Part 3: Bouchareb

Speed Control of Refrigeration Compressors with intelligent Frequency Inverters

Reduction of operating costs by energy saving and improvement of cooling quality

In these times of increasing energy costs and even more stringent environmental directives it becomes increasingly more important to save energy.

Compared with a conventional step controller, the variation of refrigeration capacity using a frequency inverter is a solution with many advantages.

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3.1 Introduction

The compressor power is precisely adapted to the required refrigeration power without having to leave the optimum and required operating point. As a consequence the refrigeration system capacity and energy efficiency increases.

Even if the refrigeration system load fluctuates, nearly constant system pressure can be obtained by the use of intelligent Frequency Inverters (**FI**), other advantages are:

Energy saving by:

- increasing the evaporation temperature
- optimizing the condensation temperature
- reducing evaporator icing and longer de-icing intervals

Improvement of cold storage quality

- reducing temperature deviations at the cooling outlets
- higher and constant relative humidity
- Improvement of cold storage quality by reducing weight losses on refrigerated goods

All new developments in refrigeration technology should be aimed at:

Building energy-optimized high-quality refrigeration systems providing a stable and reproducible cooling climate in order to ensure storage of high-quality goods without any weight or quality losses.

Modern variable-speed controlled refrigeration systems meet these requirements in most points.

In the following the reduction of operating costs will be concentrated on.

The following advantages will be given special consideration:

- Significant reduction in energy consumption
- Reliable and stable refrigeration
- Reduced weight losses of stored goods
- Short period of amortisation

3.2 Reduction of operating costs

For us, a reduction of operating costs means less energy consumption and reduced weight losses of refrigerated goods.

Energy consumption reduction is divided up in:

- *Primary* energy cost saving by directly reducing the energy consumption of the refrigeration process
- *Secondary* energy cost saving by increasing the efficiency of heat exchangers on the cooling outlets

3.3 Primary energy cost saving

Compared to single-compressor installations with on/off-switches or multi-stage compressor packs, an intelligent, frequency inverter (**FI**) controlled refrigeration system allows a continuous adjustment to the relevant refrigeration requirements. With single-compressor and multi-stage compressor installations switching in or out of compressors causes considerable suction pressure changes.

Most refrigeration systems are operated under partial load conditions for 75 to 80 % of the year. Frequent starting of single compressor stages in a multi-stage rack has a very negative effect on the energy balance. Switching-in a

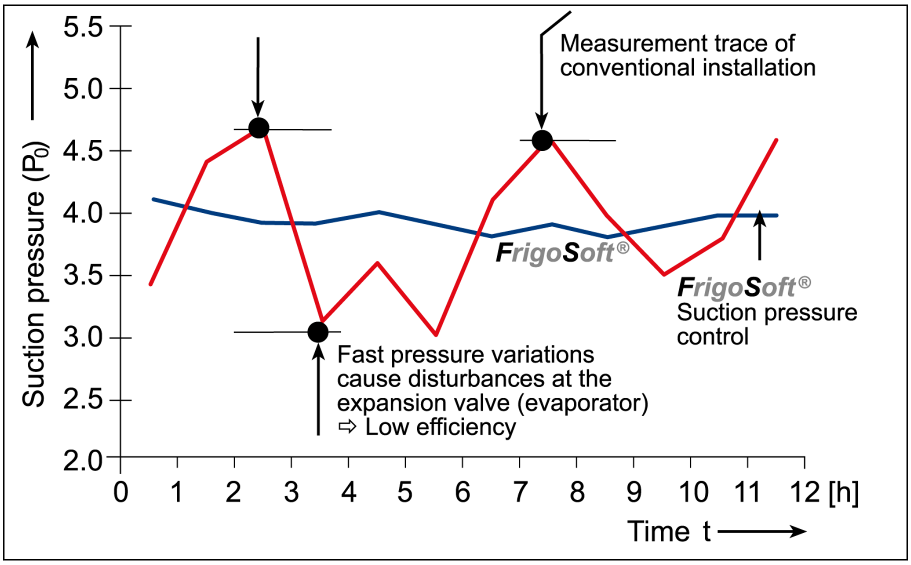

Figure 3.1: Pressure characteristics of a three-compressor system with step-switch control and a two-compressor KIMO FI controlled system

further stage of a multi-stage compressor rack mostly causes unnecessary over-power with subsequent evaporation pressure deviations, see Fig. 3.1.

