Screw compressor capacity regulated by stepless speed control

ABB Refrigeration has developed a new screw compressor drive for refrigeration and freezing plant. Called STAL Rotatune, it is based on a special high-speed motor that is fed with power from an advanced frequency converter. Stepless control allows the compressor to maintain high total efficiency even at considerably reduced loads. With a normal load profile, energy consumption can be reduced by up to 15 percent compared with conventional capacity control, and by as much as 20 percent when an economizer is used with the compressor.

It is no exaggeration to say that the cage induction motor is the workhorse of industry. Inexpensive, reliable and economical to maintain, it is normally supplied with power from a 50-Hz or 60-Hz AC network. However, this imposes two serious limitations on its use: the motor speed cannot be controlled, and the maximum speed is either 3,000 or 3,600 rev/min, depending on which frequency is used.

One solution when higher speeds are required is to use some form of step-up gearing. The capacity of the driven machine is controlled by starting and stopping the motor, or, alternatively, mechanical flow control can be used, as in the case of screw compressors [1]. The latter type of control is necessary when exact temperature regulation of the refrigeration system is required. However, this inevitably leads to energy losses.

Capacity control in refrigeration systems

Refrigeration system loads usually vary as a function of the type, quantity and temperature of the products being chilled or frozen. The performance of the refrigeration installation can also vary with climatic changes.

Configurations that permit energy-efficient capacity control have therefore always been highly valued in the refrigeration industry, the history of which goes back more than 100 years. Originally, manually operated mechanical devices were used for the control, but over the years a trend towards fully automated solutions has become firmly established.

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Throughout this development, engineers have sought to vary refrigeration system capacity automatically and at the same time maintain high efficiency through the use of a speed-controlled compressor.

Development of STAL Rotatune

An alternative drive system based on a frequency converter feeding an induction motor with power at varying frequency is easily conceivable. However, such a system is not completely without disadvantages. For example, the harmonic frequencies produced by the converter generate heat. Also, if the driven machine requires the torque to be kept constant over the full speed range, as in the case of a screw compressor, there will also be a problem with the heat generated in the motor.

To find a solution to this problem, ABB Refrigeration joined forces with ABB Motors and ABB Corporate Research in developing a variable frequency controlled drive system combining a standard frequency converter and a high-speed motor designed especially for use with converters **1**.

A precondition was that the new motor had to be designed in a way that minimizes the losses caused by the harmonic oscillations in the rotor. Theoretical studies and laboratory tests showed that it is the shape of the rotor slots in the motor that defines the motor's suitability for operation with a converter-fed supply. Standard motors are therefore less suited for such an application.

Besides generating considerably less heat than its predecessors, the new motor has been fitted with a separately driven fan. This removes the residual heat throughout the 1,000 to 6,000 rev/min speed range.

The power used by the fan is as low as 0.75 kW at 1,500 rev/min, and

1 ***Type FV 19 STAL Rotatune drive system for variable-speed capacity control of screw compressors. The frequency converter (left) feeds the high-speed induction motor with power at varying frequency.***

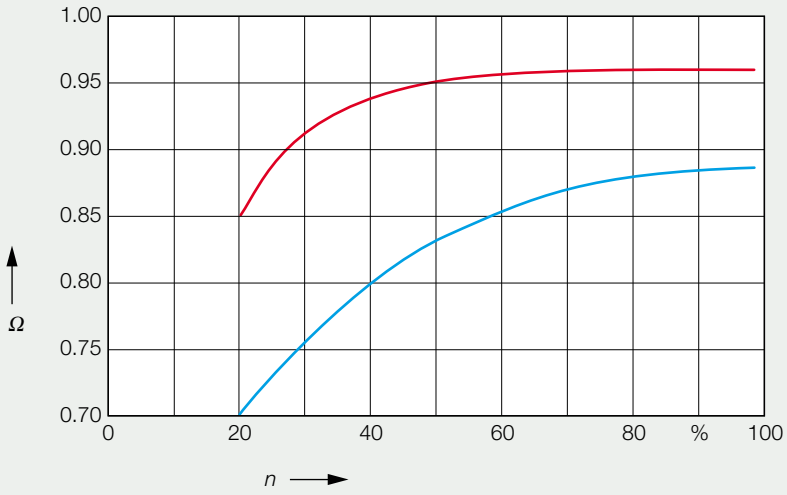
therefore makes only a very small contribution to the total power consumption of the drive system. Because of the separate fan, the motor's efficiency is 95 percent at full speed **2**.

