1984

From Water to Refrigerant: Twenty Years to Develop the Oil Injection-Free Single Screw Compressor

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FROM WATER TO REFRIGERANT: TWENTY YEARS TO DEVELOP THE OIL INJECTION-FREE SINGLE SCREW COMPRESSOR

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ABSTRACT

1982 saw the introduction on the market of the oil injection-free single screw compressor, simultaneously for oil-free air applications and for air conditioning. Although the two technologies are far apart since one deals with the compression of air, the other with halocarbons, those achievements matured simultaneously not by accident but because they are both based on the same unique features inherent in the basic structure of the single screw.

This paper presents an historical review: of the findings and tests which led very early to the consideration of oil-injection-free applications; of the theoretical problems which were solved partly by logic, partly by accident and luck; and of the practical problems which had to be overcome to achieve industrial products: basically corrosion in the case of air compression, efficiency in the case of air conditioning and heat pumps.

I. INTRODUCTION

In 1962 we started building our first single screw compressor; it was an oil free machine.

But it is only just now, twenty years later, that the first oil injection-free single screw machines are beginning to appear on the market -- simultaneously as air compressors and as refrigeration and air conditioning compressors.

Why has it taken so long?

Let us review the main problems which were encountered and the solutions which had to be found to progress from a prototype to a marketable product.

But first, for the sake of clarity, let us recall briefly what a single screw compressor is and more particularly an oil injection-free single screw compressor.

An SSC

An SSC (Single Screw Compressor) is made with one screw whose grooves are swept by the teeth of pinions, also called gaterotors. There are usually two gaterotors to double the swept volume and balance the thrusts.

SSC's are built according to various configurations described in the literature (see ref.1,2) and schematically presented in Fig.1 to 4.

There can be basically two types of screws, cylindrical or planar (sometimes conical), and two types of gaterotors, also cylindrical or planar.

This results in four combinations: CP, PP, CC and PC.

The basic advantages of all four are their compactness, cost, balanced compression and low noise which have helped them to capture around half of the Japanese screw air compressor market and are now enabling them to expand quickly in other countries.

An Oil Injection-Free SSC

An oil-injection free SSC is basically an SSC in which the oil injection associated with any screw for lubricating, sealing and cooling has been eliminated.

This does not mean that it is an oil-free machine -- since the bearing can still be oil lubricated -- but it can be.

Oil injection-free screw compressors already exist. Twin screws running at high speed and not touching each other because they are synchronized by timing gears, are well known.

Such a system would be extremely difficult to apply to a single screw machine since the shafts of the rotating parts are transverse and synchronizing them with precision would be a difficult task.

The oil injection-free SSC is only possible because of a peculiarity of the SSC, that is the gaterotors are idlers. So, little or no power is needed to turn them, which means that little or no thrust exists at the contact points between the screw and gaterotors and there is therefore no need for good lubrication. Water, whisky, champagne or any liquid can do the job.

All that is required of the liquid injection in an SSC is to cool and, if possible, to seal. Hence an obvious idea is to use, as an injection fluid, a liquid already existing in the gas to be compressed:

- for air, water since air contains moisture
- for refrigerant, the condensed gas

This prevents contamination by a foreign substance like oil.

The 1962 Prototype

This idea led to the first design in 1962 which was a 10 HP compressor; the screw was made of bronze, the casing of a cast iron sleeve in an aluminum case and the gaterotors of a plate of phenolic supported by a stainless steel gaterotor support.

This machine ran with water injection containing some molybdenum bisulfide (which later proved to be unnecessary); the bearings were grease bearings protected by mechanical seals.

The result was not a bad machine since it achieved some 9.2HP/m^3/min at 7 bars pressure (26BHP/100 cfm) i.e. some 70% isentropic efficiency and passed a 1000 hours endurance test in our first licensee's lab. Why,then,20 years before a marketable product?

II. THE WATER FLOODED AIR SSC

In retrospect, it appears that we benefited from many lucky breaks but it took us a long time to identify them properly.