By use of intelligent Frequency Inverters (**FI**s) a very high accuracy in controlling can be effected. Deviations of the evaporation temperature can be reduced to 4 - 6 K compared to multi-stage compressor controlling. Due to this smaller control range of the evaporation pressure, energy savings of about 16 to 25 % can be reached in partial load operation. This is based on the rule that an evaporation temperature rise of 1 K means 3 to 4 % energy saving.

Increasing the evaporation temperature means improving the compressor efficiency by an increase of suction pressure. The resulting over-power is compensated by a speed reduction. As a consequence condensation power and ventilation fan performance decrease by reducing the drive energy.

The resulting smaller pressure differences in the compression process are the cause for an evident energetic improvement allowing energy savings in the range of 16 to 25 %.

The main cause for saving energy in a refrigeration system lies in its optimized use by speed control of the compressor power.

The Frequency Inverter with its integrated special software keeps up a constant condensation pressure by speed control of the refrigeration fan, causing further energy savings by keeping up a constant pressure on the evaporator, see Figs. 3.2 and 3.3.

When selecting the condenser once more the rule should be considered that a condensation temperature reduction of 1 K means 3 to 4 % energy saving.

Advantages:

- Higher evaporation temperature
- Lower condensation temperature
- Increasing efficiency of the refrigeration system

3.4 Secondary energy cost saving

With a constant evaporation and condensation pressure, the pressure deviations of the thermal expansion valves are mostly reduced and an optimum refrigerant filling of the evaporator is reached. The evaporators can operate at full capacity.

The temperature difference Delta t_{L1} - t_0 decreases and there is less icing on the evaporators. Cooling intervals are prolonged and defrosting is reduced. For further energy optimizing adaptive defrosting sensors should be installed which detect if any defrosting is necessary, thereby reducing the energy entry of de-frosting considerably.

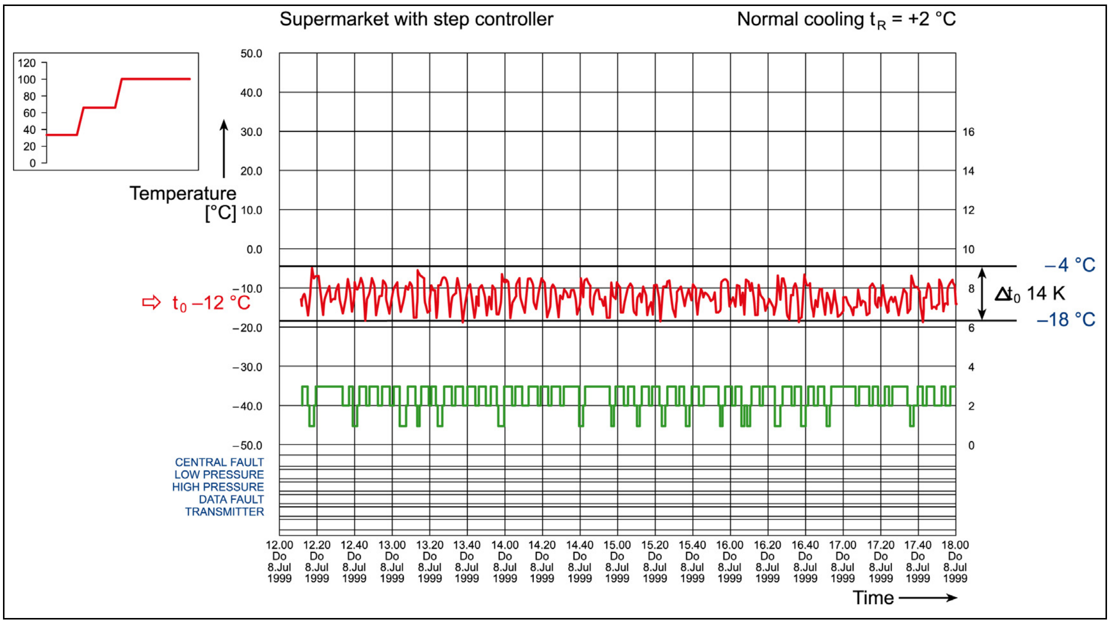

Figure 3.2: Suction pressure deviation characteristic of a four-stage compressor pack step-switch controlled system

