1986

Refrigerating Compressors for Air Conditioning of Passenger Cars

J. Reichelt

REFRIGERATING COMPRESSORS FOR AIR CONDITIONING OF PASSENGER CARS

J. Reichelt[1] et al[2,3,4]

[1]Fachhochschule Karlsruhe, D-7500 Karlsruhe 1, German Feder.Rep.
[2]G.Hartmann, Nippondenso GmbH, D-8000 München 80, German Fed.Rep.
[3]H.Rössler, Volkswagen AG, D-3180 Wolfsburg 1, German Feder.Rep.
[4]W.G.Schlüter, Adam Opel AG, D-6090 Rüsselsheim, German Fed.Rep.

ABSTRACT

A comparison will be made of compressor units for passenger cars produced in USA and Japan and the numerical development of air conditioned cars in West-Germany. In the beginning of car air conditioning (1955/1960 and thereafter) the 2-cylinder compressor was predominate, later the 4-, 5- and 7-cylinder and now, in West-Germany, about 50% are 10-cylinder compressors. A brief description for one of the new variable displacement compressors will be given by means of measured data. These compressor types have been installed in passenger cars since 1985/86 in USA and West-Germany.

In the future, rotary compressors, for example a scroll type, will become more significant. One of the requirements for these compressor types should be higher volumetric efficiency at low speeds.

The conditions to rate and measure these compressors vary greatly within West-Germany and other countries. In order to achieve homogeneity in the rating and measurements some suggestions will be made for conventional as well as for compressors with variable capacity.

SYMBOLS

t_o	evaporating temperature	°C
t_{V1}	entering compressor suction vapo temperature	°C
t_c	condensing temperature	°C
t_{E1}	entering expansion valve liquid temperature	°C

Δt_u	entering expansion valve liquid subcooling	K
Δt_u	entering compressor vapor superheating	K
p_o	evaporating absolute pressure	bar
p_{oe}	evaporating gauge pressure	bar
p_c	condensing absolute pressure	bar
p_{ce}	condensing gauge pressure	bar

INTRODUCTION

Nowhere in refrigeration compression systems have so many innovations taken place, in the last 5-8 years, like that of air conditioning compressors for passenger cars. New rotary compressors (screw and scroll types) have been developed. The latest development are variable displacement compressors. Since 1985 they have been installed in several USA-passenger cars.

COMPRESSOR PRODUCTION (UNITS) FOR PASSENGER CARS IN USA AND JAPAN BETWEEN 1980 AND 1985

In the USA there was a decrease in compressor production to 6.5 million units in 1982. In the next two years production rose to 8.3 million units and obviously a saturation has been reached, see Fig.1.

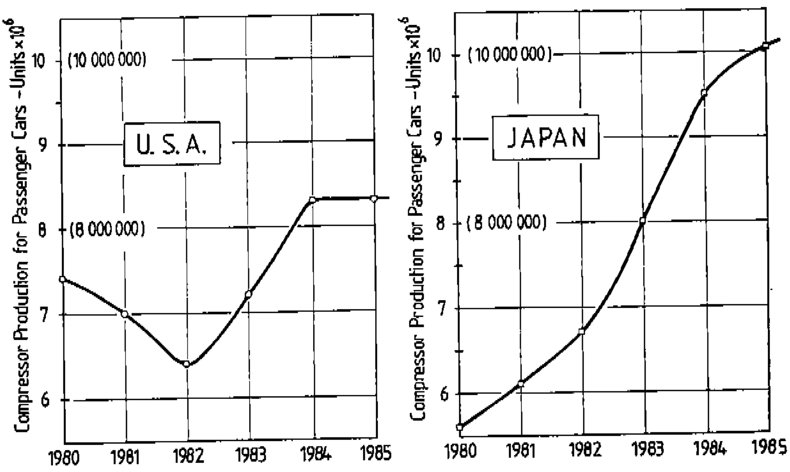


Fig. 1: Compressor Production for Passenger Cars in USA and Japan Between 1980 - 1985

In Japan, compressor production increased continuously; 1982: was about equal in units to the USA; 1985: 10.1 million compressors had been produced. Since then, a high percentage of passenger cars in Japan have been equipped with air conditioning. Higher production for the home market is not expected, the only increases coming from the market abroad. The export portion is already more than 50%. Therefore,saturation can also be assumed in Japan in the next years.