Advantages of the STAL Rotatune drive system

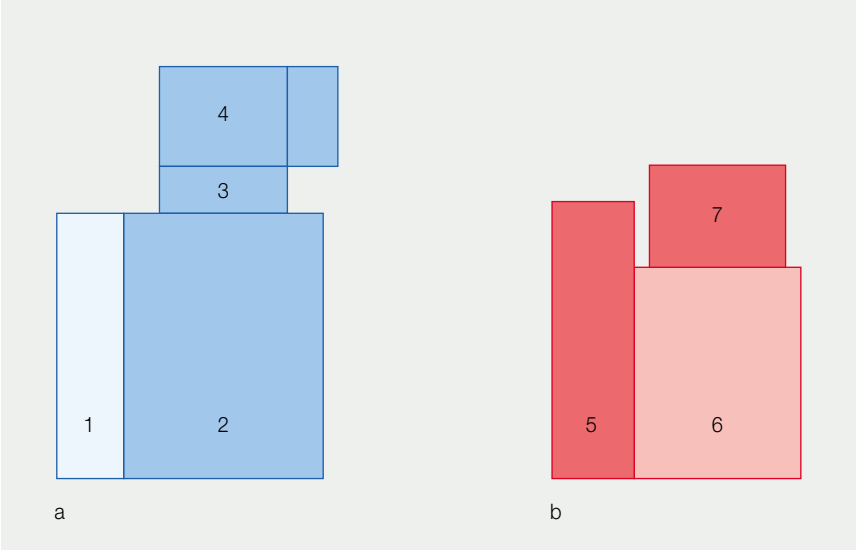
The new drive system, which is marketed under the name STAL Rotatune, allows exceptionally smooth capacity control of the refrigeration compressor, and thereby very precise refrigeration temperature regulation. User benefits include improved operating economy and better adaptation to the refrigeration requirements, which vary according to the application (foodstuffs production, chemical processes, indoor ice rinks, etc).

In addition, a screw compressor equipped with the new drive system can be designed with a much simpler configuration **3**. The reasons for this are as follows:

- The capacity control system is eliminated, this function being taken over by the speed control.
- No step-up gearing is required. The motor in the new system can be run at any speed up to 6,000 rev/min.



2 ***Efficiency Ω of the new high-speed motors used in the STAL Rotatune drive system (red) versus the relative speed n, compared with standard motors (blue)***



Comparison of a conventional screw compressor unit (a) and a compressor with STAL Rotatune (b), each with the same capacity rating. The STAL Rotatune configuration is considerably simpler. 3

1 *Starter*
2 *AC motor (frame size 280/315)*
3 *Gear*
4 *Compressor with capacity control*
5 *Frequency converter*
6 *Variable-frequency induction motor (frame size 225)*
7 *Compressor*

- No special starting equipment is needed, since the new system controls both the current and voltage directly, via the converter.
- The weight of the system is reduced as the compressor and motor are lighter than in conventional designs.

Other advantages of the new system are:

- Increased reliability on account of the compressor having fewer moving parts.
- A lower sound level – the result of the motor's low-speed cooling fan.
- Neither the compressor nor the motor has to run continuously at the rated speed.