The Floating Gaterotors

Because we had only $6,000 available to build that 1962 prototype, we used a simple method to make the gaterotors; we cut them from a thin plate of phenolic backed up by a steel support; the phenolic provided the seal, the steel took the pressure load. We reduced the roots of the teeth to give them angular flexibility and to compensate for possible angular dividing inaccuracies since our manufacturing means were quite limited.

When our first licensee, Peugeot, the car manufacturer, started its development, it very logically reduced the cost of the gaterotors by molding a plastic material over a metal support.

And this was the beginning of our troubles because no water-flooded compressor had an acceptable life.

In despair, Peugeot decided to use oil which is also a logical move for car engineers. Oil helped but did not completely cure the problem, as we discovered a few years later when I started hearing about sudden gaterotor failures happening in an erratic way.

We started investigating this problem ourselves and it occurred to us that we were probably encountering chattering or backlash resonance as often happens with a pair of gears when one is an idler; we learned later that the same thing also happens to twin screw machines when the torque on the driven screw is too small to damp the vibrations.

We realized that by making the teeth flexible on our 1962 prototype we had probably avoided this resonance phenomenon.

To overcome the problem, we hurriedly developed an improved gaterotor, now called the floating gaterotor; this solution is similar to the 1962 solution except that instead of having each tooth independently flexible, the whole plastic gaterotor can have a slight angular displacement on its metal support; the connection being made for instance by a pin and an O-ring (see Figures 5 and 6).

This is far better because the damping effect can be better controlled, the gaterotor precision can be much higher,etc...

In such floating gaterotors, if for any reason, such as a manufacturing mistake, the gaterotor is subjected to an acceleration or deceleration, only the plastic part accelerates or decelerates and, having very little inertia, this does not create wear, while the heavy part, the support, continues to rotate at constant speed.

The validity of the principle was dramatically demonstrated in 1972 when our first Japanese licensee, to convince themselves of the advantages of the single screw, ran endurance tests on two European made air-ends equipped with plain molded gaterotors and on two identical compressors equipped with floating gaterotors.

The European ones, after running fine for awhile, suddenly failed, one at around 400 hours and the second at 800. The two floating gaterotor machines had not shown any sign of loss of capacity when the endurance test was stopped at 4,000 hours.

Water Absorption By Plastics

Phenolics are excellent materials to run with water lubrication but unfortunately they absorb enough water to swell and this creates a lot of headaches in mass production because it is hard to control their accuracy. Fortunately, the development of the SSC coincided with the discovery of many high performance technical plastics and around 1974 - 75 we were able to find compounds which met the many requirements we had formulated.

The many thousands of air compressors operating in Japan with a failure rate from all causes (package components included), during the first two years of warranty, of much less than 1% are good proof thereof. And fortunately some of those plastics do not swell in water.

Corrosion

But the most baffling problem has been corrosion.

On the 1962 prototype, we did not notice it because the machine was running nearly all the time. And indeed as long as the compressor is running, there is no problem. The problem starts when the compressor is idle; the corrosion develops particularly between the crests of the screw thread and the casing so that after one or two weeks, it becomes impossible to turn the shaft.

It is of course possible to use materials such as bronze; and this is the approach pursued by the U.S.Navy which has proven the validity of a water flooded SSC, particularly the possibility of using water lubricated bearings, thereby dispensing with the costly and troublesome mechanical seals.

But bronze is too expensive for the industrial market, so only two years ago one of our Japanese licensees found what seemingly looks like the right answer: coating the cast iron with nickel so that the air-end can be made of the same inexpensive material as an oil flooded SSC, i.e. cast iron. Bearings are still protected by mechanical seals because the warranty is for 20,000 hours, but there is hope that water lubricated bearings will soon be possible.

III. THE OIL INJECTION-FREE REFRIGERATION AND AIR CONDITIONING SSC

The development of such a machine followed a parallel but later path. The original concept of injecting condensed gas into the compressor to cool it came around 1969 - 70 when it became apparent that injecting oil into the screw chamber did not provide much sealing due to dissolved refrigerant. Like everybody else we tried to find a liquid in which the refrigerant gas would not dissolve but, after a dramatic failure on an assignment we had from the aerospace industry in 1969, it became obvious that such a liquid either did not exist or would be quite exotic and would impose unrealistic operating constraints.