NUMERICAL AND PERCENTAGE DEVELOPMENT OF AIR CONDITIONED PASSENGER CARS IN WEST-GERMANY BETWEEN 1960 - 1985

While in 1960 about 10% of all passenger cars in the USA were equipped with air conditioning (700,000 units), this 10% portion in German cars was not reached until 1983. The development in the USA was:

1976	1977	1980	1982	1983
75%*	82%*	73%*	81%*	86%*

* of all passenger cars with air conditioner

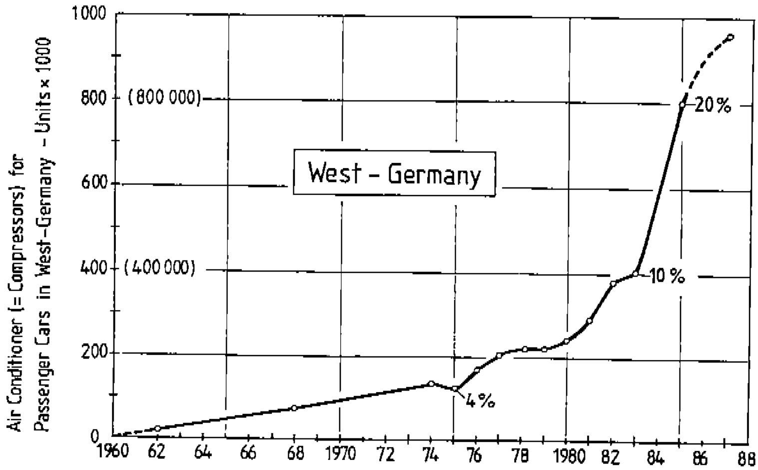


Fig. 2: Air Conditioner (Compressors) for Passenger Cars in West-Germany between 1960 - 1985

Since 1980, an essential increasing of air conditioning in German passenger cars can be observed, up to 20% in 1985. Nearly 100% of the upper class (3 liters and more) have air conditioning. Medium size cars, however, seldom or never do.

The increase between 1983 through 1985 was based on export and the profitable exchange rates. The increase will probably be only 2 - 3% in the coming years.

COMPRESSOR TYPES BETWEEN 1960 and 1990
AND SOME TECHNICAL DATES
Table I, Appendix

Between 1960 and 1970 there were two typical types of compressors that existed:

- 2-cylinder crank type compressor for the lower class and
- 6-cylinder swash plate compressor for the upper class.

Both compressors came from USA. While the 2-cylinder is still built, the production of the 6-cylinder (cast iron, 18 million units) has been phased out. The 2-cylinder compressor built for 20 years from aluminium has a weight - including the clutch - of 9 kg (20 lbs.). The weight of the 6-cylinder - with clutch - was 16 kg (35 lbs.). The weight of modern compressors with the same capacity is only 5 - 6 kg (11 - 13 lbs.).

In the 70's a 4-cylinder radial piston type reciprocating compressor was added, also from USA. A vane rotary type compressor was developed in several places: USA, Japan and West-Germany. In these years (1970 - 1980) the compressor production in Japan grew.

At the end of the 70's/beginning of the 80's the diversity of compressor types - especially from Japan - expanded: rolling piston-, wankel-, screw- and scroll type compressors. The number of cylinders in the swash plate compressor was raised from 5 to 6 and 7 to 10 cylinders. Instead of 4 vanes in the vane rotary compressor, 5 vanes were installed. The compressor operation, in all cases, had been decidedly improved: smaller discharge pressure and torque pulsation and smoother and quieter operation.

In addition, there was a reduction in size, weight, oil charge and displacement (especially in rotary compressors). While maximum speed of the compressors of the 60's and 70' was 6000 to 7000 rpm, modern rotary compressors are able to run up to 14,000 rpm. For the last 2 - 3 years there have been variable capacity compressors and variable displacement - and capacity - compressors.

