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Semi-Hermetic Motor-Compressor Unit with the Motor Outside of die Refrigeration Circuit

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TITLE

SEMI-HERMETIC MOTOR-COMPRESSOR UNIT WITH THE MOTOR OUTSIDE OF THE REFRIGERATION CIRCUIT.

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ABSTRACT

This paper refers to the laboratory tests of two motor-compressors: the first is a standard one, commonly installed in air conditioning applications, on the market for years. The second is a prototype, actually a variation on the first one, with the electric motor assembled on the shaft extension of the compressor, but entirely segregated from the refrigerant system. The motor is indirectly cooled by the suction refrigerant vapor thru a secondary dielectric fluid, in which the motor is fully immersed (see Figure 1).

The tests covered a large range of temperatures commonly used in comfort air conditioning and in perishable goods refrigeration from 10°C to -30°C (from 50°F to -34.1°F). Both motor-compressors have been tested thru startup and shutdown cycles, at different intervals, in order to check the behaviour at significant transient conditions.

Objective of the test program was to compare the behaviour of the two motor-compressors under identical running conditions.

INTRODUCTION AND BACKGROUND

Historically hermetic and semi-hermetic motor-compressors were developed to overcome the pressing problem of leaks through the refrigeration compressor rotary seal. The development of the CFC refrigerants was the determinant factor of the success of the hermetic unit and the decline of the compressor driven by a separate motor, forming the so called open type unit.

In spite of the outstanding technical development of the hermetic units and specifically of their electric motor protection, motor burnout has been the major cause of failure of the motor-compressor units and, by far, the most expensive to repair.

In addition to the cost of repairing or replacing the motor compressor unit, in the case of burnout, the entire system must be carefully cleaned and all the particles of the winding insulation removed from the system. The procedure that was recommended by refrigerant manufacturers, in order to avoid a "relapse" burnout, was to evacuate from the system the refrigerant and the lubricating oil that had to be replaced anyhow; then to thourougly clean the system, preferably with R-11.

before charging with new refrigerant, the filter had be replaced and a temporary suction side filter had to be installed.

Other procedures had to be followed, but nobody could guarantee the user from a new burnout in a short while.

With the restrictions enforced by almost all the western countries against any release of CFC fluids to the environment, in the recent years the problem have become more and more complex and no clear procedure has been established in case of motor burnout.

The feeling that a solution had to be found, led to the idea of modifying the semi-hermetic unit in order to keep its advantages avoiding the problem represented by the motor installed in the refrigerant system.

In the last two decades the rotary seal manufacturing industry has developed seals which are far more reliable and wear resistent than the old ones. Modern rotary seal can be regarded as a fool proof accessory also on continues and severe service applications, especially when operating in stable and moderate temperature applications, with no shaft misalignment stresses.

This long and meticulous description was necessary in order to consider the idea of adding new components to a machine in the proper way.

The economic impact of the above depicted modification has not been completely assessed as yet, mainly as regards machining and assembling costs.

The main additional costs are represented by the rotary seal and the heat exchanger (plate or other types), the last being required in the larger units.

Substantial savings are expected in the cost of the stator, because the impregnation of the windings can be avoided. Another saving will take place because the sophisticated motor protection will be replaced by a standard protection for regular motors.

A unique advantage offered to the customer will be the fact that in case of a motor burnout, any electrician can replace the motor without disassembling the unit from the system, avoiding the assistence of a refrigeration repairman, in a fraction of the time needed in conventional units.

The compressor is the largest single cost item in a refrigeration system (1), it is also the major responsable for system failure shutdowns and, more specifically, in the semi-hermetic units, the electric motor is statistically the most frequent cause of failures.

The additional cost of the new motor-compressor will vary according to the size of the unit; anyhow it should not exceed 5% of the cost of the unit and therefore can be regarded as a profitable investment.