The reasoning was that, since there was no sealing effect, and since from air-water tests, we knew lubrication was not needed, we could just cool by injecting the condensed liquid.

It was my good fortune at that time to meet one of the men whose enlightened intelligence has most contributed to the successful development of the SSC and who, by supporting the above views, gave us the psychological backing we needed to undertake what looked like a formidable task. I am referring to Mr. L.C.CONSTANT, director of engineering at HALL THERMOTANK PRODUCTS LTD.

Indeed, when we started testing an R 22 liquid-injected SSC around 1975, it gave very poor performance; we were happy to reach 50% isentropic efficiency at a pressure ratio of 3 and a high speed of around 7000 to 8000 rpm. But these were very small machines in the 4HP range.

The reason for choosing so small a size was that we knew it would not be much of a problem to achieve reasonable efficiencies in large compressors above 100Kw but that the interesting market was below 100Kw where the screw had difficulty beating the recip because of its oil circuit, the cost of which makes the system non-competitive, particularly for air conditioning. An interesting detail about our development effort is that we theorize that one of the configurations of SSC, the PC tyoe, was the ideal candidate for such refrigeration and heat pump oil-free application; indeed it is the only compressor to our knowledge all of whose clearances can be reduced to 0 after assembly by a slight displacement of the parts, whereas most screw compressors have built-in clearances that have to be lived with. In 1977 to 1980, we spent many hundreds of thousands of dollars developing machine tools for that purpose and making prototypes but all to no avail.

The machine never exceeded the 70% isentropic efficiency we had set as our minimum target, though it just barely reached it.

Fortunately, at the same time I had convinced one of our licensees to try this oil-free orientation for a large machine of the CP type and the results were much better than forecast.

We got the message and at the end of 1980, by means of a three month crash program we designed, manufactured and tested a 30Kw CP compressor which, on the first run, gave us the 75% we had been looking for for so many years along with all the extra features we needed: low noise (around 80db), direct drive (3000 or 3600 rpm) capacity modulation continuous or step-by-step from 100% to 15% etc...

This, plus successful endurance tests on totally oil-free heat pumps (see reference 4) seem to have helped HALL THERMOTANK to decide that it was time to launch the oil injection-free SSC (see reference 5).

It is worth noting that many of the improvements needed to achieve this result came from solutions developed for the PC but which were transposed to the CP. So our efforts were not wasted.

IV. CONCLUSION

One question might be raised: Could the development have been carried out more quickly since 20 years is a long period of time?

We are tempted to say "yes" and blame all the adverse conditions which stood in our way.

But in all honesty we should say we do not know.

Development processes are tortuous paths, not straight forward; there is probably a right time for every idea and it takes time for them to mature and this whole process is not at all under human control.

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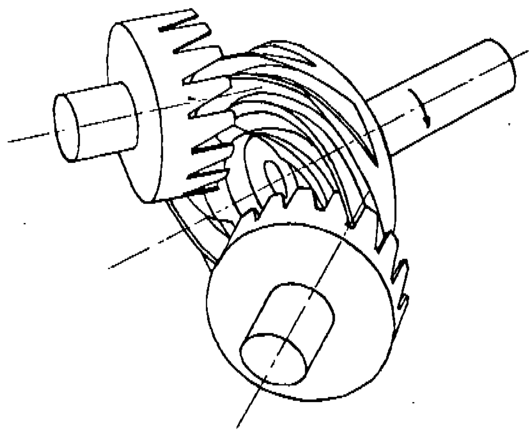

Fig.1

PC Type
(Planar screw/cylindrical gaterotors)

