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Problems Encountered and Results obtained in Direct Steam Compression utilizing and Oil Injection Free Single Screw Compressor

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PROBLEMS ENCOUNTERED AND RESULTS OBTAINED IN DIRECT STEAM COMPRESSION UTILIZING AN OIL INJECTION FREE SINGLE SCREW COMPRESSOR

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ABSTRACT

An extensive research program has been initiated by ELECTRICITE DE FRANCE to test an oil free single screw compressor in the compression of steam. Technical problems encountered limiting the reliability and preliminary results have already been published.

This paper presents the solutions which have been successfully used to overcome the reliability problems, comprehensive results over a range of speeds, pressure ratios and intake pressures, and an economic comparison with other existing oil free solutions.

1 - INTRODUCTION

In order to achieve energy savings in certain industrial sectors it is compulsory to design and develop economic volumetric compressors able to handle steam or media obtained by distillation, without oil.

In the framework of its activities, the Direction des Etudes et Recherches (Study and Research Division) of ELECTRICITE DE FRANCE, co-operating with the companies CREUSOT-LOIRE and OMPHALE, has realized compression tests on steam with an oil-injection free SINGLE SCREW compressor.

This paper describes the technical solutions adopted to ensure a reliable operation of the compressor, the results obtained for various speeds and compression ratios and compares the cost and performances of the SINGLE SCREW compressor with those of other existing oil-free machines.

2 - TEST INSTALLATION (Figure 1)

ELECTRICITE DE FRANCE has at its disposal a test rig permitting the test of compressors under operating conditions comparable to those encountered in the industry.

A detailed description of this test installation is given in Ref. (1).

3 - THE TESTED SINGLE SCREW COMPRESSOR

3.1 - Description - Figures (2), (3) and (4)

The tested SINGLE SCREW compressor is of the type already described in Ref. (2)

It is comprised of a central cylindrical screw (1) and of two identical gaterotors (2) located in a plane passing through the axis of the screw. The screw and the gaterotors are placed in a tight casing (3). The screw is driven from the outside and in turn drives the two gaterotors. The intake plenum (9) is located at one end of the casing and the discharge ports (7) on each side of the screw, at the opposite end.

3.2 - Characteristics

The rotating speed envisaged for industrial use is 3000 rpm. Then the swept volume is 360 m^3/h. The compressor weighs approwimately 100 daN and its main dimensions are: .52 m x .24 m x .40 m.

The cast iron screw and casing and the plastic gaterotors are taken from a mass produced, oil lubricated air compressor manufactured by the Japanese company MITSUI SEIKI.

The main modifications that have been made on this standard model refer to the following:

- ensure tightness of the compressor with respect to vacuum;

- ensure tightness between the section of the compressor that is filled by steam and the bearings supporting the screw and the gaterotors, by means of magnetic glands;

- lubricate the bearings with oil and therefore adapt a pump on one of the gaterotor shafts;

- provide oil injection orifices in the casing of the compressor. The injected water allows desuperheating the compressed steam, but also ensuring lubrication and sealing at the line of contact between screw and gaterotors.

4 - TESTS

Partial results have been disclosed in Ref. (1) after 1300 hours of tests that have permitted demonstrating that the operation of a SINGLE SCREW compressor without oil injection was satisfactory for the compression of steam.

Deteriorations had appeared at the end of the grooves of the screw, on the discharge side and on each gaterotor tooth; these deteriorations had no incidence on the sealing characteristics.

The tests have been completed in order to examine the evolution of these defects in the course of time and the possibility to avoid deterioration at the extremity of the groove of the screw.

On another hand, numerous sources of heat are only available at a temperature below 100° C, which results in using the compressor with an intake pressure below atmospheric pressure. Thus the SINGLE SCREW compressor has been tested under these conditions.