NUMBER AND PERCENTAGE OF THE 10-CYLINDER COMPRESSOR
IN GERMAN AIR AIR CONDITIONED CARS

Based on its very quiet operation, the 10-cylinder compressor is preferred more and more in German passenger cars, now about 50%, see Fig. 3. The trend is increasing. The reason is car producers want higher comfort levels for the export markets as well domestic markets.

VARIABLE DISPLACEMENT COMPRESSORS
FOR AIR CONDITIONING OF PASSENGER CARS

<u>Construction and Working by Means of an Example /1/</u>

Fig. 4 shows a 5-cylinder infinitely variable displacement compressor(abbreviation: V-D-Compr.),produced in USA. It was introduced about three years ago and has been installed since August 1985 in several USA-passenger cars with engine displacements from 1.8 - 2.5 liters. The first passenger car in West-Germany will be equipped with this compressor in August,1986. The center of control of the compressor displacement is a control valve that senses suction pressure. The swash plate angle, and in turn compressor displacement, is controlled by the crankcase-suction pressure differential. The dis-

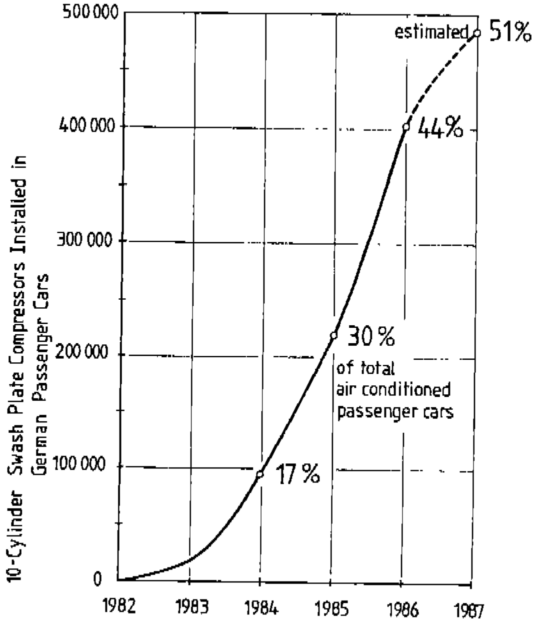


Figure 3:

10-Cylinder Swash Plate Compressors

Installed in German Passenger Cars between 1982 - 1986

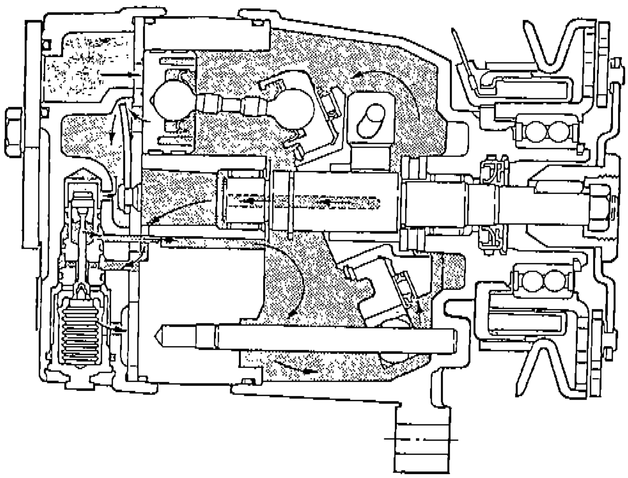


Figure 4:

5-Cylinder Variable Displacement Swash Plate Compressor/1/

Displacement: 151 to 10 cm^3

placement range is from 151 to 10 cm^3 per rotation. Clutch cycling switch is (nearly) eliminated and evaporator temperatures are more uniform. Practical experiences have shown that the adaptation of the above mentioned control valve is one of the most important requirements.