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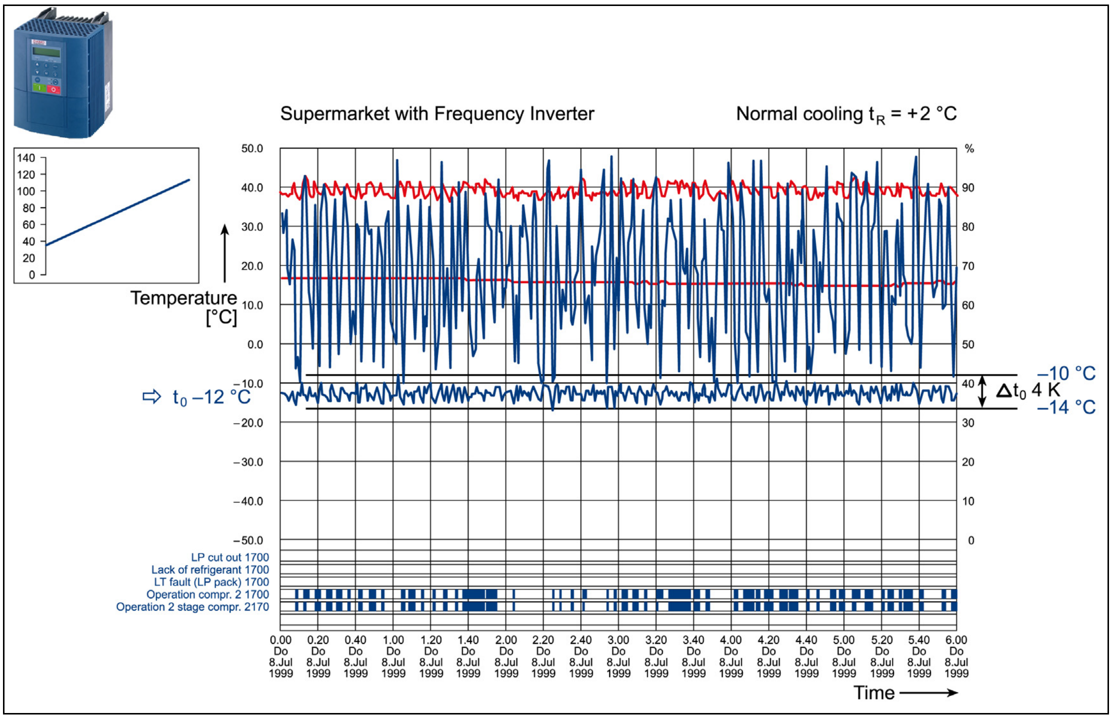

Figure 3.3: Suction pressure deviation characteristic of a KIMO FI-controlled two-compressor pack located in a big restaurant at the Karlsruhe central station

Independent of compressor type, changing operating conditions or charging level of the cooling outlets, in any operating condition the optimum necessary refrigeration power is automatically determined and disposed to the refrigeration system. Even compressor packs with a larger number of compressors and stepping switch control are ranging far behind a two-compressor rack with intelligent Frequency Inverter (**FI**) control, see Figs. 3.4 and 3.5.

Advantages:

- Higher evaporator efficiency by optimum filling of the evaporator
- Less icing on the evaporator
- Longer de-icing intervals

3.5 Improvement of cooling quality

Most sorts of fruit and vegetables are to be stored at a temperature of between 0 °C and 3 °C depending on the goods, and at a high level of humidity with minor temperature deviations.

For a reduction of losses and quality improvement of sensitive cooling goods like fruit, vegetables and meat only small temperature differences are acceptable for the cooling chamber (resp. heat exchanger). There must not be any major changes like water losses on cooled goods.

