Design and Operating Characteristics of the Zimmern Single Screw Compressor

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by

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The initial concept of the Zimmern single screw compressor goes back to 1960.

After one year of theoretical engineering, it was submitted to several French and American companies but, after examination, was rejected for various reasons.

In 1962, a $5,000 grant from a quasi-governmental agency called SARST, which is responsible for aiding inventors, made possible the construction of a prototype of 10 HP at 5,000 rpm which even at that early date showed an efficiency of 25 to 26 HP/100 cfm and lasted more than 1,000 hours on life test.

The first manufacturing license covering certain portions of the compressed air field was granted in 1963 to Société des Automobiles Peugeot, the manufacturer of the Peugeot car, who successively developed various 40, 70, 30 and 20 HP models of both portable and stationary air compressors. The speed of these compressors, equivalent to that of the Lysholm type, enabled them to be directly coupled to six pole electric motors (3,000 rpm at 50 Hz or 3,600 at 60 Hz) or to the high speed diesel engines (3,000 rpm at rated speed) which Peugeot had just developed. More than a thousand of these compressors are already in service.

Since 1963, other manufacturing licenses have been granted. In the U.S., Chicago Pneumatic undertook the development and exploitation of the machine for compressed air applications. In Japan, Mitsui took the license for the same field. In Europe, tests are under way with one of the largest manufacturers there of industrial refrigeration compressors and the results already look promising.

GENERAL DESIGN

The Zimmern compressor consists of a single screw which cooperates with two toothed gaterotors symmetrically located with respect to the screw. The screw is of the hour-glass type so that the roots of the threads, which are located substantially along an arc of a circle, cooperate with the outside diameter of the gaterotors. The screw rotates within a cylindrical casing which cooperates with the crests of the screw threads. The outlet ports consist of substantially triangular holes provided in the bore of the casing. This compressor is of the wet type and operates with auxiliary liquid injection.

The screw is extended at the high pressure end by a solid section which seals off the ends of the grooves that serve as the compression chambers. The leakage which passes between this solid section and the casing is returned to the intake through holes drilled at appropriate locations in the casing. This makes it possible to have a screw which is subjected to neither radial nor axial thrusts and simplifies considerably the problems of the bearings.

NUMBER OF TEETH AND THREADS

The screw is designed with 6 threads and the gaterotors with 11 teeth.

The number of threads is determined by the desired compression ratio. An increase in the number of threads causes an increase in the compression ratio but also a reduction in the swept volume. Up to a compression ratio of 3 or 4, it is possible to use screws with 4 threads. For higher ratios, ranging from 7 to 10, it is preferable, in order to obtain an optimum thermodynamic efficiency, to use screws with 6 threads. It is possible to obtain higher compression ratios, ranging from 10 to 16, by using screws having 8 threads, or by means of other designs now being developed.

The number of gaterotor teeth and the number of screw threads have been selected with no common factors so that each tooth sweeps each groove from turn to turn. Thus it is not necessary in assembling the machine to be concerned with a preferential position of a tooth with respect to a given thread.

Incidentally, it was sought to reduce to a minimum the size of the gaterotors (which have a diameter substantially equal to that of the screw) so they would have the least number of teeth. Since 7 teeth resulted in a gaterotor which would have meshed with the screw over nearly 180° and would have left no place for the gaterotor shaft, the next highest integer having no common factor with 6 was selected, namely 11.

MATERIALS

Since the screw is not subjected to any lateral force and since the depth of the grooves diminishes as the pressure increases in the compression chambers, it was possible to select the material for the screw not as a function of its strength but as a function of its coefficient of friction with the gaterotors. The material chosen was bronze which has an excellent coefficient of friction and is not susceptible of seizing against cast steel in the event of improper assembly into the casing. Other materials are being tested, particularly for operation with ammonia, but for air compressors, the cost savings to be gained from going to materials such as aluminum are too small to justify abandoning the advantages of bronze's coefficient of friction.