Refrigerating Capacity, Power Input and Coefficient of Performance

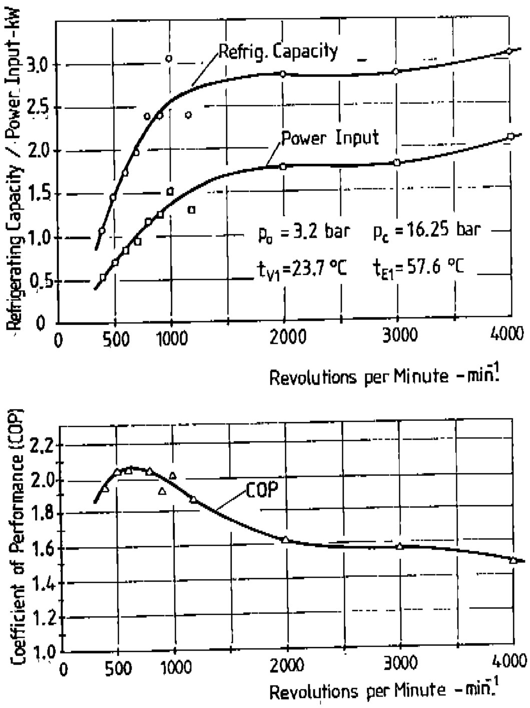


Fig. 5: Refrigerating Capacity, Power Input and COP of the 5-Cyl. Variable Displacement Compressor, see Fig. 4

Below are measured results for the V-D-Compressor.

Fig. 5 shows the refrigerating capacity, power input and COP versus a speed range from 400 to 4000 rpm. Between 1500 and 4000 rpm these 3 parameters are relativly constant.

Below 1000 rpm the refrigerating capacity and power input decrease: this means, the swash plate has reached the greatest possible angle.

COP has a maximum of 2.1 between 500 - 800 rpm. While the condensing pressure is adjustable the evaporating pressure cannot be influenced. At this condensing pressure the evaporating pressure oscillated around p_o = 3.15 bar (46 psia).

COP-Comparison of the Variable Displacement Compressor with a Conventional (Non-Variable) Displacement Compressor

In Fig. 6 the COP of the V-D-Compr., see Fig. 5 below, is compared with a conventional (Non-V-D) 7-cylinder swash plate compressor with nearly the same displacement. The condensing pressure (p_c= 15.7 bar = 230 psia)for the conventional compressor is 0.55 bar = 8 psi lower than at the V-D-Compr. with p_c = 16.2 bar = 238 psia. If the evaporating pressure of the V-D-Compr. (p_o = 3.2 bar = 47 psia) is "sorted" in these evaporating pressures of the Non-V-D-Compr. (p_o = 3.0 to 3.5 bar = 44 to 51 psia), the COP of both compressors are nearly the same.

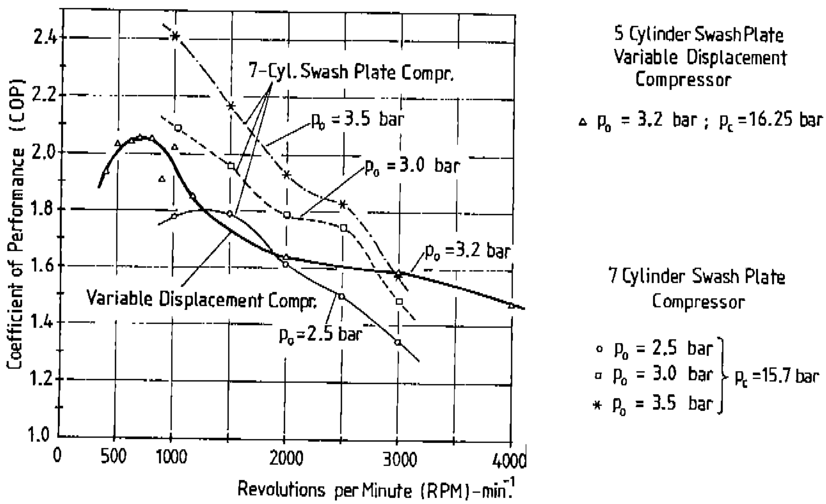


Fig. 6: COP of the 5-Cylinder Variable Displacement Compressor in Comparison with a Conventional 7-Cylinder Compressor

