APPLICATION OF LSPM ELECTRICAL MOTORS IN HERMETIC SCROLL COMPRESSORS FOR LIQUID CHILLERS AND PERFORMANCE COMPARISON WITH R410A AND R454B

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1. Introduction: the evolution of the regulatory context and the consequent need to update the products

In recent years there has been a strong impulse to change in the refrigeration and air conditioning sector in Europe. A striking example of this pressing change is undoubtedly represented by the refrigeration systems adopted in the supermarkets which, anticipating other sectors of our refrigeration industry, have undergone in almost a few years the almost total elimination of R404A / R507A in new plants after about twenty years of systematic use of these high GWP refrigerants. The desired reduction on greenhouse gas emissions has triggered an inevitable and justified decline for R404A / R507A in favor of other less impactful solutions such as the cascaded R134a / CO2 cycles (alternatively R513A / CO2) at the same time opening the doors for a massive use of CO2 booster systems in a large number of realizations where the climate conditions allow it.

The main driving force of this change is undoubtedly the F-Gas regulation which, in imposing a progressive reduction of emissions year by year, has in fact put a noose around the neck of traditional refrigerants starting to tighten from those with higher GWP. The R404A / R507A is only the first of the victims and will soon be in good company. The R410A is already in obvious difficulty and after the exit of the R404A / R507A it represents the refrigerant currently used with the highest GWP (2088). It is very likely that within a few months the price of this refrigerant will increase to make it uneconomic to use.

The other major player in the technological transformation of these and the coming years is the Ecodesign Directive 2016/2281 which obliges equipment manufacturers to comply with defined minimum levels of energy efficiency (MEPS) in order to be able to offer their products on the European market. From a practical point of view there is a substantial difference between the Ecodesign Directive and the F-Gas Regulation: the first clearly defines the minimum levels of efficiency to be achieved in order to sell its products, while the second does not specify in any way, except for some rare cases where bans have been placed, which are the refrigerants to use and those to be eliminated for the different refrigeration applications. In this way a situation of uncertainty was created in many areas of our sector with consequent difficulty in identifying a technological choice that could be effective if not in the long term at least in the medium term.

The current difficulty of companies in our sector, in particular chiller manufacturers with scroll compressors, lies in identifying a medium-term technological strategy on which to invest their money to comply with the changed regulatory context while maintaining a position of correct market competitiveness.

2. Refrigerants: possible candidates for replacing the R410A

Carbon dioxide, ammonia, hydrocarbons and HFO are among the substances currently available with GWP close to zero. It would seem spontaneous to choose among them today to solve the problems of direct emissions. Unfortunately the current chillers designed and optimized for R410A with scroll compressors could not work with these refrigerants in an efficient and competitive way. Instead, a huge investment in R&D would be necessary to change the compressor and chiller technology with the enormous risk of not being ultimately competitive in terms of product cost.

In the hypothesis of abandoning the R410A soon in chiller scroll applications and considering that solutions with almost zero GWP (or GWP <150) will not be available on a large scale and competitive shortly, in the next 8/10 years it will be necessary to adopt a transition technology very similar to that of the R410A, using a refrigerant with intermediate GWP (in a range 450..700) with capacity, dimensions, efficiencies and costs very close to those of current technology.
We can evaluate the following options all belonging to the A2L category (mildly flammable fluids):

R32: GWP = 675; (100% R32); temp glide 0 K

R452B: GWP = 676; (67% R32 / 7% R125 / 26% R1234yf); temp glide 1 K

R454B: GWP = 467; (68.9% R32 / 31.1% R1234yf); temp glide 1.5 K

R32 appears in all three considered options even if in different percentages. This refrigerant offers good thermodynamic characteristics (operating pressures, energy efficiency, heat transfer coefficients) but it presents some special aspects: a decidedly high discharge gas temperature, a volumetric cooling capacity quite different from that of R410A and relatively high GWP. The large-scale adoption of this refrigerant in applications with scroll compressors would therefore necessarily entail a significant redesign of the compressor and of some other parts of refrigerating circuit, due to the greater volumetric cooling effect and the higher discharge gas temperature (especially in heat pump applications). Having therefore to face a conspicuous investment in terms of redesign of the compressor and the chiller it is absolutely necessary to ask what the life cycle of this solution will be. In other words: how long will the market price of this refrigerant remain acceptable given the progressive restrictions on GWP determined by the F-Gas regulation? Now (mid 2019) R32 has still an acceptable market price; but how fast will it grow in the next 8..10 years?