During the early years the gaterotors were made of steel castings covered with a nylon molding and were assembled, rough molded, without machining. But for various reasons, particularly resistance to high temperatures, the tendency has been to return to gaterotors of phenolic resin -- the same material used for the vanes in sliding vane compressors -- mounted on a rigid support of rough cast steel. These combinations have made possible endurances on life test whose ultimate limits it is difficult to predict because this development is still in its infancy. However, many machines have exceeded 10,000 hours without any drop in delivery.

It seems that between the teeth of the gaterotors and the threads of the screw there forms a hydraulic wedge which prevents any solid to solid contact. Otherwise such endurances would be impossible with the peripheral speeds used for the screw which are commonly as high as 30 to 40 meters per second.

INJECTION

The compressor is provided with two symmetrical injections of liquid. Since the optimum injection pressures are between 15 and 45 psi depending on the design, it is not necessary to provide an auxiliary pump for injecting the liquid. This is in contrast to most other rotary compressors whether of the sliding vane or screw type. The outlet pressure of the compressor is sufficient to insure the necessary circulation.

Moreover, the efficiency of the machine is practically unaffected (variation of less than 2%) when the speed is varied by a factor of two above or below the rated speed. This gives very great flexibility for variable speed portable machines.

The location of the injections, which initially were of the axial type, is in the process of being modified since it was found that so-called tangential injections near that part of the screw where the teeth of the gaterotors have their maximum penetration into the grooves reduced the leakage and improved the efficiency by nearly 10%.

CLEARANCES

This machine is quite straightforward and does not require tight tolerances. The working clearance between the screw and the casing for a compressor of 180 cfm at 3,600 rpm and 100 psi is on the order of 10 mils, and the clearance between the gaterotors and the flanks of the screw threads is 4 to 8 mils which has made it possible, in particular, to mold the gaterotors without machining the edges of their teeth.

BEARINGS; DYNAMIC LOADS AND STRESSES

As previously indicated, the screw is not subjected to any radial or axial thrust. It is sufficient to position it with a pair of tapered roller or oblique contact ball bearings, or even with two stops, the other end of the shaft being supported by a roller or ball bearing. With normal lubrication or greasing, the life of such bearings is theoretically infinite.

As far as the gaterotors are concerned, the axial thrust resulting from the compression is very low because the area of the tooth exposed to the gas pressure diminishes as the pressure increases. For example, a gaterotor of a 180 cfm compressor is subjected to an average thrust of only 100 pounds which is a load easily supported by oblique contact ball bearings.

There is a certain modulation of this thrust at the rotation frequency multiplied by the number of threads, but this modulation does not exceed 20% of the average thrust and therefore remains negligible.

FLOW FLUCTUATIONS AND NOISE LEVEL

(Because of the 6 threads, the frequency is higher than that of compressors of the Lysholm type whose male rotors have 4 lobes. The result is a reduction in the cyclical flow fluctuations and a very much lower noise level. When the compressor is equipped with a standard electric motor, it is the motor and not the compressor which is heard.)1*

Measurement of the noise of the compressor itself is therefore not easy, and it is all the more difficult since it depends on the type of air filter used. In refrigeration compressors or certain vacuum pump applications where the inlet is not connected to an air filter but to an enclosure, noise levels of less than 80 dB have been measured at a distance of 3 feet.

EFFICIENCY

(This compressor has the advantage over the Lysholm of not having any blow hole which, even compared to the new asymmetrical profiles, gives it an initial advantage of 5 to 7%.)2*

Indeed, on small volume machines, 180 cfm for example, "dry" efficiencies(1) on the order of 21 HP/100 cfm and "overall" efficiencies(1) on the order of 22 to 23 HP/100 cfm are obtained for air compressors having an outlet pressure of 100 psi. The adiabatic efficiency of the machine is therefore around 85% with air, and analogous results are expected in the near future with ammonia for equivalent powers.

This does seem to represent a gain of approximately 5 to 7% over asymmetrical Lysholm compressors and a very substantial improvement with respect to sliding vane compressors.