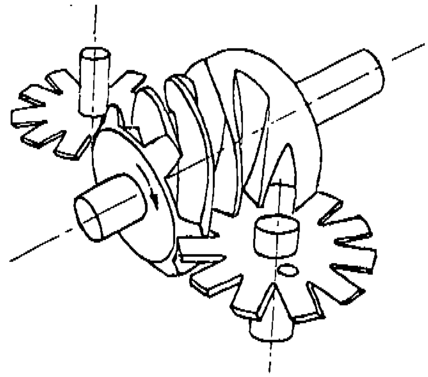

Fig.2

CP Type
(Cylindrical screw/planar gaterotors)

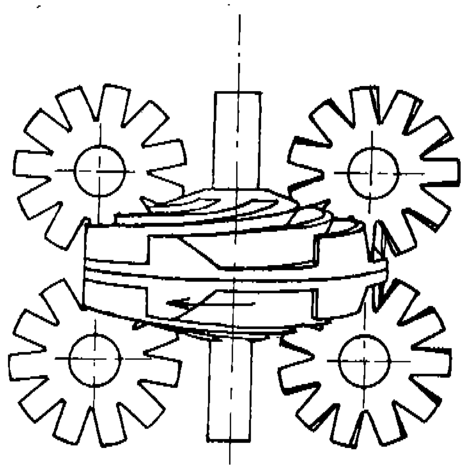

Fig.3

PP Type
(Planar screw/planar gaterotors)

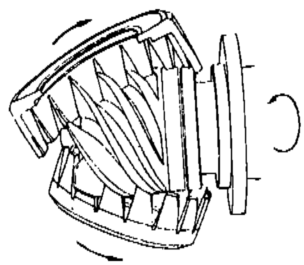

Fig.4

CC Type
(Cylindrical screw/cylindrical gaterotors)

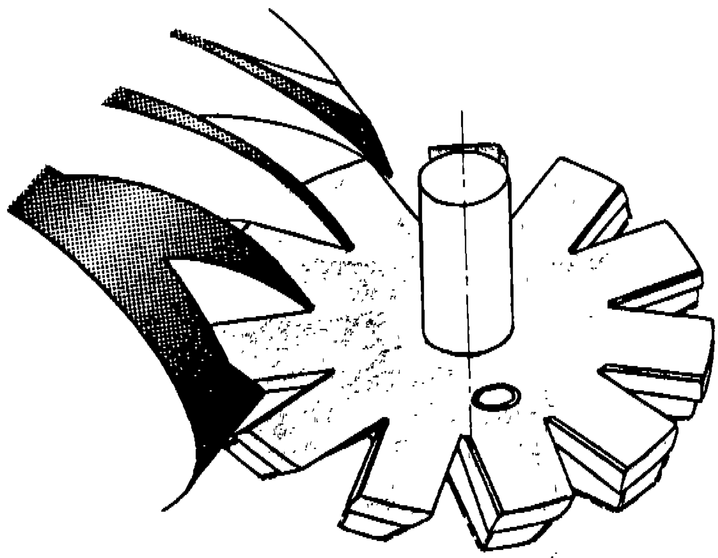

Fig.5

Floating gaterotor

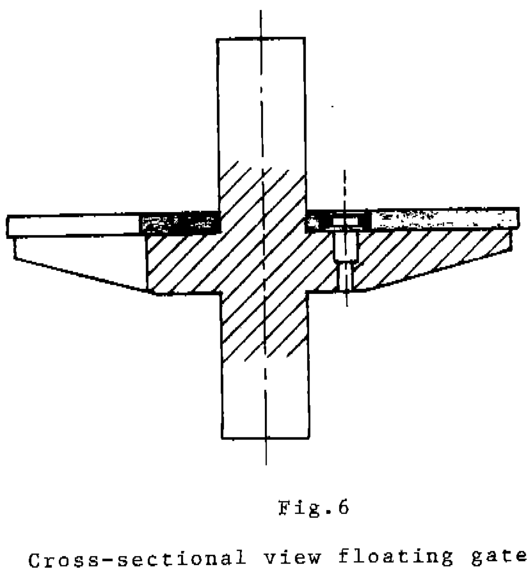

Fig.6

Cross-sectional view floating gaterotor