The R454B and R452B are more similar to R410A (in terms of operating pressures, volumetric cooling effect, efficiency and discharge temperature) with the advantage that the redesign of the scroll compressor and refrigeration unit can really be minimized. The R452B has a GWP similar to that of the R32 and this allows us to hypothesize a relatively short life cycle for this fluid on a par with the R32.The R454B therefore appears to be the solution with the greatest chances in the medium term: redesign costs minimized with the concrete possibility of a relatively longer life cycle compared to the other two options, thanks to a clearly lower GWP.

3. LSPM motor technology (Line Start Permanent Magnet)

The LSPM (Line Start Permanent Magnet) motor is a known technology but not yet applied in the scroll compressor for applications in chillers for A / C. It can be considered a hybrid between an asynchronous squirrel cage motor and a permanent magnet synchronous motor. The stator is similar to that of an asynchronous motor while the rotor contains both the squirrel cage and the permanent magnet insertions.

Fig. 1: Rotor of an LSPM (Line Start Permanent Motor) motor.
Squirrel cage combined with permanent magnet insertions.

The development and construction of this electrical motor involves two phases: design of the squirrel cage to allow start-up when the motor is connected to the net (by means of a common contactor) and the design of permanent magnets for operation in nominal conditions at the synchronous speed.

In this way the benefits of the two different technologies are combined together: one gets a motor that starts easily, without the obligation of an external starter (frequency inverter) like with the conventional permanent magnet motors and can guarantee a higher electrical efficiency during normal operation.
The advantages of this technology are many. The primary aspect is the reduction of electrical losses in the rotor, in fact when the motor works at a synchronous speed in the squirrel cage there is no current flow with the consequent elimination of losses related to the magnetizing currents.
As it is a hermetic scroll compressor, the cooling of the electrical motor is realized by the suction gas. Being able to count on a more efficient electrical motor, the heating of the suction gas when flowing through the motor will be attenuated, with a consequent slight increase in the density of the intake gas and consequently of the cooling capacity. Another advantage is that the compressor, passing from asynchronous operation to synchronous operation, increases the speed of rotation, proportionally increasing the cooling capacity provided by the compressor (about 3..5% additional capacity depending on the operating conditions and the selected compressor model) .

4. Energy efficiency of the proposed solutions

To evaluate the benefit of the proposed technologies on the efficiency and cooling capacity of an air cooled chiller, the values of capacity and SEER (EN14825) obtainable with the various solutions were compared:

- ORBIT Standard 10hp scroll compressor model GSD60120VA with R410A (AS motor)
- ORBIT + 10hp compressor (LSPM) scroll model GSU60120VL with R410A
- ORBIT+ 10hp compressor (LSPM) scroll model GSU60120VL with R454B

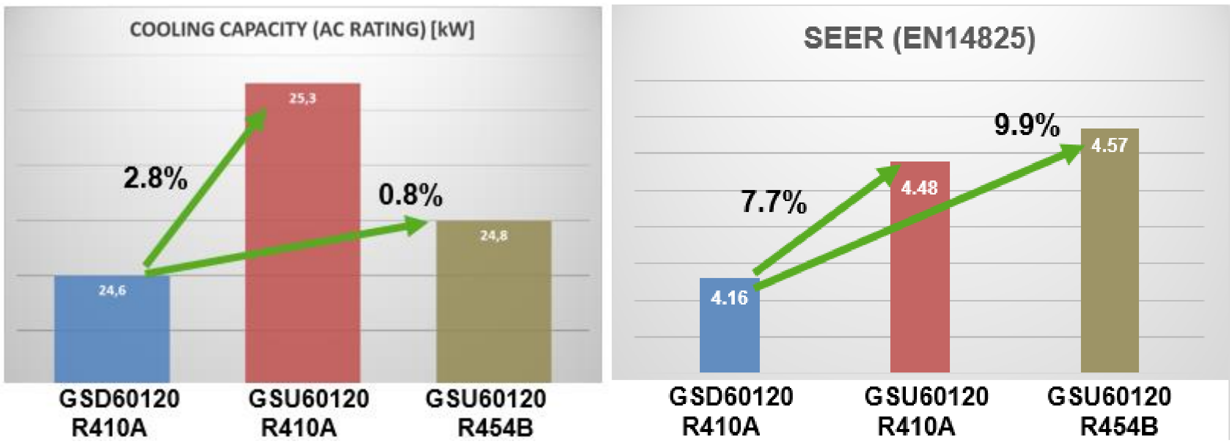

Fig. 2: Cooling capacity and efficiency change obtainable with the application of the LSPM motor and passing from R410A to R454B in an air-cooled scroll chiller.

