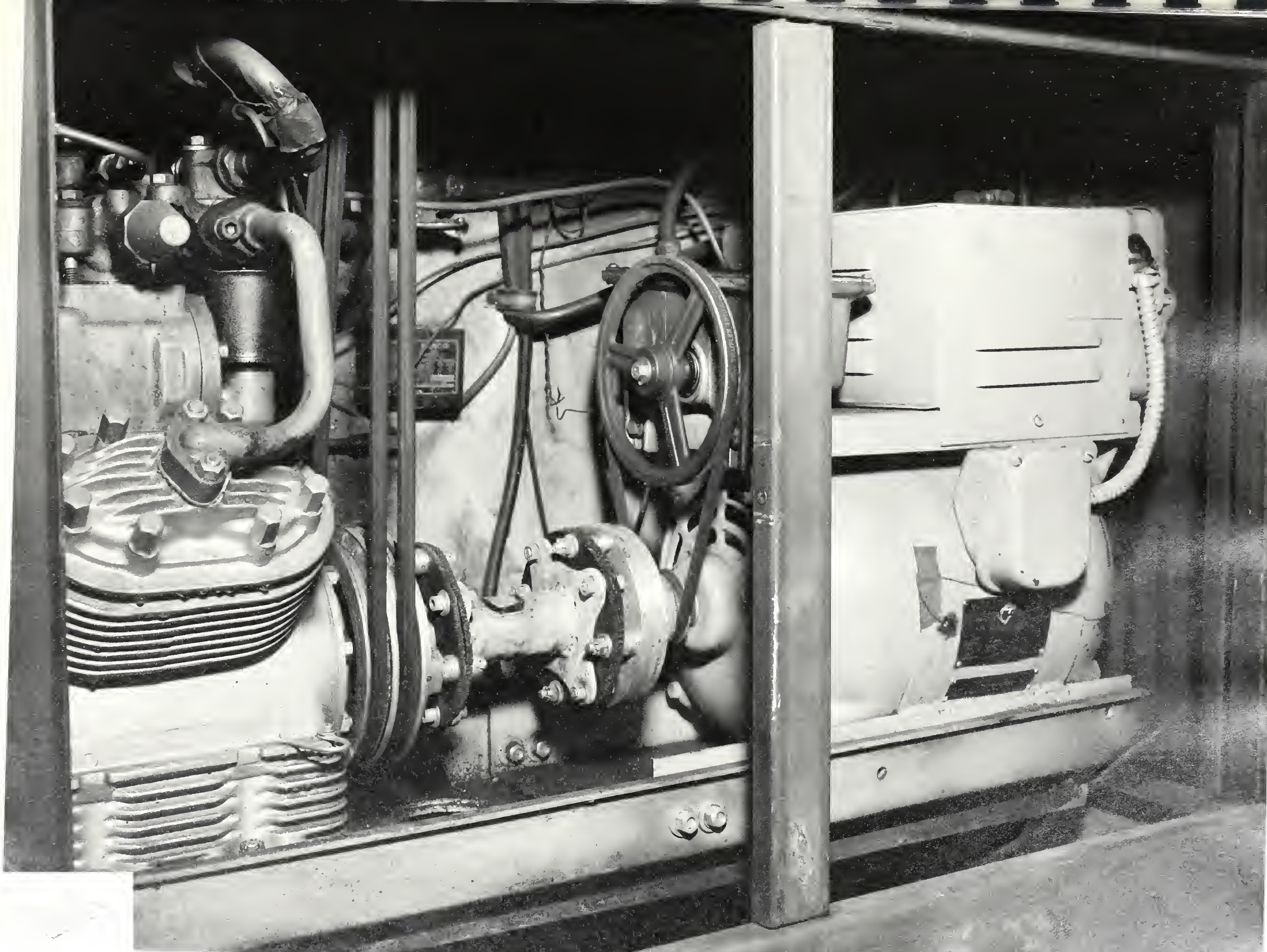

Fig. 5

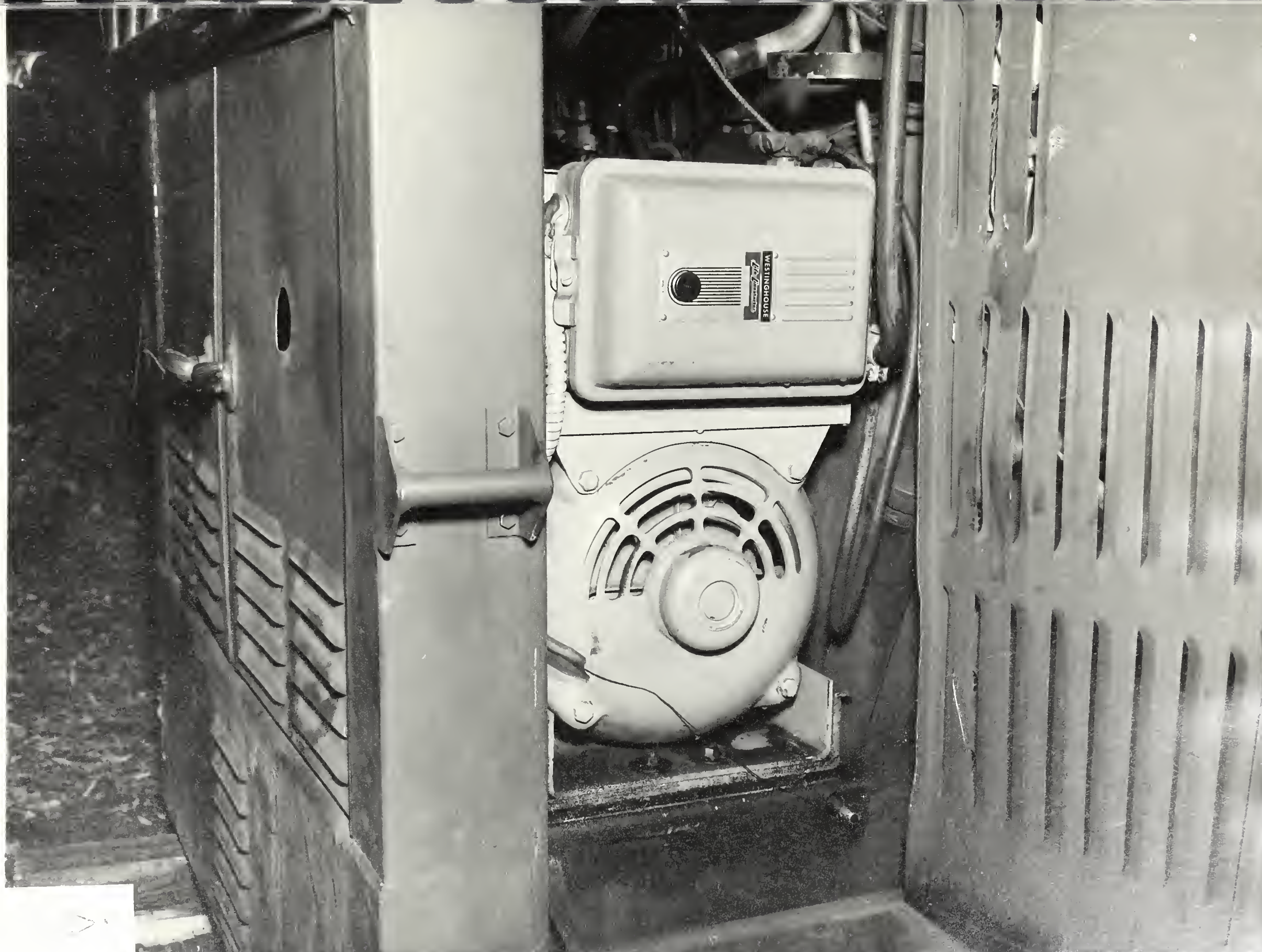

Fig. 6

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