FLOW REGULATION

The flow regulator is very similar to the one used in twin screw compressors. An inlet valve makes it possible to control the flow rate. Below a certain flow rate, it is necessary to recycle the compressed gas to insure a minimum inlet pressure and avoid hydraulic pounding which is a source of vibration and noise. This phenomenon is well known in other rotary compressors.

For refrigeration compressors, simple regulating devices are being developed which are still confidential.

CONCLUSIONS

By inventing 36 years ago the compressor which bears his name, Lysholm opened the way for screw compressors which are proving today to be extremely interesting because of the advantages they offer of compactness, small number of parts, elimination of foundations and smoothness of flow (which avoids the use of enormous air tanks); in short a considerable cost saving with repect to reciprocating compressors. These advantages also apply with respect to sliding vane compressors. But in contrast to sliding vane compressors, screw compressors offer the advantages of long life without maintenance, and high speeds which permit them to be directly coupled to 3,600 rpm electric motors or to diesel engines whose speeds are constantly being increased, i.e. performance not yet attainable by sliding vane machines.

(The single screw compressor offers on these points the same advantages as the twin screw Lysholm compressor. If, in addition, it is more attractive from the point of view of cost, efficiency and noise level, it is perhaps because it is a newer development and a place should therefore be made for it beside its predecessor)3*

* Corrections

1) **Because of the 6 threads, there is a reduction in the cyclical flow fluctuations and a low noise level.**

2) **This compressor requires no blow hole, which improves its efficiency 5% to 7% over machines which have blow holes.**

3) **The single screw compressor offers on these points the same advantages as twin screw rotating compressors. In addition, this new single screw compressor appears in its early stages of application to have advantages of low cost, excellent efficiency and good noise level.**

(1) By "dry" efficiency is meant the efficiency measured without air filter, the drain line closed and the pressure measured before oil separation. By "overall" efficiency is meant the efficiency including the pressure drop through the air filter, the pressure drop through the separator and the leakage through the drain line, hence under normal field conditions.