Losses of water are losses of weight and therefore are of high economic importance leading very quickly to the unsaleability of a product. With carrots for example, a water loss of 10 % means an economic loss of 100 % [1].

One of the main causes for a quality loss on the storage of goods is water loss of the goods, arising from steam diffusion out of the stored goods (like fruit, vegetables, meat, fish, ...) into the ambient air of the cooling chamber. The driving force for these losses of water on fruit and vegetables is a steam pressure deficit between the cooling chamber and the interior of the stored goods which is too big [2].

Water vapour pressure deficits mostly arise from temperature deviations in the cold store. Temperature deviations on the other hand are resulting from unstable suction pressures.

Temperature and relative humidity in the cold store are two physical quantities which cannot be discussed separately as there is a mutual influence between

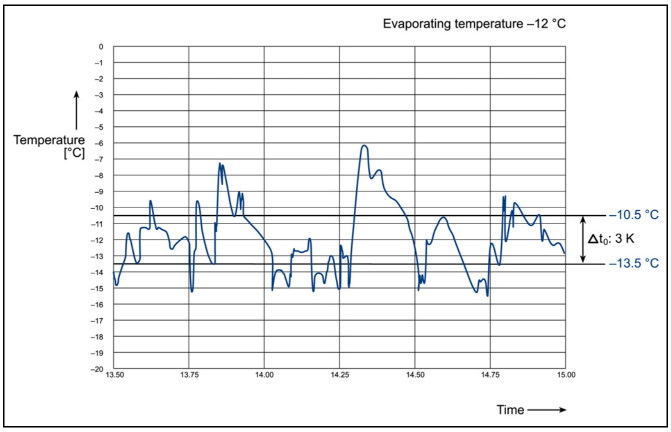

Figure 3.4: Suction pressure deviation characteristic of a pack with four asymmetric compressors and ten binary switched steps

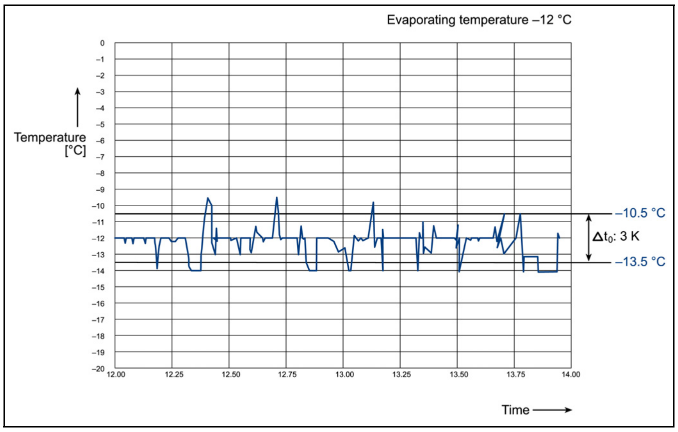

Figure 3.5: Suction pressure deviation characteristic of a KIMO FI-controlled two-compressor pack