GOALS FOR COMPRESSORS IN A/Cs OF PASSENGER CARS IN FUTURE AND ITS CAPACITY CONTROL

Compressors

The compressors of the future are certainly not reciprocating but rotary compressors. Screw compressors will find their place in buses, scroll compressors probably in passenger cars. One of the disadvantages of the scroll type, until now, was: Between 500 - 1500 rpm, where cooling is needed, the volumetric efficiency (refrigerating capacity) was lower than for a reciprocating compressor.

The advantages of rotary compressors, like scroll, are:

- smaller size, light weight
- high speed operation possible (now: 14,000 rpm)
- smaller torque pulsation, quiet operation
- higher durability against slugging
- longer life (reduction in the number of parts)

Capacity Control

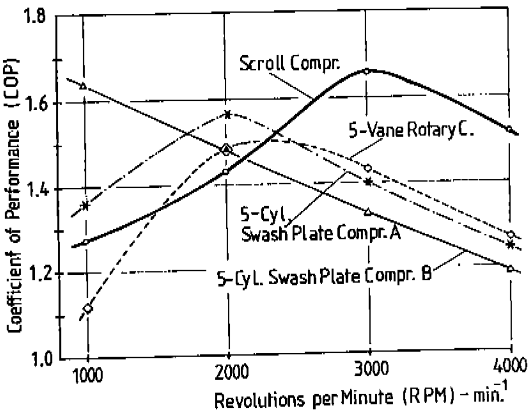
Variable displacement compressors, which are now available, are controlled by the suction pressure differential, external control is not possible. Capacity controlled compressors in the future should be controlled by an electrical signal from outside, for example the thermostat or a microcomputer. These should be possible by a signal from:

- kick-down
- car or motor speed
- evaporator fan speed
- condensing pressure
- motor water temp.
- etc.

Finally, the capacity control should be able to go to "0" in order to spare the clutch.

COP FOR A SCROLL COMPRESSOR IN COMPARISON TO TWO 5-CYLINDER SWASH PLATE COMPRESSORS AND A VANE ROTARY COMPRESSOR

Fig. 7 shows the measured COP's of the above mentioned compressors.



p_0 = 2.41 bar ≙ t_0 = -7.3 °C

p_c = 16.2 bar ≙ t_c = 62.5 °C

t_{V1} = 23.9 °C ≙ Δt_0 = 31 K

t_{E1} = 60.0 °C ≙ Δt_u = 2.5 K

Fig. 7: COP of a Scroll Compressor in Comparison with 3 Conventional Compressors: 2 Swash Plate and 1 Vane Rotary Compressor

Above 2400 rpm the COP of the scroll type compressor is significantly higher than the other three compressors; below 2000 rpm the COP's of the other compressors are higher. The reason for the better COP's at higher speed for the scroll: No valves and therefore higher volumetric efficiency. At lower speeds, the leak rates of the scroll are less favorable.

THE VARYING MEASUREMENT CONDITIONS FOR DETERMINATION OF CAR COMPRESSOR CAPACITY IN WEST GERMANY AND OTHER COUNTRIES WITH SOME EXAMPLES

There is no one standard to determine the refrigerating capacity, power consumption, COP etc. for these special compressors in USA, Japan or West-Germany. Table II, see appendix, illustrates how different the measurement conditions are now at 4 car producers in West-Germany, 2 compressor producers in Japan and ASHRAE-Standard 23 - 59:

- evaporating temperatures : +15 to -13°C (59 - 8°F)
- condensing temperatures : 57 to 84°C (133 - 182°F)
- suction vapor superheating: 5 to 20 K (9 to 36°F)
- liquid subcooling : 0 to 5 K (0 to 9°F)
- compressor speed : 500 to 8000 rpm's

As a result, it is not possible to compare capacity data from different producers. For stationary compressors there are standards in our country (DIN 8977) as well as in other countries (USA: ASHRAE-standard 23-59 and international (ISO 917). It would be desirable to create an international standard for these compressor types. This could be done in an ASHRAE-Committee.