4.1 Mechanical behaviour of the compressor

4.1.1 Screw

After the deteriorations observed at the end of the groove, on discharge side, and which have been described in Ref. (1), a stellited insert has been adapted in one of the cavities, while the others were not modified.

The compressor was disassembled after 600 hours of operation, i.e. a total of 2150 hours. It was observed that the stellited insert showed no defect and that the deteriorations in the other grooves had not evolved.

One may explain this stabilization by the presence of water in the cavity, thus ensuring a protection as soon as the cavity reaches a sufficient size.

At the end of the tests after 2400 cumulated hours of operation it has been confirmed that the deteriorations were stabilized. It should be noted that the presence of cavities at the end of the grooves does not alter the performances fo the compressor.

4.1.2 Glands

The problems encountered with respect to the glands have not been solved and the importance of the leakages has led to the termination of the tests.

The space available in the casing of the standard compressor used did not allow implementing more efficient glands.

4.2 Results of the tests

4.2.1 Definition of the measured efficiencies and COPs

- Discharge volumetric efficiency

The volumetric efficiency of the compressor is the ratio of the volumetric flow of the steam measured at compressor discharge, reduced to the intake conditions, over the volume swept by the compressor.

- Global isentropic efficiency

The global isentropic efficiency is the ratio of the theoretical isentropic compression power, calculated for the discharge flow of the compressor, over the shaft power.

- Coefficient of performance of the heat pump associated with the compressor

The practical coefficient of performance is defined as the ratio of the power that would be available at the condenser of the heat pump associated with the compressor over the compressor shaft power. It is evaluated at zero subcooling conditions. The CARNOT theoretical coefficient of performance is the ratio of the absolute saturation temperature at discharge over the difference between saturation temperatures at discharge and intake.

4.2.2 Influence of the various parameters

- Rotating speed

When increasing the compressor rotating speed from 3000 to 4500 rpm, at 2.9 compression ratio, 400 l/h injection water flow, the volumetric efficiency at discharge increases by 24 % and the practical COP by 9 %. These results illustrate the interest of increasing the nominal speed of the compressor.

- Injection water

The influence of the injection of water flow and temperature on the performances of the compressor has been tested.

One notes that for a temperature around 135° C, the discharge flow is always greater than the suction flow, which indicates that part of the injected water evaporates.

For a temperature of 110° C, when the water flow exceeds 350 l/h, the discharge steam volume becomes smaller than the suction volume; the injected water causes part of the steam taken in at the suction to condense.

Under the operating conditions that have been tested, the best efficiencies were obtained with a flow of injected water below 300 l/h at 110° C temperature.

- Suction pressure below atmosphere

Numerous heat sources exist at temperature below 100 ° C, thus it is interesting to test the compressor for suction pressures below atmosphere.

The discharge volumetric efficiency, the isentropic efficiency and the ratio of the practical over the CARNOT COPs are shown on Figure 5, at 3000 rpm nominal speed, injection water flow of 200 l/h at 100° C, suction pressures ranging from .5 to .7 bar and compression ratios ranging from 2.9 to 5.6.

4.2.3 Performances at nominal speed

The performances of the compressor have been measured at a rotating speed of 3000 rpm, an injection water flow of 280 l/h at a temperature of 110° C and compression ratios extending from 2.65 to 3.4. Under such conditions:

- the discharge volumetric efficiencies obtained at constant suction pressure: 1.3 bar or at constant discharge pressure: 3.8 bar are plotted on Figure (6).

- the global isentropic efficiencies obtained at 3.8 bar discharge pressure are shown on Figure (7).

- the CARNOT COP, the practical COP and the ratio of the practical COP over the CARNOT COP are shown on Figure (8), for a discharge pressure of 3.8 bar.

5 - COMPARISON BETWEEN THE MACHINE TESTED AND OTHER VOLUMETRIC OIL FREE COMPRESSORS IN THE CASE OF STEAM COMPRESSION

5.1 Technical aspects

There exists already installations utilizing volumetric compressors for the compression of steam (Ref. 3), but the performances of the compressors used have never been published.