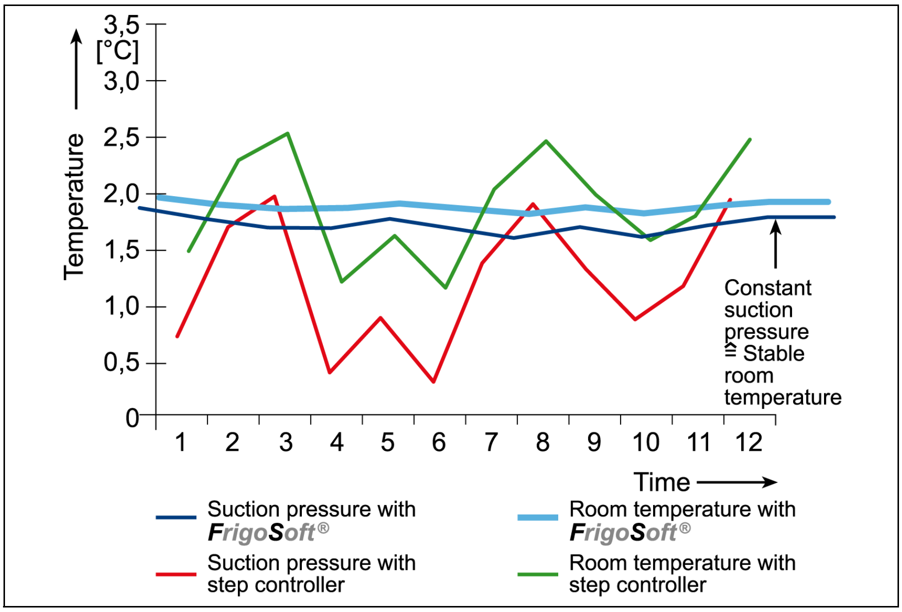

Figure 3.6: Temperature characteristic of::
A) Three-compressor pack step-switch controlled system
B) Two-compressor pack KIMO FI-controlled system

them.

Temperature deviations in the cooling chamber automatically result in deviations of the relative humidity. They mainly depend on the step change hysterisis in the refrigeration process (compressor pack).

Major fluctuations of the evaporation temperature t_0 as well as excessive overheat do have a negative impact on evaporation-dependent quantities like temperature and humidity. In the cooling process the water extracted from the goods stored condensates on the evaporator lamella surface and freezes at lower evaporation temperatures t_0. Therefore the cooling air re-ventilated into the cooling chamber is dry and receptive for taking in more humidity out of the goods stored. This effect is more intensive the bigger the temperature difference between evaporation and stored goods is.

Thus it is necessary to run the refrigeration system at lowest possible delta t_{L1} - t_0.

With Frequency Inverter control, suction pressure is almost constant, the temperature difference of delta t_{L1} - t_0 is reduced, a higher level of humidity can be effected preventing the stored goods from drying out excessively, see Figs. 3.6 and 3.7.

Frequency Inverter controlled compressor packs are able to react self-adaptively to the changing requirements in the cooling system. Small temperature deviations are not only depending on a stable suction pressure, but also on the evaporator type chosen. In order to reach a highly efficient suction pressure control by Frequency Inverters, it is necessary to install evaporators with an adequate surface and a good distribution of the cooling air in the chamber.

Frequency Inverters can also be retrofitted into existing cooling systems, offering the following advantages:

- Reduction of temperature deviations at the cooling outlets
- Higher relative humidity
- Improved quality of stored goods
- Weight loss reduction

3.6 Amortisation

There are different kinds of calculation for amortisation. In most cases they refer to the repayment period of additional investment costs in refrigeration systems.

The use of **FI**s does not really involve additional investment costs.

Three to four compressors are necessary for a conventional step-switch controlled compressor rack, in an **FI**-controlled system however, two compressors are sufficient. Compressors are dimensioned only slightly bigger, as the output of an **FI**-controlled reciprocating compressor increases by 20 % when operated e.g. at 75 Hz [3].

Consequently **FI**-controlled systems do not cause any additional investment costs. It can be assumed that investment costs are equal respectively lower than with step-switch controlled systems.

With **FI**-controlled systems an energy saving of 16 to 25 % can be effected compared to step-switch controlled systems [4] and even up to 40 % energy saving compared to single-compressor systems with on/off-switching. With **FI**-controlled systems considerable economic gains concerning weight loss reduction can be realized which will be illustrated in the following.

3.7 Conclusion

Whether for short-term or long-term storage, for supermarkets or in other refrigeration systems, in a time of constantly increasing energy costs, an energy saving of 16 to 25 % does have a positive effect on the economics of a cooling system.

