Energy Efficiency for Machines: the smart choice for the motorization

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Make the most of your energy

Schneider Electric

Summary

Executive Summary I

Forward III

The AC motor 1

Constitution 1

Operation and limitations 1

The synchronous motor 3

Constitution 3

Operation 3

Motors comparison 5

Application example 7

Airport luggage carrier 7

Conclusion 9

Executive summary

Industry and infrastructures consume more than 31% of the available energy and electrical motors, alone, represent more than 60% of this.

Fossil energy is phasing out, leading inexorably to a cost increase. Smart use electricity is a major concern for users and manufacturers.

When decision is made to acquire a new machine, investor should consider the amount of energy which will be consumed by this machine during its lifespan. Among expenses from the acquisition to dismantling, the purchase price accounts for 2 to 3% of the overall costs, the remainder being, mainly, the energy consumption .

This energy is necessarily charged to the end product and impacts the competitiveness of the company.

Smarts solutions exist to make the most of the available energy.

- enhance machine efficiency,
- choose an operating mode allowing to switch off an unloaded machine (example stop a conveyor),
- use variable speed drive,
- choose less energy demanding strategies of movements,
- use high efficiency motors.

Forward

Any machine is designed according to performance criteria and productivity. The goals of the engineer is to find the most efficient, economic and competitive solutions.

Motors selection is the result of these choices.

Generally, it is finalised when the mechanical part is mainly defined and the power consumption on the long run is not always taken into account.

However, the growing cost of energy imposes new strategies. The choice of the motor should be the starting point of any reflection in order to reduce the power demand.

Considering the mechanical requests, the motors which will equip the machine must answer several criteria.

First, they allow machine continuous operation and provide the needed torque at the rated speed. This first consideration determines the motor size. The designer must also take in consideration the motor torque requested to start the machine. Eventually, the motor may have to be oversized.

Duty cycle is also a key point. Any time the machine is started, there is a motor heating and it is essential not to exceed a limit which, at last, will end with the failure of the motor.

The ultimate decision is based on the environmental conditions and will take into account the temperature and the altitude at which the machine is due to operate.

When all these evaluations are made, the selected motor is usually larger that necessary for continuous operation. As the motor is not running at its rated power, its efficiency is reduced. That inevitably leads to increased energy consumption. Due to motor and machine efficiency, part of this energy is simply wasted.

In order to save fossil resources, European Union stated that in 2020, all motors in the field must be EFF1, in other words High Efficiency Motors.

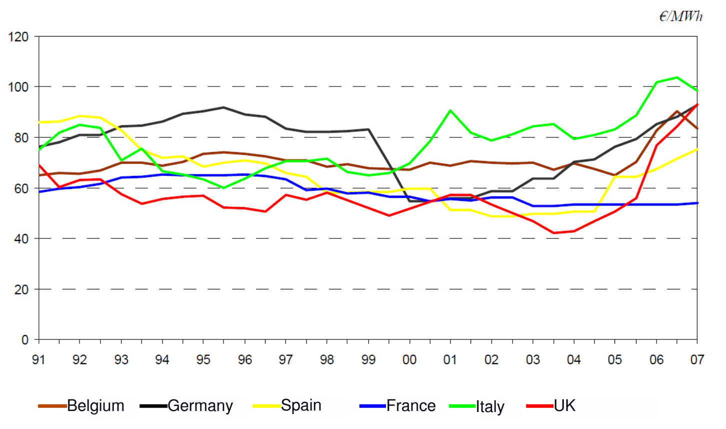
With the use of high efficiency motors and already available solutions, in Europe alone, energy savings could reach 202 TWh per year.

This represents 45 nuclear power plants in the 1000 MW range, or 130 power stations using fuel or 3,8 times the totality of the energy produced by wind farms (value 2007).

Effects on environment can be estimated to 79 million tons of CO_2 reduction and a drastic reduction of nitrogen and sulfur oxides.

Introduction

On the expense point of view, curves of the energy cost (graphs opposite from the Observatory of Energy according to Eurostat - January 2007) clearly show a continuous growth from 2004.



Depletion of fossil energy reserves will do nothing but accentuate this growth.

Motor choice is a paramount for energy savings.

Part of the energy taken from the network is wasted in heating. According to the technology of the selected motor, these losses are more or less important. They also vary between suppliers and a comparison is essential.