PROPOSALS FOR HOMOGENEOUS MEASUREMENT CONDITIONS FOR CONVENTIONAL (NON CONTROLLED) COMPRESSORS

In Table III there are some proposals for compressor measurements, test points and calculated data. After that every compressor has to be to measured at the following conditions:

- four speeds : 500, 1000, 2000, 3000 rpm
- three evaporating temperatures: -6.5, -1.0, +4.0°C
  (20, 30, 40 °F)
- one condensing temperature : +62°C (142°F)

this means 12 measuring points for each compressor.

PROPOSALS FOR HOMOGENEOUS MEASUREMENT CONDITIONS FOR VARIABLE DISPLACEMENT COMPRESSORS

- To measure these compressor types it's only possible with a real refrigerating cycle the way it is used in cars.
- The compressor capacity is to be determined, as usual, with the two methods:
  - refrigerating mass flow rate and enthalpy difference and
  - calorimeter heating capacity.
- The evaporating temperatures are a result of the air volume flow rate through the evaporator, for example with three or four fan speeds.
- Compressor speed and condensing temperature: see Table III.
- Further details (refrigerant charge, condenser size, oil flow rate, safty test, idle test etc.) have to be determined.

CONCLUSIONS

Japan and USA are the main producers of compressors for air conditioning of passenger cars. In West-Germany, compressors from both countries are used. The measurement conditions are very different in these three countries and furthermore different within West-Germany. Therefore,it is not possible to compare the typical compressor data. Certainly the demands are also very different in these countries. In West-Germany there is no speed limit and,therefore,the compressor speed requirements are higher than in the USA or Japan. Moreover, in German cars there is less space for the evaporator and the condenser and recently - based on motor covers for diesel engines - higher ambient temperatures for the compressor. However, there should be conformity in the measurement conditions.

REFERENCE

/1/ Technical papers from Harrison Radiator/USA

Remark: Some statements of the author (compressor in the future) are not in complete agreement with the co-authors.

ACKNOWLEDGMENT

The author wishes to thank ADAM OPEL AG, especially Mr.W.G. Schlüter, for permission to publish some results of measurements which were taken during commission of OPEL-Rüsselsheim, most of them from A.Barth, DIN-Test-Institut, Fachochschule Karlsruhe.

Table 1: Compressor Types Between 1960 - 1990 and some Typical Technical Data

Technical data \ Compressor types	1960–1970		1970 - 1980				1980 - 1990							1990 and after			
	Reciprocating	Swash plate	Reciprocating	Radial piston	Swash plate	Rotary vane	Radial piston	Rotary vane	Swash plate	Scroll	Screw	Wankel	Rolling piston	Rotary vane	Swash plate	Scroll	perhaps a different rotary compressor
Number of cylinders or vanes	2	6	2	4	5/6	4	4	4/5	5/6 7/10	-	-	-	-	5	7/10	-	-
Gaspulsation x/xx/xxx[1]	x	x(x)	→											x(x)	x(x)	x(x)	-
Torque fluctuation x/xx/xxx[1]	x	x(x)	→											x(x)	xx(x)	xxx	-
COP and Volumetric efficiency at 500 - 1000 rpm	xx(x)	xx(x)	→											xx(x)	xx(x)	x^2	-
at = 1500 - 2000 rpm	x	x	→											xx(x)	x(x)	xxx	-
Displacement in cm^3 per revolution	140	200	→											≦ 80 - 150			
Weight with Clutch - kg	9	16	→											≦ 3 - 6			
Length with Clutch - mm	200	320	→											≦ 100 - 200			
Oil charge - cm^3	150	250	→											≦ 100 - 150			
Maximum speed - rpm	7000	6000	→											≦ 8000 - 14000			

[1]x: bad; xx: *medium* xxx: good [2]at present

Table II: The Various Conditions for Measurements; Refrigerating Capacity of Compressors (USA, Japan, Germ.)