The novelty application is not limited to reciprocating units, but can be incorporated, with similar results, to any other semi-hermetic compressor, such as rotary, screw, scroll, centrifugal, etc.

SCOPE OF THE TESTS

For the sake of a complete and significant comparison between the traditional design compressor (Standard Model) and the modified one (Prototype) a model already in the market was selected.

The Prototype is identical to the Standard as far as compressor and motor are concerned, while the motor chamber is totally separate from the refrigeration system, by means of a compressor casting alteration. So the suction side refrigerant passes thru a jacket formed all around the motor compartment of the compressor body.

The two units have been tested in the same testing facilities, including measurements, data recording and processing system.

In order to obtain the most uniform tests, it was decided to run the two compressors with the same valve plate.

The model selected was a 10.56 KW (3TR) unit, that doesn't include the plate type heat exchanger which is, instead, supplied to larger compressors.

The secondary heat-exchange, that necessarily takes place in the Prototype does not exist in the Standard unit, and could have been a negative factor, increasing the motor temperature beyond the operating limits set by the electric motor suppliers.

Scope of the comparative tests was to assess the increase of the windings temperatures due to the secondary heat exchange and the influence on the thermodynamic behaviour of the Prototype, compared with the Standard Model. As mentioned above, in the Standard Model the motor is cooled directly by the refrigerant fluid, while in the Prototype the cooling is obtained by properly modifying the Standard Model.

Due to the fact that vapor compression cycle frequently operates in transient mode, a serie of tests was carried out to determine the behaviour of the two units during frequent startup and shutdown cycles.

TEST FACILITIES

The compressors test facilities are designed according to UNI 8773 STANDARD (UNI is the Italian Bureau of Standards).

They consist mainly of the following parts:
- Two U shaped tube, dry expansion evaporators with manually controlled expansion valves and sight glasses operating in separate circuits.

- One shell and tube design condenser with build-in liquid subcooler.

The system is thoroughly insulated and furnished with the usual accessories such as filter dryer, dial gauges, shut off valves and safety controls.

The water, or other liquid, flowing thru the evaporators and condenser is controlled by precision flow valves and meters. An insulated tank delivers water or low freezing point liquid at desired temperatures to a small vessel, that keeps superheated suction vapor at a set temperature.

The testing system is schematically represented in Figure 1, which indicates the type of measurements and sensor locations.

Tests were carried out using a microcomputer based data acquisition system with 19 analog inputs, 32 khz maximum sampling rate and 12 bits sampling accuracy.

The Ohmic resistence is measured by a special apparatus to control the motor winding temperatures.

The compressors to be tested were R-22 two cylinder in-line semi-hermetic type units, driven by an overhung 2.2 kW (3HP), three phase, four pole induction motor.

CONCLUSIONS

The two motor-compressors were tested at 45°C (113° F) condensing temperature and several evaporating temperatures ranging from -30°C (-22° F) to 10°C (50° F).

The most significant performance data of the capacities, duly adjusted according to the relevant suction superheated vapor and the liquid subcooling temperatures, are the followings:

Model	Evap. Temp. (°C)	Adjus.refr. Capacity (°C)	Motor Input (W)	Windings Temp. (°C)
Standard :	10	9665	2859	34
Prototype :	10	10071	3015	77
Standard :	0	6490	2736	42
Prototype :	0	6240	2852	92
Standard :	-10	4500	2393	52
Prototype :	-10	4061	2444	98
Standard :	-30	1412	1483*	57*
Prototype :	-30	1419	1403*	83*

* Side ventilation external cooling.

A more complete collection of test datas can be seen at Table 1.

The scope of the tests being to ascertain the actual ability of the prototype to perform normally at test conditions, the objective was fully achieved.

In order to decrease or eliminate the presently existing differences between the prototype motor-compressor and the standard one, the characteristics that should be improved in the prototype are the followings:

- Decrease the windings temperatures thru an improved heat exchange between suction refrigerant and dielectric fluid.