AC motor is quite usual on many machines. This motor is designed to operate at a constant speed. However electronic drives used with this motor, improve the flexibility of the machines.

The synchronous motor is another extremely interesting solution.

The goal of this White Paper is to compare these two technologies, estimate the limits and give information to the designer and the user in order to make a smart choice.

For this comparison, the two motors are fed through an Altivar 32 variable speed drive (VSD)

Use of a VSD eliminates most of AC motor weaknesses :

- inrush current,
- power-factor (cosine φ),
- effects of voltage fluctuations on motor torque,
- speed drop when the motor supplied through a flux vector control VSD,
- unloaded current.

*

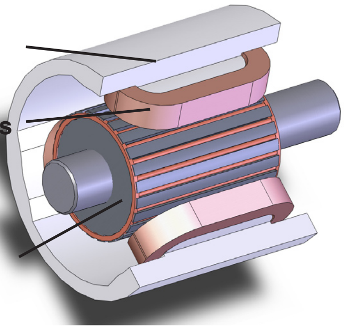
The smart choice
for the motorisation

The AC motor

Constitution

The components of an asynchronous or induction motor, commonly named AC motor or squirrel cage motor, are a stator made of magnetic material with embedded polyphase windings and a rotor also built of magnetic material, in which conductor in short-circuit are located.

The following very simplified drawing illustrates the constitution of this motor.



Operation and limitations

In spite of the manufacturer's efforts, AC motor has, by design, physical limitations impossible to circumvent.

Today, class EFF1 reaches the limit of what can be done in an economic way. If improvements are still possible, they will probably be extremely tiny.

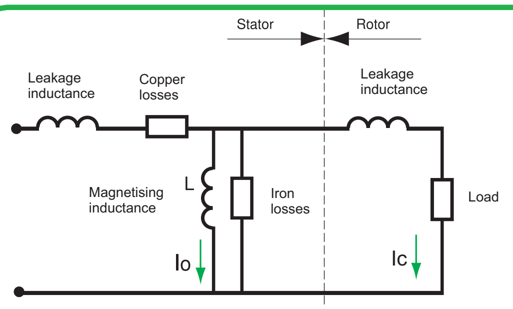
Limits are linked to the very principle of this motor. We will analyze those which remain when an AC motor is supplied from a drive in order to compare with more promising and now available solutions.

FIRST LIMIT: GENERATION OF THE MAGNETIC FIELD AND CONSEQUENCES

As for any electrical motor, torque generation is linked to the existence of a magnetic flux in the machine.

This flux noted ϕ is produced by the stator windings which, when they are connected to a polyphase alternating network, create a rotating field.

We will study what occurs in a theoretical machine represented by the following diagram.



If we neglect the windings resistance, we see that the voltage applied to the magnetizing coil noted L creates a current named I_0.

Flux expression is

$$\phi = kI_0$$

Inevitably, this magnetising current creates iron losses.

Output power is represented by the voltage across an imaginary resistance which simulates the load. Noting Ic the current in this resistance, torque can be written.

$$T = kI_0 \, I_c$$

We immediately see that if the supply voltage decreases, flux and current Ic decrease

The AC motor

simultaneously in the same ratio and that torque varies like the square of voltage. Use of a drive which controls this voltage allows to eliminate this weakness.

SECOND LIMIT : SLIP

Current induced in the rotor is the origin of torque. This current is the result of Lenz's law which says «An induced current is always in such a direction as to oppose the motion or change causing it"

Magnitude of this current, which is a function of difference between the rotating field and the rotor RPM, creates torque. This difference is called "slip" (S) and is expressed in % the speed of synchronism.

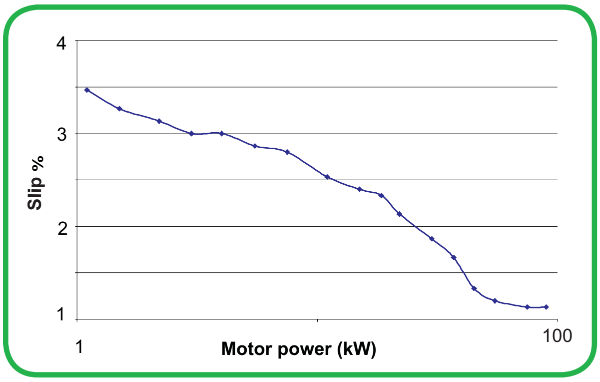
g = [(Ns - N) / Ns] x 100

In no case, slip cannot be equal to zero, because there would be no induced current and, as a consequence, no torque .