Standard Producer	Evaporating Pressure (Temp.) p_o or p_{oe}	Condensing Pressure (Temp.) p_c or p_{ce}	Vapor Superheating or Suction Temperat. Compressor Inlet $\Delta t_{ü}$ or t_{V1}	Subcooling of Refrig. Liquid Expans. Valve Inlet Δt_u	Speed Range n / rpm
ASHRAE-STANDARD 23 - 59 Imaca 308	p_{oe} = 35 psig (+3°C)	p_{ce} = 235 psig (65.2°C)	t_{V1} = 75°F (23.9°C)	5°F (2.8 K)	---
A	p_o = 3.0 kg/cm^2 (-1.4°C)	p_c = 16.0 kg/cm^2 (61°C)	$\Delta t_{ü}$ = 10 or. 20 K	4 K	500 - 3000
B	p_{oe} = 1.35/3.30 kg/m^2 (-8 /+10.5°C)	p_{ce} = 17 / 22 kg/cm^2 (67 / 79°C)	t_{V1} = 4.4/16.1°C	5 K	700 - 5000
C	p_{oe} = 1.86 bar (-2.2°C) = 2.0 bar (+1.0°C) = 2.47 bar (+3.0°C) = 2.98 bar (+8.0°C) = 3.46 bar (+11.5°C)	p_{ce} = 13.5 bar (57°C) p_{ce} = 14.7 bar (61°C) p_{ce} = 16.7 bar (66.5°C)	$\Delta t_{ü}$ = 10 or 15 K	0 K	1000 - 5000
D	p_{oe} = 2.0 bar (-1.0°C)	p_{ce} = 16 bar (65°C)	$\Delta t_{ü}$ = 15 K	?	1000 - 4000
E	p_{oe} = 1.5/2.0/2.5 bar (-6.5/-1.0/+3.8 °C)	p_{ce} = 14.7 bar (61°C)	$\Delta t_{ü}$ = 10 K	5 K	1000 - 3000
F	p_o = 1.96/2.8/5.0 bar (-13.2/-3.0/15.4°C)	p_c = 16.0/25.0 bar (62.0/83.5°C)	$\Delta t_{ü}$ = 15 K	5 K	500 - 8000

The compressor ambient temperature during the measurements should be also mentioned.

Table III: Proposals for Measurements of Refrigerating Capacity, Power Input and Coefficient of Performance Conventional (Non-Variable-Capacity or Displacement) Compressors for Passenger Cars

Refrigerant: R12					Measurement 1a - 1d at 500, 1000, 2000 and 3000 rpm	Measurement 2a - 2d at 500, 1000, 2000 and 3000 rpm	Measurement 3a - 3d at 500, 1000, 2000 and 3000 rpm
Nr.	Kind of Measurement	Measurement point	Formula sign	Dimension	Operation point	Operation point	Operation point
1	Pressure	leaving compressor	p_{V2}	bar	16.0 (62°C)	16.0 (62°C)	16.0 (62°C)
2	Temperature	entering expansion valve	t_{E1}	°C	57	57	57
3	Pressure	leaving evaporator ≙ entering compressor	p_{o2}	bar	2.5 (-6.5°C)	3.0 (-1.0°C)	3.5 (+4.0°C)
4	Temperature	leaving evaporator ≙ entering compressor	$t_{o2h} \hat{=} t_{V1}$	°C	+4	+11	+14

To measure:

1. Compressor speed
2. R12 - liquid flow rate
3. R12 - pressure entering compressor
4. R12 - pressure leaving compressor
5. R12 - pressure entering expansion valve
6. R12 - pressure leaving evaporator
7. R12 - temperature entering compressor
8. R12 - temperature leaving compressor
9. R12 - temperatur entering expansion valve
10. R12 - temperature leaving evaporator
11. Torque compressor shaft
12. Oil flow rate
13. Refrigerant charge
14. Compressor ambient temperature

To calculate (and diagram ; versus speed):

1. Compressor capacity
   1.1 through refrigerant mass flow
   1.2 through calorimeter
2. Power input
3. Coefficient of performance