- Reduce friction losses present in the motor chamber thru a lower viscosity intermediate fluid and an inprovement in the rotor shape.

No significant increase in the cost of the machine is expected from the above improvements.

At the completion of the tests, with the motor-compressor still warm, the replacement of the stator was completed in less then half an hour, with only a common mechanic tools set (see Picture 1).

The results of the test at transient conditions did not reveal significant differences between Standard and Prototype motor-compressors.

However an additional serie of tests on this subject is scheduled according to the methods described in references (2) and (3).

FUTURE TESTS

In addition to the tests mentioned in the preceding section, other tests are scheduled to compare a standard semi-hermetic motor-compressor unit of larger capacity to a prototype of the same characteristics.

The prototype will have the electric motor on the same shaft as the compressor, immersed in the cooling fluid, rotary seal, and motor chamber completely segregated from the refrigerant system.

In addition to verifying the comparative behaviour of the two motor-compressors, the objective of the tests will be to probe the possibility of utilizing the fluid cooling the motor as a heat source for thermal applications. This way, in addition to the advantage of lowering the motor temperature, better thermodynamic characteristics of the motor-compressor can be achieved, reducing the amount of cooling effect lost removing the heat generated by the motor (see Figure 3).

ACKNOWLEDGMENT

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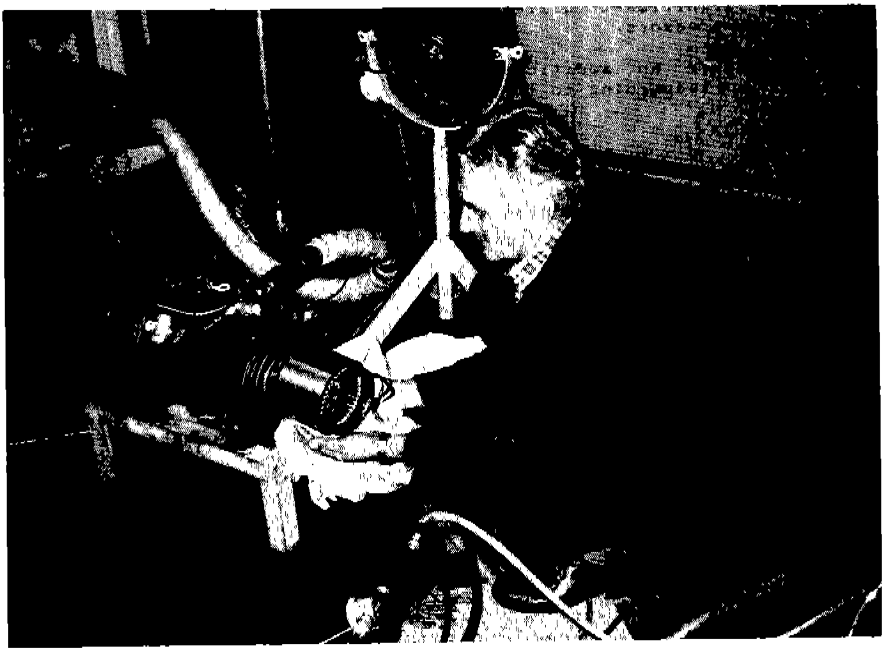


Picture 1

COMPRESSORS

Manufacturer: DURIN - Mod.300 CC - Displac.: 3.1 L/s (6.567 CFM)

__Tested Units:__

Standard = Stand.
Prototype = Prot.