Slip is a "necessary evil" generating unwanted losses.

Special care used to manufacture the motor allows a slip reduction, but it is impossible to cancel it. It varies from 4% to a little more than 1%.

Diagram which follows represents slip for EFF1 (high efficiency motors) from 1 to 90kW.



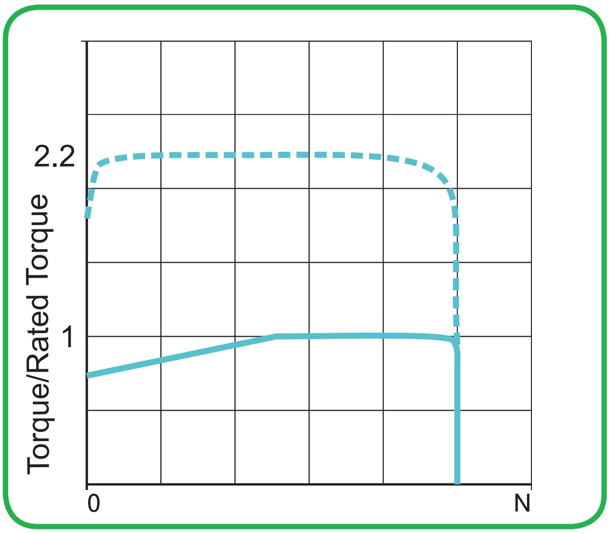
THIRD LIMIT: MAXIMUM AVAILABLE TORQUE

AC motors have limited torque performance.

Following diagram represents the characteristic of an AC motor associated with a drive.

Curve in dotted lines is the transitory available torque . This value (approximately 2,2 times motor nominal torque) is a limit imposed by the motor and not by the drive. This extra torque allows to move inertia of the machine and overcome static frictions, but it is obvious that the dynamic speed performance is weak.

Permanent torque, plain line, is limited at low speed by motor losses and inefficient motor cooling.

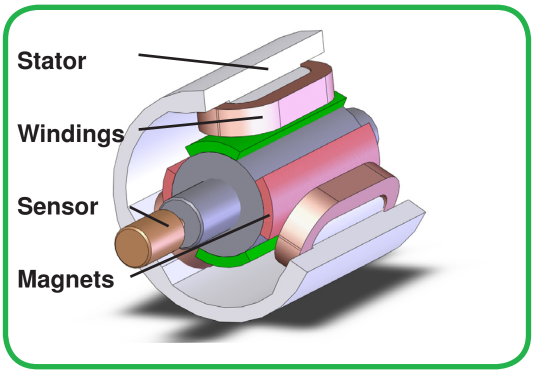


The synchronous motor

Constitution

The synchronous motor is another solution for low range power. As an AC motor, parts are a stator and a rotor separated by an air-gap.

The very simplified drawing, which follows, represents such a motor.



The stator has an embedded three-phase winding.

The rotor, made of magnetic material, carries permanent magnets North poles and S poles represented in green and red.

Synchronous motor is connected to a an electronic drive which ensures the servo control. This is why we represented a sensor connected to the shaft .

The principle of this control exceeds the framework of this document and we encourage readers to consult publications as “Automation Solution Guide” from Schneider Electric or “Motion Control” from Gimelec for further information.

Suitably fed, it does not present any limitation of AC motor.

Operation

MAGNETIC FIELD GENERATION AND CONSEQUENCES

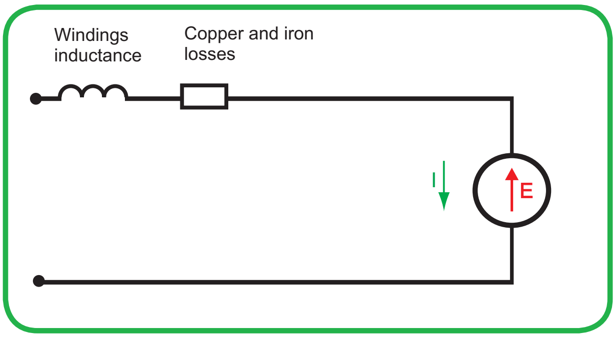
Flux in the air-gap is not due to a component of the stator current, but to permanent magnets placed onto the rotorwhich produces a constant flux.