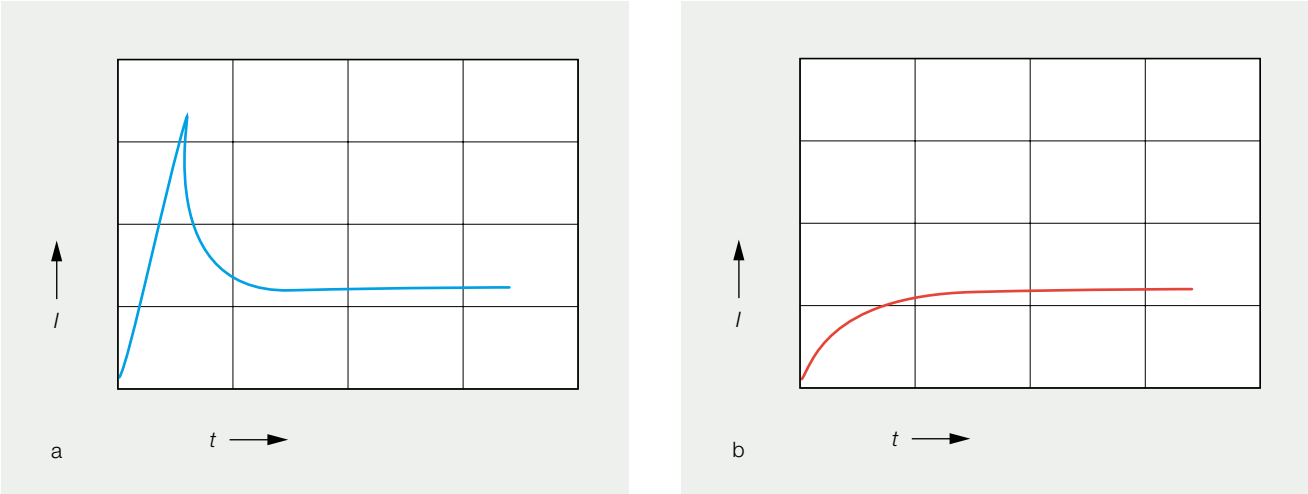
Soft starts and stops

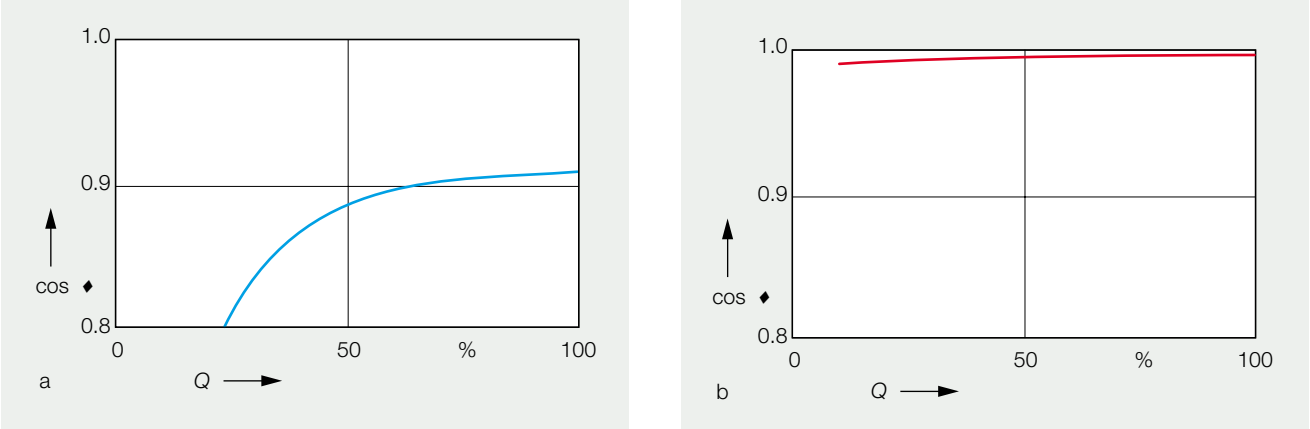
The new drive system also features a number of improvements which benefit the general operation of refrigeration installations.

The converter allows soft starting and soft stopping with controlled acceleration and retardation of the compressor 4. This reduces the load exerted on the electrical and mechanical equipment and eliminates current peaks during start-up. The current taken from the electrical supply can never exceed the motor's rated current.

As a result, there is no limit to the number of compressor restarts per unit of time. This allows the operation of the refrigeration system to be more easily adapted to variations in the refrigeration requirements.