__Test Conditions:__

Condensing T.		45		
Evaporating T.	10	0	-10	-30

__Test Parameters:__

	Stand.	Prot.	Stand.	Prot.	Stand.	Prot.	Stand.	Prot.
__Condenser__								
Ent. Wat. T.	17.6	15.5	17.4	16.8	18.0	14.2	19.5	14.1
Leav. Wat.T.	30.8	31.0	30.7	30.2	30.4	31.9	41.2	43.[illegible]
Superh.Comp.T.	71.4	76.9	96.7	99.5	112.0	111.9	104.8	104.3
Liq.Subcool.T.	38.3	38.4	36.7	37.1	35.9	36.1	36.4	37.0
Wat.Qty l/min.	15.4	13.4	11.3	10.9	8.3	8.3	1.5	1.1
Cond. P. Bar	N.R.	16.2	N.R.	N.R.	N.R.	16.2	16.2	N.R.
__Evaporator__								
Ent. Wat. T.	30.1	28.0	21.2	20.2	24.3	19.2	18.5	19.0
Leav. Wat. T.	22.0	19.4	15.7	14.9	16.5	12.0	11.7	12.2
Suct.Superh.T.	20.1	19.2	20.0	19.3	20.0	19.6	20.0	20.2
Wat.Qty.l/min.	21.0	20.8	21.0	20.9	10.3	10.0	3.7	3.7
Evap. P. Bar	N.R.	N.R.	3.95	3.95	2.55	2.55	0.68	0.65
__Elect.Measur.__								
M.Voltage (V)	386	380	385	384	383	382	384	386
Ph.Curr(A) I1	5.38	5.44	5.14	5.18	4.73	4.57	3.55	3.28
I2	5.43	5.45	5.26	5.08	4.73	4.75	3.66	3.45
I3	5.24	5.35	5.11	5.12	4.62	4.38	3.48	3.19
Pow.Input (W)	2859	3015	2736	2852	2393	2444	1483*	1403*
Pow.Fact.cos.	0.79	0.83	0.79	0.83	0.76	0.80	0.62*	0.64*
M.Res.cold(Ω)	2.81	2.82	2.81	2.81	2.75	2.73	2.75	2.[illegible]
M.Res.hot (Ω)	2.95	3.45	3.03	3.60	3.10	3.61	3.15*	3.51*
Winding T.	34	77	42	92	52	98	57*	83*
Motor cooling Fluid T.	==	56.6	==	N.R.	==	68.2	==	62*
__Other Measur.__								
Ambient T.	20.9	21.0	20.9	20.8	20.9	17.2	20.8	20.5
Act.Cool.Cap.	10206	10629	6930	6646	4820	4320	1509	1509
Adj.Cool.Cap.	9665	10071	6490	6240	4500	4061	1412	1419

* Side Ventilation Cooling

__Nomenclature:__

N.R. = Not measured
T. = Temperature (°C)
M.Res. = Mean Resistence (Ohms)
Cool.Cap.= Cooling Capacity (Thermal Watts)
P. = Pressure
Act. = Actual
Adj. = Adjusted