Weight loss reductions on sensitive cold storage like fruit, vegetables or meat do have multiple positive effects on the economic efficiency of a business. Dif-

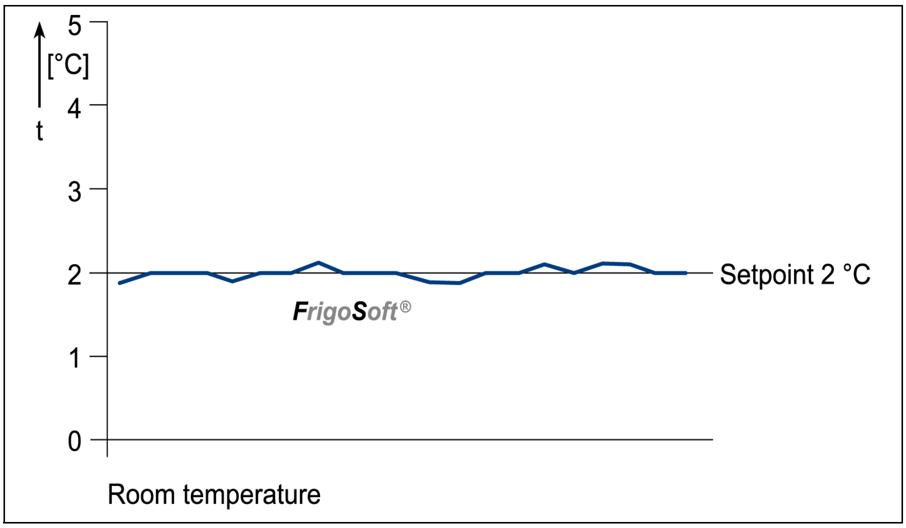

Figure 3.7: Temperature characteristic of a two-compressor pack KIMO FI-controlled system

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Store A: Large deviations in suction pressure (e.g. with a step-controlled compressor pack) **Store B: Practically constant suction pressure (e.g. with a Frequency Inverter controlled compressor pack)**			
		Store A	**Store B**
Value at goods-in	€/t	253,00	253,00
Loss due to shrinkage	%	18	3
Cost at ***goods-out***	€/t	308,53	260,82
Achievable market price	€/t	300,00	300,00
Profit/Loss	**€/t**	**-8,53**	**+39,18**

Table 1: Effect of cooling chamber climate on economic efficiency

ferent practical tests and reports show that considerable suction pressure deviations on cooling systems do cause storage losses of up to 18 % by goods drying up [1].

In systems with constant suction pressure (as in **FI**-controlled systems) however, storage losses are reduced to 3 % [1].

The following calculation based on the example of a vegetable store with five cooling chambers of 200 tons volume each (1000 tons totally) will demonstrate the economic influence of weight loss by drying, see Table 1.

Consequently the storage losses in a 1000 tons vegetable store would produce the following operating results:

In store A a *negative* operating result of: 1000 t x (-8,53 €/t) = -8.530,00 €

In store B a *positive* operating result of: 1000 t x (+39,18 €/t) = +39.180,00 €

With the use of Frequency Inverters another 25 % energy could be saved, thereby improving the already possible operating result of store B by about 12,66 %, see Table 2.

An energy saving of 25 % will improve the economic result considerably, especially with respect to the constantly increasing energy costs in the future.

3.8 Literature

[1] Weichmann, J.: Kühlräume für Obst und Gemüse - Einfluss des Raumklimas auf die Kühlqualität. Küba Symposium (1992)

[2] Seisenberger, M.: Untersuchung zur Verbesserung des Lagerklimas für Gemüse. Dissertation (1996) TU Müchnen

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[4] Bouchareb, M., Gibson, J., Lubich, F.: Drehzahlregelung von Kälteverdichtern mit intelligenten Frequenzumrichtern - Planung und Ausführung, KI Luft- und Kältetechnik 39 (2003) 4, S. 180

3.9 Key words

Refrigeration
Compressor
Frequency Inverter
Control
Energy

Store B: Practically constant suction pressure (e.g. with a Frequency Inverter controlled compressor pack)							
Energy saving		**0%**	**5%**	**10%**	**15%**	**20%**	**25%**
Costs at goods-in	€/t	253,00	252,05	251,09	250,12	249,15	248,18
Cost/Price at ***goods-out***							
Cost (at 3% loss)	€/t	260,82	259,85	258,86	257,86	256,86	255,86
Achievable market price	€/t	300,00	300,00	300,00	300,00	300,00	300,00
Profit	**€/t**	**39,18**	**40,15**	**41,14**	**42,14**	**43,14**	**44,14**

Table 2: Effect of energy saving in store B on economic efficiency