In order to compare data we only have at our disposal the values measured on a liquid ring compressor by the CENTRE DE RECHERCHE TEXTILE DE MULHOUSE (4) and those measured on a lobe (ROOTS) compressor at ELECTRICITE DE FRANCE (5).

On Table 1 one shall note that for equivalent ratios of practical COP over theoretical COP, the SINGLE SCREW compressor permits obtaining compression ratios and differences between condensing and evaporating temperatures that are significantly higher than with the liquid ring or the ROOTS compressors.

5.2 Economic aspects

We have plotted on Figure (9) price examples, in French Francs per cubic meter per hour of various volumetric compressors used for the compression of steam. We have compared them with those of liquid ring, single or twin lubricated screw air compressors, which are the equipments leading to the lowest investment costs, and with those of lobe or twin screw, externally synchronized, air compressors, which are more expensive.

The steam compressors of the liquid ring or lobe type remain the most economic, whilst building non-lubricated piston or twin-screw steam compressors results in much higher prices.

The cost of a SINGLE SCREW steam compressor should be located between that of an air and that of a refrigeration compressor of the same type, i.e somewhat above the cost of liquid ring steam compressor.

6 - CONCLUSIONS

The tests of a SINGLE SCREW compressor performed at ELECTRICITE DE FRANCE for the compression of steam have permitted to demonstrate that this equipment could be utilised for suction pressures higher or lower than atmospheric pressure with coefficients of performance superior to those attainable with liquid ring or lobe compressors.

The mass production price of the SINGLE SCREW steam compressor should not significantly exceed that of a liquid ring compressor. It will be notably below that of lobe non-lubricated piston or twin-screw compressors presently offered for steam compression.

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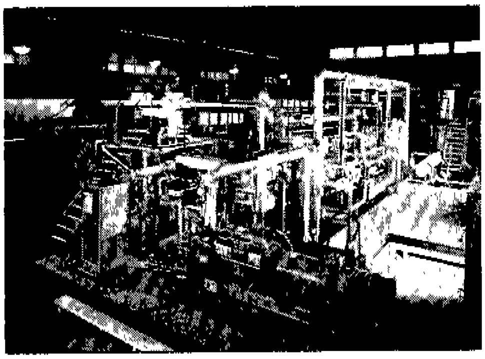