The application of the LSPM motor allows to slightly increase the number of revolutions (ORBIT standard with asynchronous motor: 2900rpm) due to the fact that the rotor increases its speed up to the synchronism speed (3000 rpm). The cooling capacity increases by 2.8%, while the SEER increases by 7.7% in this specific case.

The subsequent transition from R410A to the new A2L R454B refrigerant marginally reduces the cooling capacity but allows a further contribution to the increase in energy efficiency (SEER) of the considered system.

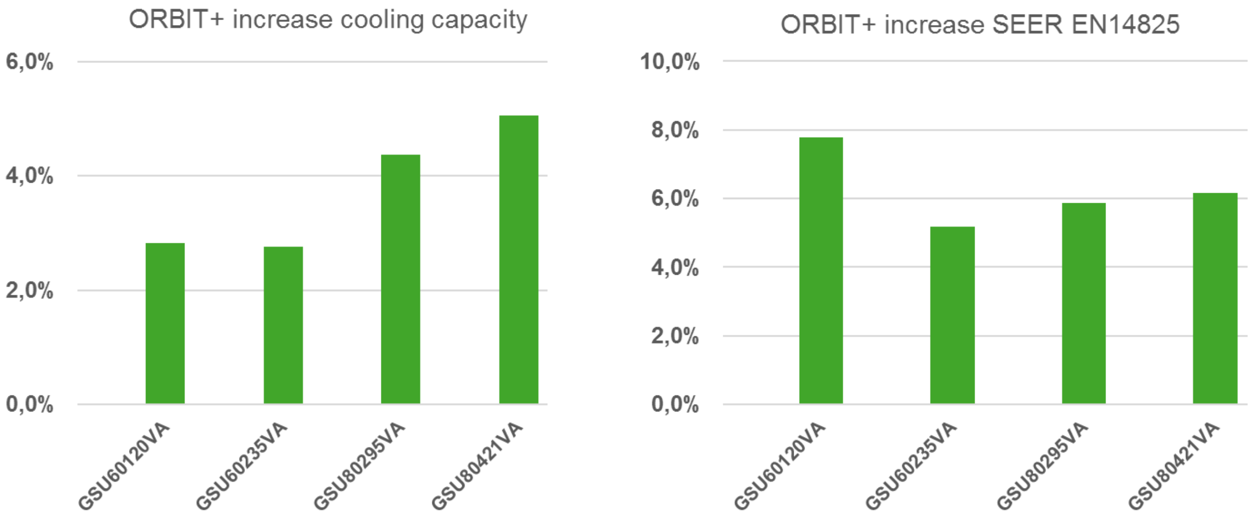

Fig. 3: Increased cooling capacity and SEER (EN14825) due to the use of the LSPM motor on different models of hermetic scroll compressors (R410A).

From figure 3 it can be seen that the application of the LSPM motor allows for the hiller an increase in the cooling capacity of around 3-5% depending on the model of considered compressor and an increase in efficiency (SEER) variable between 5 and 8 %.

At this point it must be said that the LSPM motor represents an excellent compromise in terms of simplicity of use, reliability and increased efficiency. The slight increase in cooling capacity makes it possible to compensate, at least to a small extent, the cost increase due to this technology.

It is undoubtedly true that the use of rare earths for the production of magnets involves a considerable increase in the overall cost of the compressor, but it must also be recognized that this solution (LSPM motor) allows a net increase in efficiency in all possible operating conditions for the compressor and not only in a restricted area of operation. Other solutions, with a lower economic impact, allow instead to improve efficiency only under the conditions foreseen by the standards for the compilation of the SEER index but do not ensure a corresponding energy saving in other operating situations.

5. <u>Cost optimization</u>

The traditional criteria for equalizing the oil level in the oil sump of scroll compressors connected in parallel (tandem or trio) are based on the principle of communicating vessels. This solution obliges the manufacturer of the assembly to systematically look for for the geometric and fluid-dynamic symmetry in the suction and delivery refrigeration lines to equalize the load losses and obtain homogeneity of the pressures in the oil sumps and create ideally the correct conditions for the validity of the principle of communicating vessels.
Unfortunately, this apparently trivial activity (homogenization of pressure losses) is actually particularly difficult if we consider the usual production tolerances for the pipes and the compressors themselves. Those who practice multiscroll chillers will be able to confirm that often the oil level visible in the compressor sight glasses is anything but homogeneous.
To solve this issue innovative solutions are available (BAHT piping - Bitzer Andvantage Header Technology) which, by moving away from the communicating vessel principle and introducing practical criteria with simple implementation, allow to parallel scroll compressors of different capacities with a reliable oil equalization.