With the use of rare earth magnets made of neodymium or samarium material, high value of flux can obtained in a reduced volume, therefore very compact motors.

Toque has as the general expression: $T=kI\phi$

There are neither magnetizing current nor related losses.

The synchronous motor can be represented as follow :



E is a image of the electromotive force of the machine which depends on flux, created by the magnets and the number of revolutions ω.

Power can be written: :

$P=EI = k\phi\omega$

The synchronous motor

GENERATION OF ELECTROMAGNETIC TORQUE

Opposite to AC motor, electromagnetic torque does not depend any more on a current induced in the rotor.

The permanent field created by the magnets is aligned with the rotating field created by the stator. The torque is generated by the angular shift between rotating field position of and that of the rotor.

Rotor, unlike AC motor, thus turns without slip, at the speed of the rotating field creates by the stator.

There is neither loss nor heating within the rotor. There is no risk of expansion and the air-gap can be reduced, which is beneficial to the torque developed by the motor.

CURRENT DRAWN

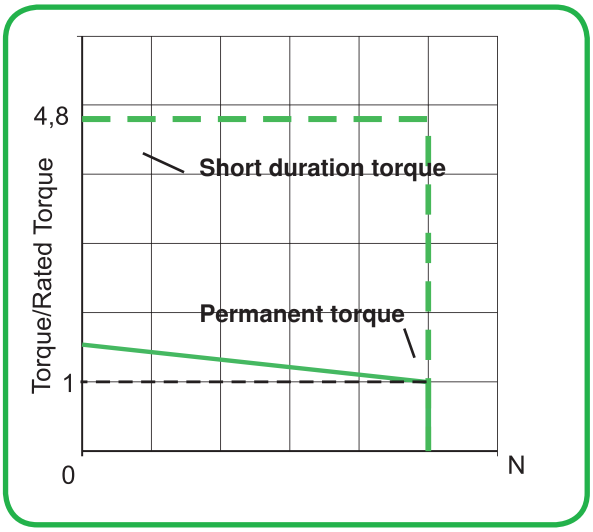
Current drawn is only that necessary to generate power times efficiency.

For the same size, there are neither losses related to slip nor of additional losses due to magnetizing current, so a a synchronous motor draws a current appreciably lower than an AC motor.

AVAILABLE STARTING AND MAXIMUM TORQUE

Flux of synchronous motor being completely independent of the supply voltage, torque characteristic is clearly improved.

Curve which follows is that of a BMH1003P motor from Schneider Electric connected to its servo controller.

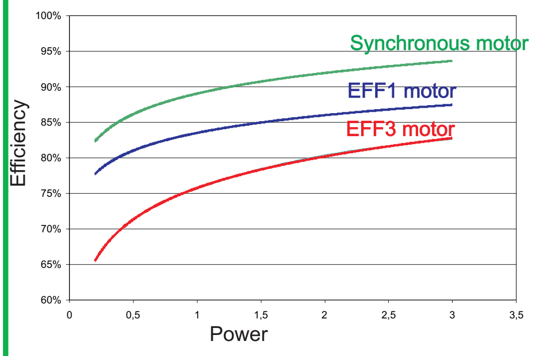


Its nominal torque is 5,2 Nm at 3000 rpm which produces 1.6kW.

Intermittent torque, usable for starting and stopping is 4,8 times nominal rating.

Motors comparison

Taking into account the absence of slip and a nominal current lower for a same power, synchronous motor outperforms the efficiency of EFF1 AC motor , as illustrated on the following graph :



Part of AC motor weakness disappears, in particular the power-factor.

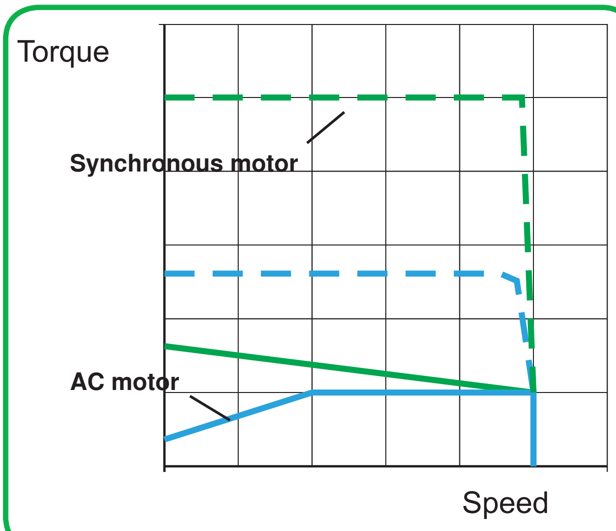
Nevertheless, the available maximum torque is seldom higher than twice nominal torque and continuous operation at low speed is impossible because of the heating of the motor.