Fig. 1 Test rig at Electricité de France, Chatou

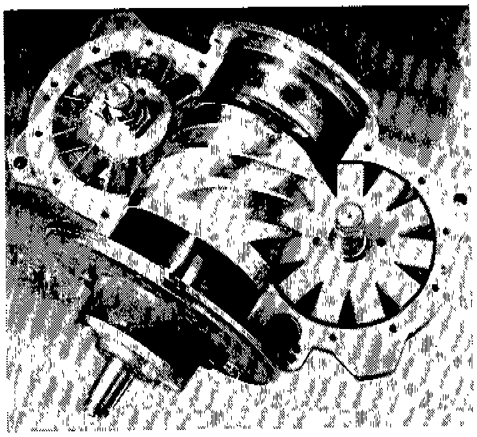

Fig. 2 A single screw compressor

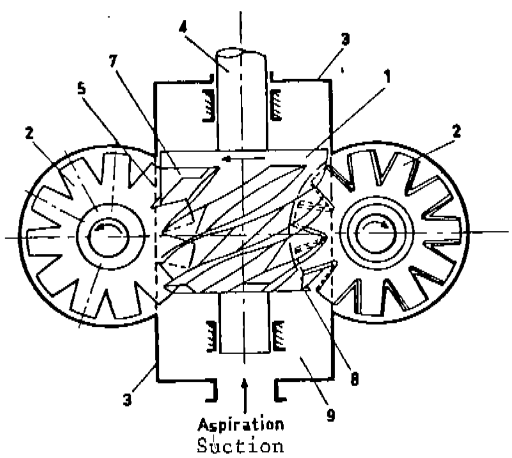

Fig. 3

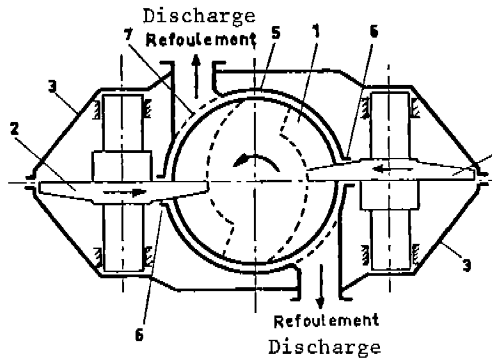

Fig. 4

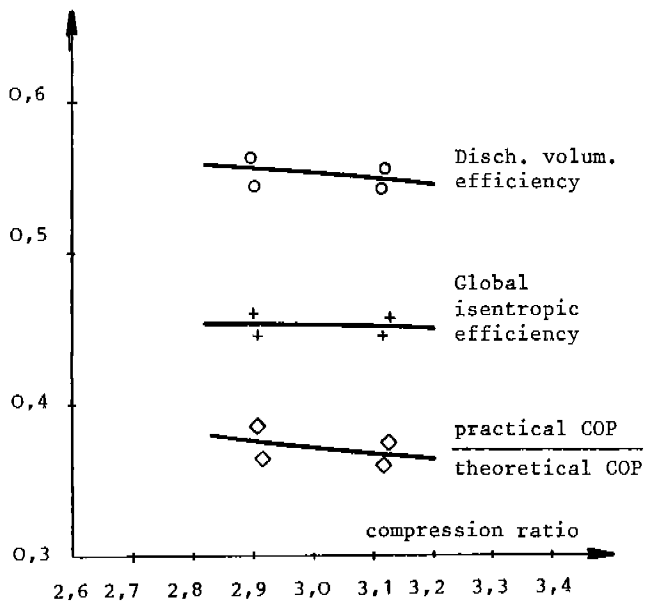

Fig. 5 Efficiencies and ratio of the COPs obtained with suction pressures below atmosphere and constant discharge pressure of 2 bar

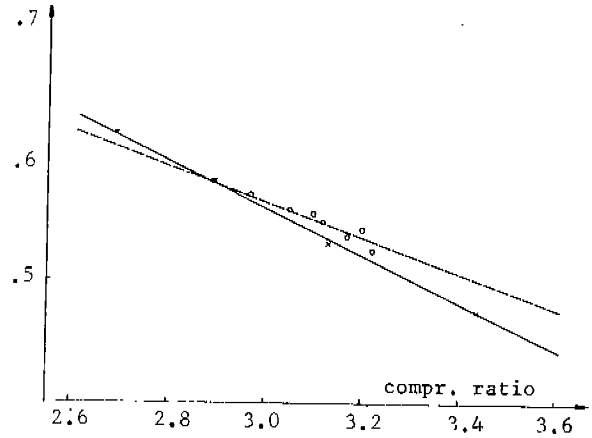

Fig. 6 Discharge volumetric efficiencies

Speed 3000 rpm
Water injection 280 l/h 110° C
Constant discharge pressue 3.8 bar
Constant suction pressure 1.3 bar