With this premise it becomes extremely easy to combine in parallel compressors of different cooling capacity or with different electric motors.
It is therefore possible and even easy to combine in parallel, for now in tandem but in the future also in trio, compressors with traditional asynchronous motor and compressors with synchronous motor LSPM. This opportunity offers a large degree of freedom in choosing compressors to be paralleled to maximize the efficiency (SEER) of the unit.

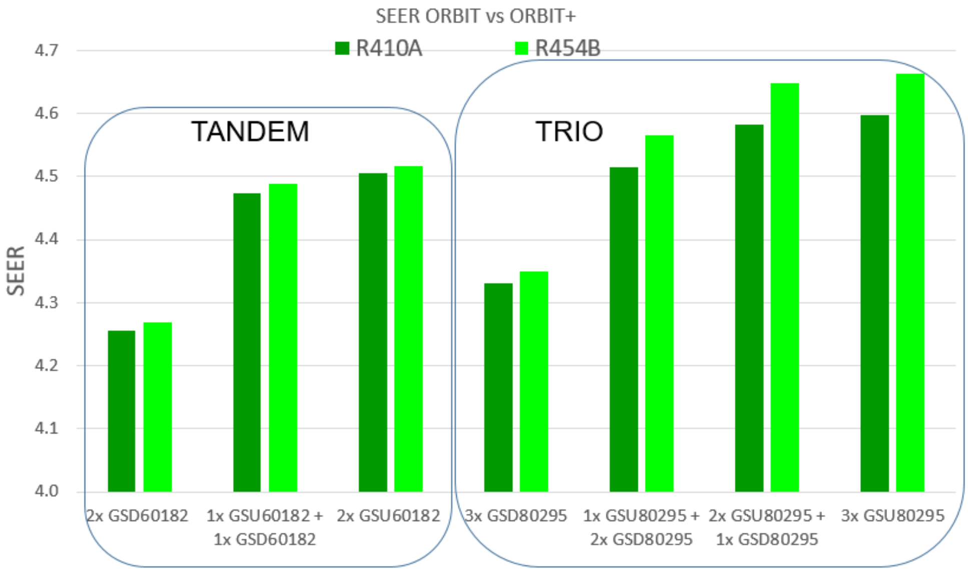

Fig. 4: Increased SEER (EN14825) thanks to the parallel combination of compressors with traditional asynchronous motor and compressors with LSPM motor.

Figure 4 shows that the maximum efficiency gain is obviously achievable by replacing all the compressors with a conventional motor with the same number using an LSPM motor, obviously this is also the most expensive solution. An optimal compromise is to replace only a part of the asynchronous with LSPM compressors and modify the operating logic of the unit using as much as possible the most efficient compressors. The resulting efficiency gain is only slightly lower than the maximum achievable by replacing all the compressors, while the cost increase is thus significantly attenuated.
In a multiscroll chiller it is thus possible to flexibly choose the mix between asynchronous compressors and LSPM compressors, even of different sizes, depending on the efficiency targets to be obtained and the application being considered.

6. Conclusions

The extreme degree of complexity determined by the continuous evolution of the regulatory framework puts a strain on our industrial sector. The technologies used must be continuously updated, making technical strategy choices that are often risky due to the very high price volatility of refrigerants in the present European market.
In this dynamic and confused context, only in some applications it is possible to switch directly to natural refrigerants with almost zero GWP (for example NH_3 for industrial refrigeration, CO_2 for commercial refrigeration). In other sectors, for example in air conditioning or process cooling, this direct passage to natural fluids at this time could represent the classic "longest step of the leg".
In this work a technical strategy has been proposed, applicable to commercial scroll systems, which allows to considerably increase the overall efficiency of the system by using scroll compressors with an innovative LSPM electric motor and introducing an A2L refrigerant (R454B) with reduced GWP that is very similar to R410A.
Finally, a method has been proposed to minimize the extra costs due to the use of the new LSPM technology, while achieving significant increases in efficiency for the system.

Riferences:

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