Table 1

SECTIONAL VIEW OF PROTOTYPE COMPRESSOR

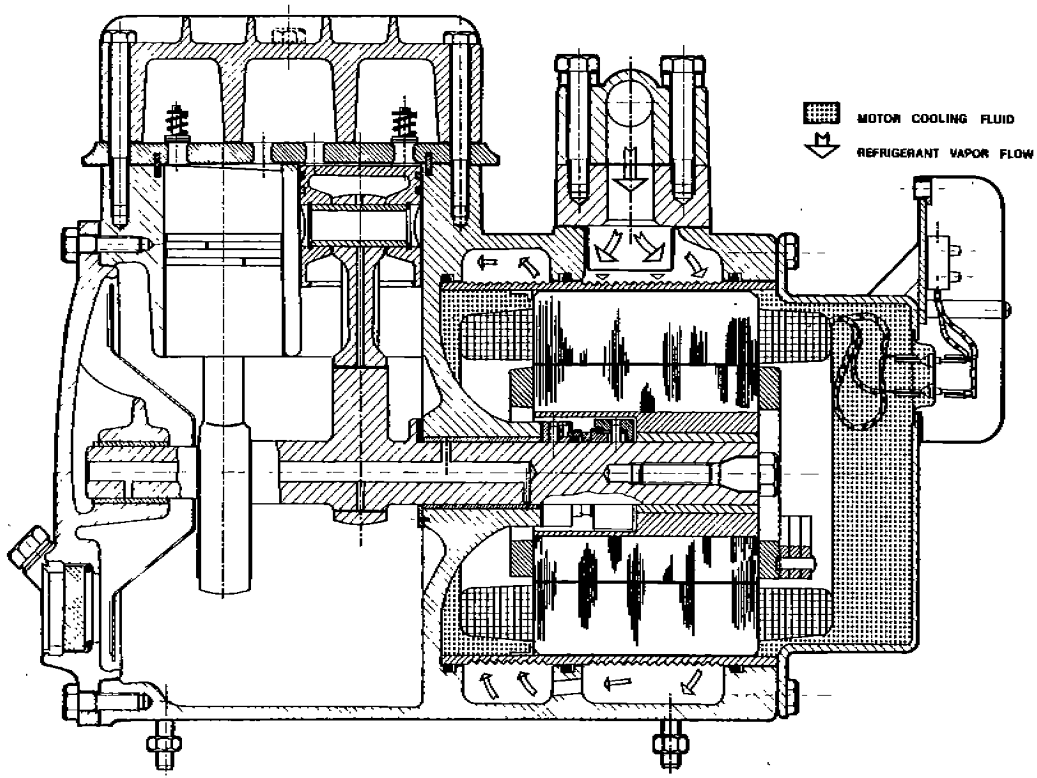
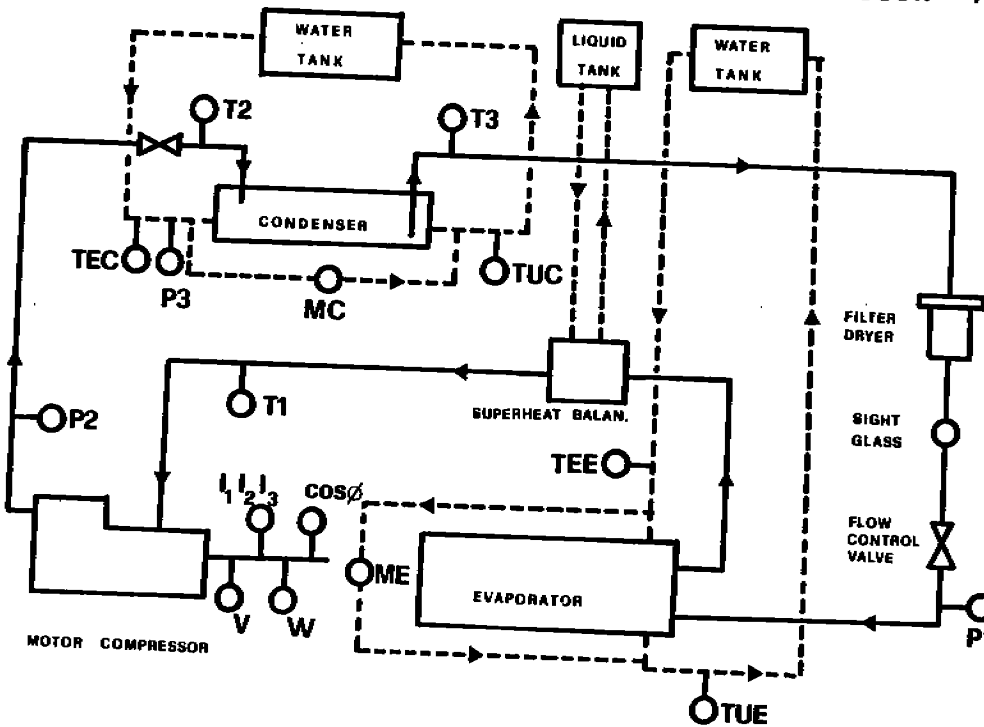