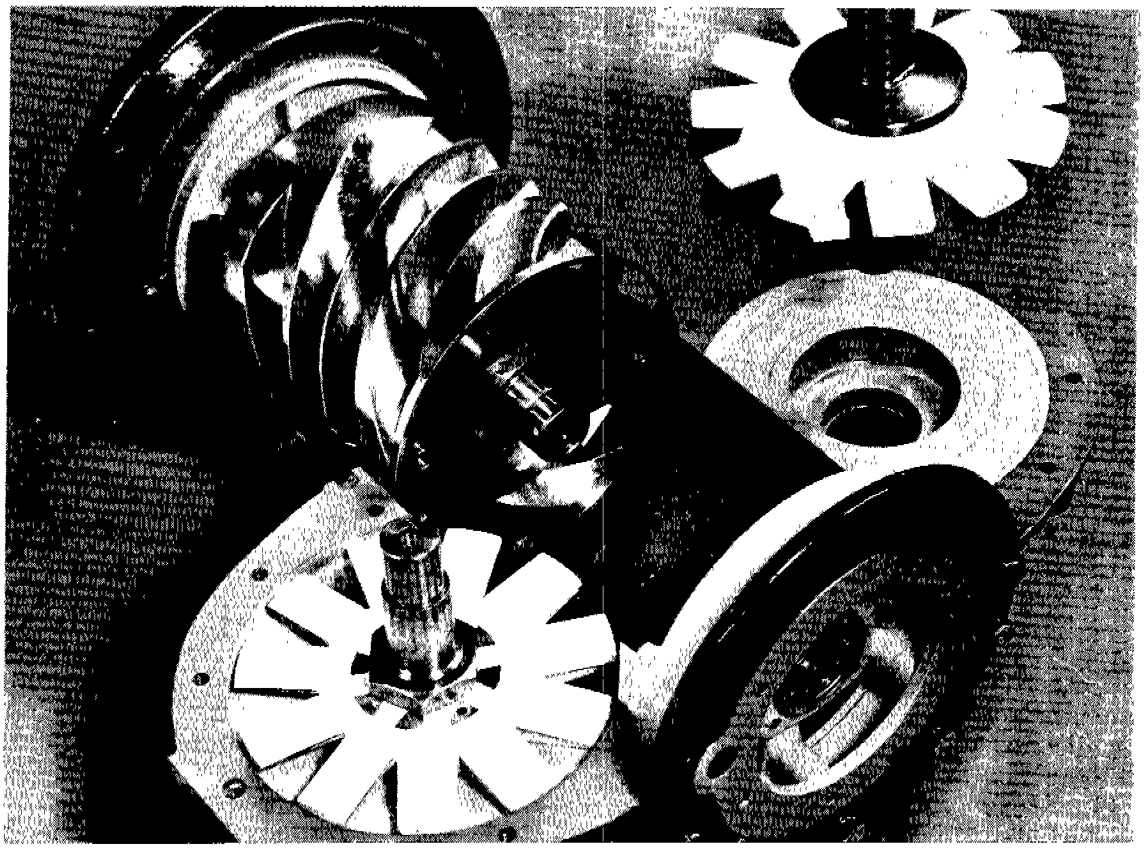

Figure 1. Exploded View of a Zimmern Single Screw Compressor

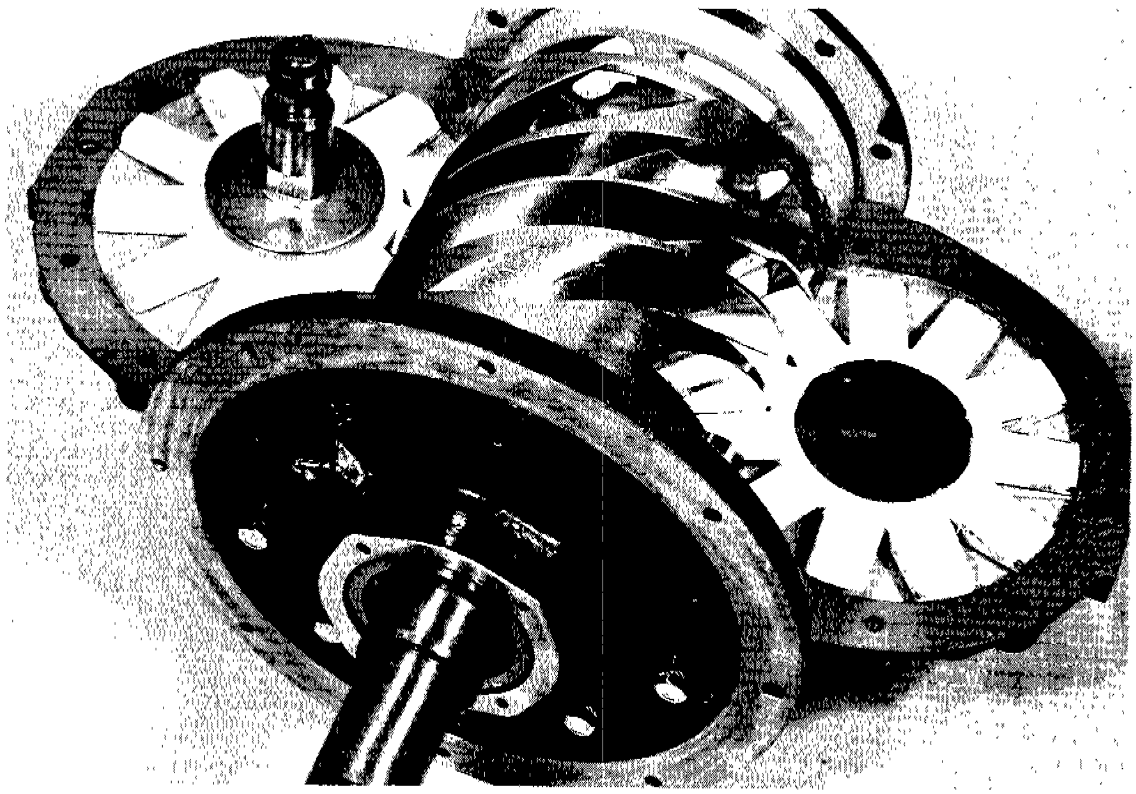

Figure 2. Assembled View