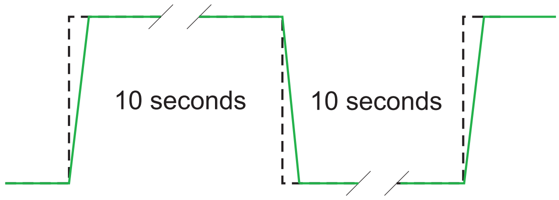
Intermittent torque of the synchronous motor is definitely much higher, which leads to faster accelerations and decelerations.

To emphasize this characteristic, we took the example of a machine running according to the cycle reproduced below.

Current VSD's equipped with flux vector control, like an Altivar 32 from Schneider Electric, allow to use an AC motor or a synchronous motor for more and more complex applications and for large speed range.

The diagram which follows represents at the same scale the performances of two similar size motor.





Characteristics of the machine are as follow::

- resistive torque 1,3 Nm,
- motor speed Rpm 3000 rpm,
- load inertia at the motor shaft is 5 1 04 m ² kg.

With these data, the requested power is 408 W.

Taking into account the duty cycle, in our example 0,5, we can choose a motor rated 350 W.

Motors comparison

We have two possible choices: a synchronous motor or AC motor. Our objective is to obtain virtually identical dynamic performances.

The synchronous motor, BMHH0701P, is selected in the Lexium range. It can be associated with an ATV 32H037N4 VSD for speed control or a servo drive for position control LXM32•U60N4.

Its principal characteristics are as follow

Rated torque	1,1 Nm
Peak torque	4,2 Nm
Rated power	350 W
Reted speed	3000 rpm
Inertia	3,2 10 $^{-4}$ kg m²
Weight	1,6 kg

Calculated performances are shown in the table below:

Acceleration time	88 ms
Deceleration time	47 ms
Braking energy	40 joules

Trying to obtain identical dynamic performances, we must choose an AC motor allowing to develop a peak torque of at least 4,2 Nm when connected to a VSD. Inevitably, the increase of inertia leads to oversize the motor. We find in the Leroy Somer catalogue a motor (LS EL 80 L) which could be suitable. Connected to a VSD, its maximum torque will be approximately 8 Nm.

Its principal characteristics are as follow

Rated torque	3,7 Nm
Peak torque	8 Nm
Rated power	1,1 kW
Reted speed	2877 rpm
Inertia	11 10 $^{-4}$ kg m²
Weight	11,3 kg

Calculated performances are shown in the following table:

Acceleration time	75 ms
Deceleration time	54 ms
Braking energy	79 joules

In the real life, this acceleration time will be a little longer because this evaluation does not take into account the time to establish the flux in the machine nor the torque reduction as it will be mandatory to run the motor at 52 Hz to obtain 3000 rpm.

We can consider that our objective of performance is achieved.

We will consider that braking energy is entirety dissipated in a braking resistor.

In addition to this comparison, the AC motor functions at little less than 25% its rated power. and efficiency is approximately 63%.

With a VSD, efficiency is less than 60%.

On the other hand, the efficiency of the synchronous motor and itsdrivewill be higher than 88%.

Benefit of the synchronous motor is obvious. The table below shows the ratios AC motor/ synchronous motor.

Power increase	314%
Weight increase	706%
Losses increase	197 %
Efficiency deterioration	-31%

Foot-note, efficiency deterioration does not take into account wasted braking energy.

Application example

Airport luggage carrier

DESCRIPTION

Such a conveyor is used in airport to move luggage onto a conveyor belt running continuously behind the counters.

While booking passengers and their luggage, conveyor is at rest. Then it is energized to move luggage onto the conveying belt running in the background.

Operation is by nature discontinuous with variable loads from few hundreds grams to 50 kg.

Stop must be as repetitive and accurate as possible whatever load weighs.

To ensure a correct operation, the manufacturer (Crisplant A/S Denmark) uses an AC motor connected to a VSD.

The machine is controlled by a PLC which manages the various position encoders and transmits speed settings to the drive.

The current solution does not give entirely satisfaction as starting and stopping of the conveyor vary appreciably between no load and full load.