FIGURE 1

SCHEMATIC DIAGRAM OF THE COMPRESSOR TEST SYSTEM



P1 = EVAPORATING PRESS
P2 = CONDENSIN PRESS
P3 = LIQUID REFR PRESS
ME = CHILLED H_2O FLOW
MC = CONDENS H_2O FLOW
T1 = SUCTION SUPERHEAT
T2 = COMPRESS SUPERHEAT
T3 = LIQUID SUBCOOLIG
TEE = EVAP WATER IN TEMP
TUE = EVAP WATER OUT TEMP
TEC = COND WATER IN TEMP
TUC = COND WATER OUT TEMP
$I_1 I_2 I_3$ = PHASE CURRENT
V = MEAN VOLTAGE
W = POWER INPUT
COSØ = POWER FACTOR

FIGURE 2

LARGE CAPACITY PROTOTYPE

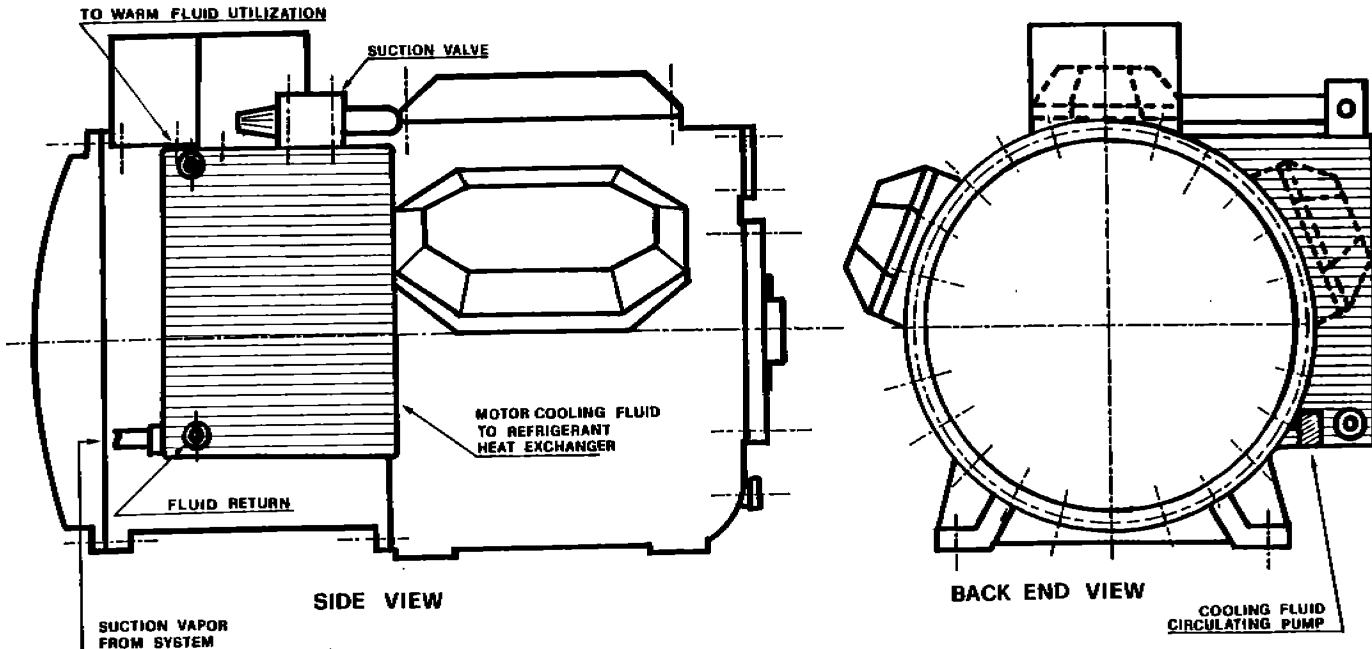


FIGURE 3