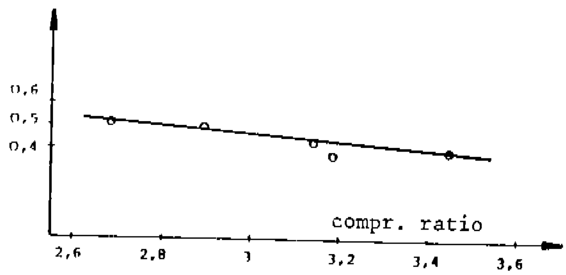

Fig. 7 Global isentropic efficiencies

Speed 3000 rpm
Discharge pressure 3.8 bar
Water injection 280 l/h 110° C

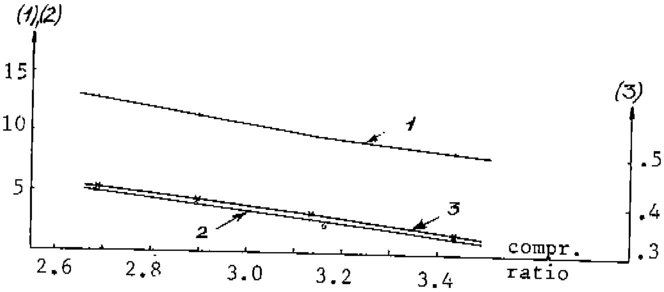

Fig. 8 Coefficient of performance

(1) Theoretical Carnot COP
(2) Practical COP
(3) Ratio $\frac{\text{practical COP}}{\text{theoretical COP}}$
Speed 3000 rpm
Discharge pressure 3.8 bar
Water injection 280 l/h 110° C

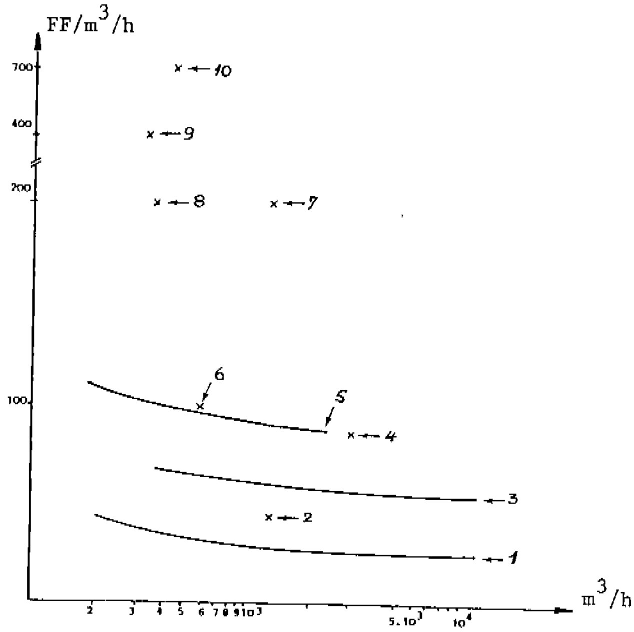

Fig. 9 Examples of the costs of volumetric steam compressors

(1) Lubricated single and twin screw, and liquid ring air compressors
(2) Liquid ring steam compressor
(3) Lobe (Roots) air compressors
(4) Twin screw, gear driven, air compressor
(5) Single or twin screw refrigeration compressors
(6) Lobe, single stage, steam compressor
(7) Lobe, double stage, steam compressor
(8) Dry reciprocating, double stage, steam compr.
(9) Dry piston (Labyrinth), 2-stage, steam compr.
(10) Dry twin screw steam compressor

Table 1

MEASURED VALUES FOR SEVERAL VOLUMETRIC ROTARY STEAM COMPRESSORS

Compressor type	Speed rpm	Power kW	Evap. Temp °C	Cond. Temp °C	Volum. Eff.	Global Eff.	Practical COP	pract. COP / theor. COP	Source
Liquid ring NEYRPIC	500	4	123	132			21.8	.48	Centre de Recherche Textile
	500	4	132	141			25.3	.55	
ROOTS	2500	6	60	86	.83	.50	5.8	.42	E.D.F. CHATOU
	2760	6	81	92	.78	.59	18.6	.56	
	2000	6	81	98	.67	.45	9.0	.42	
SINGLE SCREW	3000	20	110	142	.61	.50	5.52	.42	E.D.F. CHATOU
	3000	11	86	122	.57	.48	4.79	.395	
	3750	28	110	148	.68	.57	4.92	.47	