Motor current I versus time for a conventional screw compressor (a) and a compressor with STAL Rotatune drive (b). In (b) a soft start is used and no current peaks occur. 4





Power factor as a function of the relative capacity Q for a conventional screw compressor (a) and a compressor with STAL Rotatune drive (b). In (b) the power factor of almost 1 shows that practically no reactive power is taken from the network. **5**

Furthermore, since the system works without a star-delta switch or similar starting equipment, and is not exposed to even the reduced starting current, the size of the supply transformer and the connecting cables can be reduced.

Finally, the motor has a power factor close to unity over the whole speed range **5**. This and the high efficiency of the converter ensure low losses for the drive system. The reactive power is practically zero, translating into a substantial reduction in costs as a result of expensive power factor compensation not being needed.

Reduced sound level

The refrigeration capacity of a screw compressor equipped with the new STAL Rotatune drive system is proportional to the speed. This means that the motor and compressor need only be run at the speed required at any particular time to achieve the necessary refrigerant flow.

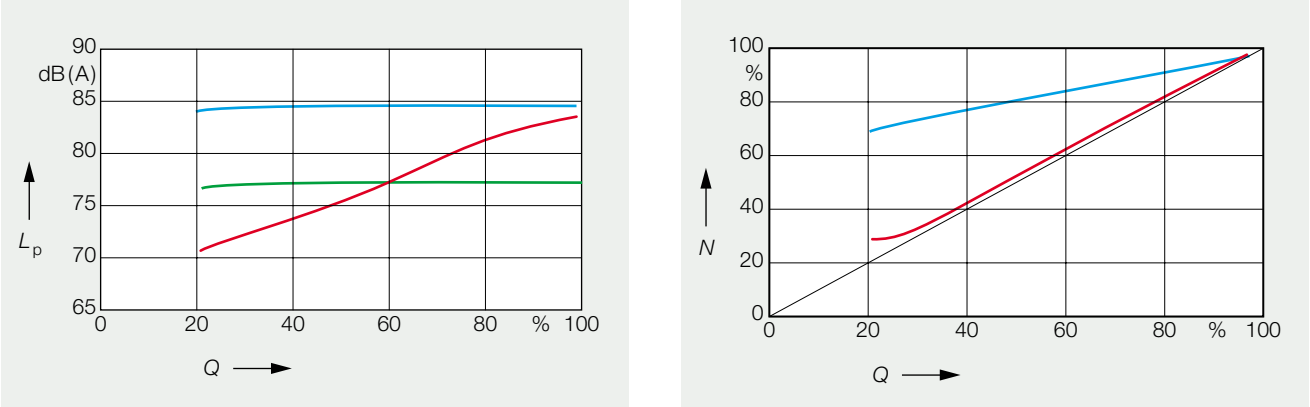
Since most refrigeration applications require only 40 to 70 percent of the maximum capacity during most of the time it is operating, the STAL Rotatune drive system runs at a relatively low speed for long periods, thereby ensuring a low sound level **6**.

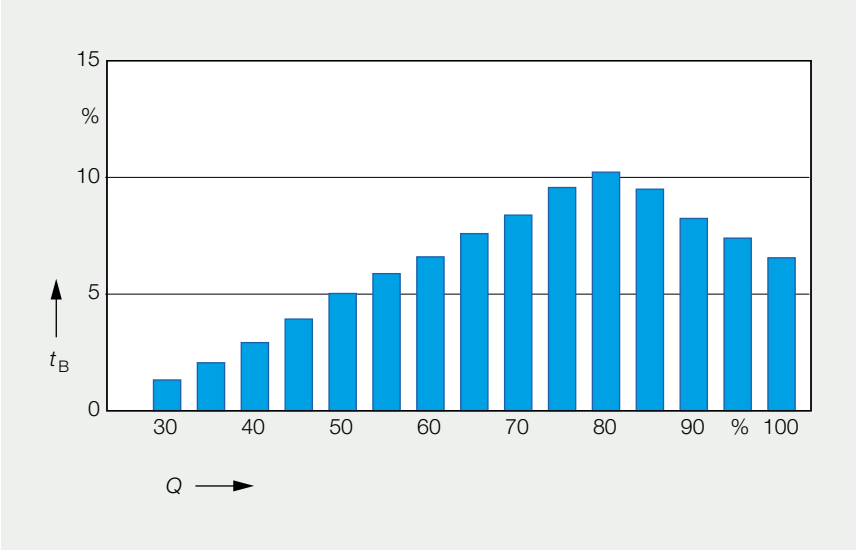
Pay-back in one year through energy saving