MANUFACTURER OBJECTIVES

Manufacturer wishes to carry out on a testing machine a comparison between synchronous and AC motor without changing the drive.

The goal is to check energy consumption of and the repeatability of stoppage with no load and full load.

HARDWARE

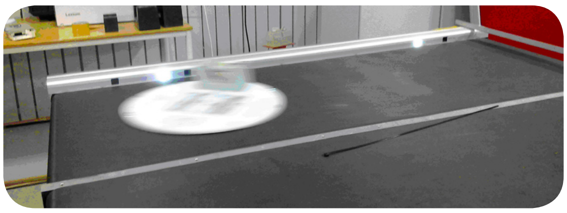
Hardware is supplied by Schneider Electric.

The characteristics of the components are indicated in the following table :

Motor	BMH1402P06A1A
Inertia	$3\ 10^{-4}$ m² kg
Rated power	4 kW
Voltage	460 V
Rated current	9,8 A
Rated speed	3500 rpm
VSD	ATV32BHU40N4

TESTING BENCH

Test is performed on a bench, reproducing accurately actual operation.



Te load on the conveyer is adjustable up to 50 kg.

Conveyer is accelerated to 67 Hz (3500 rpm) then stopped.

Motion is carried out in the two directions of displacement, back and forth, with and without a load.

Application example

TEST PROCEDURE

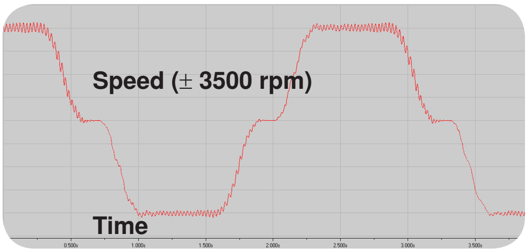
After introduction the motor parameters, VSD auto tuning is performed which allows to obtain fast and adapted adjustments.

Records which follow represent the machine speed as a function of time.

No-load test :

One notes a slight oscillation speed without noticeable effect on the conveyor displacement.

Stop precision, which is one of the key points, stays within ± 1mm

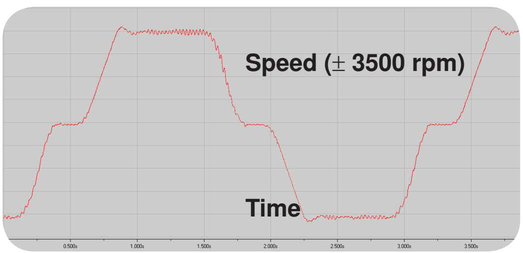


Test with a 50kg. load

Oscillation is very well damped, acceleration and deceleration slopes are identical between no load and full load conditions.

One notes a light overshoot perfectly acceptable for the operation.

Stop precision is within ± 2mm. This difference is insignificant for this application.



There is no doubt that use of an dedicated servo drive like Lexium32 ensuring a synchronous motor servo control would have given definitely better positionning accuracy, but the customer requirements are fullfilled.

ENERGY SAVING

Following data were given by the conveyor manufacturer.

Records have been made with two similar conveyors, one been driven by a synchronous motor, the other one by an AC motor.

Motor sizes are identical (1,5 kw.).

Operating conditions	Synchronous	AC motor	Savings
Running continuously in one direction	320W	450W	29%
No load	240 W	340W	29%
10 kg	280W	390W	28%
30 kg	370W	520W	29%
50 kg	460W	640W	28%

Records highlight a significant energy saving in favour of the synchronous motor.

Conclusion

In this White Paper, we only cover the efficiency of two motors based solely on technological aspect.

From the preceding second example, it appears that the replacement of a 1,5 kw AC motor of by a synchronous motor of an identical size is able to generate nearly 30% of energy saving.

This savings, alone, allows a fast return on investment.

In complement, with the use of a dedicated controller, dynamic performances would have been clearly improved.

We made the choice not to not evoke other solution to improve savings which, according to the applications, can be obtained by strategies of command or calculations of trajectories involving shorter operation.

These processes allow to increase the productivity and reduce production, time which, by a domino effect, are beneficial to the manufacturing chain as a whole.

A closer examination of the machine, its modes of operation and dynamic performances is the best way to choose the most suitable motor technology

Use of synchronous motor allows to ,with higher dynamic performances, generate, at least, 20% of energy saving.

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