The capacity of a screw compressor running at constant speed is normally

Sound level L_p versus relative capacity Q for a conventional screw compressor (blue) and a compressor with STAL Rotatune (red). The green line shows the average sound level. **6**

Relative power consumption N versus relative capacity Q for a conventional screw compressor (blue) and a compressor with STAL Rotatune (red). The new drive system offers better efficiency, especially at part load. **7**





Typical load profile for a compressor: running hours t_B (in percent) at different capacity values Q **8**

controlled by a system of valves and some form of flow control (eg, a bypass). Energy losses are therefore inevitable.

With STAL Rotatune, such arrangements are unnecessary and the compressor's full load capacity can be utilized over the entire speed range. This saves energy, especially when the refrigeration system is operating at reduced capacity **7**. If, in addition, the compressor is connected to an economizer, the increased specific capacity can be utilized in every operating situation.

Calculations show that, in a refrigeration system with normal load profile **8**, it is realistic to expect energy savings of 10 to 17 percent with the new drive system. Assuming a 100-kW motor and 6,000 hours of operation a year, the annual saving will be about 50,000 kWh. Depending on local electricity prices, investment in the STAL Rotatune could pay for itself in less than a year.

In addition, the power consumption of a screw compressor with the STAL Rotatune drive is lower than that of a reciprocating compressor, even at part load. Finally, more precise temperature control is possible with STAL Rotatune than with conventional equipment.

Liquid chiller in a Swedish district cooling system. The unit includes a type FV 26 STAL Rotatune for precise adaptation of capacity to the system load. **9**

A screw compressor installation for freezing fruit at a Spanish food producer. Capacity control of the plant is provided by a type FV 19 STAL Rotatune unit with economizer. 10

Designed to be versatile

The new STAL Rotatune concept offers the most efficient capacity control for refrigeration systems available on the market. By replacing conventional methods of capacity control by stepless speed control, an optimum volume ratio can be obtained without energy losses, even at part load.

The STAL Rotatune system is ideal for all small and medium-size installations where the load varies over time. The drive system also has advantages for capacity control in large multicompressor installations, where it can be used to drive one or two compressors. In such cases, the other compressors are run only at maximum capacity when in operation. STAL Rotatune can therefore help refrigeration systems in large installations to adapt to load variations while maintaining maximum efficiency.

STAL Rotatune is also designed for use with the Stalectronic 700 microprocessor-based controller. This can be used for sequence control and monitoring of up to eight compressors. An important feature is the system's user-friendly man-machine communication.

The STAL Rotatune drive is currently available for three screw compressor sizes 1, 9, 10 *(Table 1)*. As mentioned, the motors are specially designed for operation with a frequency converter.

Low life-cycle costs

The elimination of mechanical control equipment means that screw compressors with a STAL Rotatune drive have considerably fewer moving parts than compressors with a conventional drive system. This feature, together with the soft starting and stopping, increases reliability and reduces wear.

The high efficiency and availability offered by STAL Rotatune satisfy the key refrigeration market requirements. ABB Refrigeration's after-market organization and a wide range of services that include service contracts and an emergency hot-line, ensure that these qualities can be maintained year after year, keeping life-cycle costs for customers to a minimum.

Table 1:
Available sizes of screw compressor with the STAL Rotatune drive system

Size	Max. capacity m^3/h	Motor rating kW
FV 19	400	90
FV 24	660	145
FV 26	925	225

Reference

[1] T. Asplund, L. Rolfsman: New refrigeration compressors – energy-efficient and environmentally sound. ABB Review 9/95, 10–14.

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