Energy efficiency optimization of a dust extractor: An industrial case study

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Abstract

The Eco-design directive published by the European Union aims at 34TWh of annual savings with industrial fans by the year 2020. This is about 10% of the total saving aim of 366TWh. Electric motors are still responsible for over 40% of the planned savings with 135TWh of annual savings by 2020.

These aims are translated into European directives to guide the market towards more energy efficient systems. An evolution within those regulations is the fact that directives are not only focusing on one particular part in the drive system (e.g. the induction motor), but consider the entire system with all its parts to rise the overall system energy efficiency. Examples of this total system approach are the latest EU directives on circulator pumps [1] [2], air conditioning systems [3], domestic comfort fans [3] and industrial fans [4].

This system approach demands a thorough analysis of all the different parts of the drive system in order to make a sound technical and economical choice on which part to invest to rise the overall system efficiency.

This paper describes a practical case study carried out on an industrial dust extractor in preparation of a new research project proposal in which o.a. the EU-directive 327/2011 [4] will be investigated. The different drive parts were analyzed based on their efficiency and replaced if technically and economically feasible. Research and test bench results of previous and on-going research projects on energy efficiency were used to predict the potential savings. At each step energy consumption measurements were carried out before and after to validate the estimated savings.

Measurement procedure

The case consists of an industrial dust extractor used to extract dust from shearing carpets. The axial fan has backward placed fins and is driven by 3xSPB2000 V-belts connected with a ratio of 1/1.47 (fan runs faster) to a 30kW, 4 pole induction motor with no indicated efficiency class. Taking into account the age of the setup, the efficiency class can be Eff3 or even lower (Figure 1).

![Figure 1: Original test setup: industrial fan](image)

The optimization procedure was carried out in different sequential steps. Before and after each step an electric energy measurement on grid side with suitable power measurement devices was done to quantify the improvement. Because at some steps rather small improvements were expected, an energy logging was done during several days at each step in order to detect even small efficiency improvements.
The following steps were taken during the measurement procedure:

1. Reference energy logging no.1
2. Maintenance: belt tension / pulley alignment / greasing
3. Energy logging no.2
4. Redimensioning and implementing new electric motor
5. Energy logging no.3
6. Implementing speed control and optimizing speed
7. Energy logging no.4
8. Maintenance: cleaning air ducts and fan
9. Energy logging no.5
10. Redimensioning drive train: implementing direct drive principle
11. Energy logging no.6

A general remark regarding drawing conclusions on energy efficiency improvements for these kinds of practical cases is the need for a continuous load during the tests. If the production process results in a non-continuous load, it is quite difficult to draw closing conclusions on energy efficiency improvements. If this is the case, tests under controlled conditions in a lab on a test bench can help to confirm practical measurements. In this particular case, measurements have shown that the load could be considered as quite continuous, but even then some steps in the optimization procedure are based on previous laboratory tests in our facilities.

Step 1: Reference energy logging no.1

A first reference energy logging was carried out during about 170h. This measurement gave an average active power drawn by the motor from the grid of 19.38 kW. (Figure 2) This result was found after eliminating all the standstills during the test. Furthermore, it can be noticed that the load can be considered to be quite stable, which is a prerequisite to draw closing conclusions on further improvement steps.

![Figure 2: Reference energy logging no. 1](image)

Step 2: Maintenance

In this step the effect of some maintenance activities on the energy efficiency was investigated. One of the goals of this step was to determine the effect of applying a correct belt tension and pulley alignment during maintenance activities. In the past, this was checked completely manually every 3 months,
without using some adequate equipment. In this step, the correct belt frequency was calculated and applied using an optical belt frequency measurement device and the pulley alignment was checked using laser equipment (Figure 3). Also the bearings of the drive shaft were greased.

![Figure 3: Pulley alignment and checking belt tension using adequate equipment](image)

Although the belt tension was checked manually in the past (just by “feeling” the tension), this test showed the belt frequency was nearly perfect. The calculated belt frequency was 39.07Hz. Before the maintenance a belt frequency was measured of 38Hz in average. This is mainly due to the experience of the maintenance personnel in the company. The pulley misalignment was about 5mm before maintenance and was corrected using the laser equipment device.

**Step 3: Energy logging no. 2**

A new measurement was started for about 170h and after filtering standstills and startups out of the results a reduction of 0.05% in average active power was measured. Taking into account the measurement errors this can be considered as negligible. This result was within the expectations regarding the rather small adjustments, which had been made during the maintenance activities.

**Step 4: Redimensioning electric motor**

Based upon the energy measurements one can conclude that the induction motor of 30kW is over dimensioned for the driven fan. The average measured input power was 19.38kW. This means the motor is loaded for about 60%. Because of the lack of information on the efficiency of the present motor, the efficiency in that working point was very conservatively estimated at 91.1%. This is based on measurements and extrapolations done on a 4pole, 15kW IE1 induction machine at our test facilities and catalog data.

With an estimated shaft power of 17.7kW (19.38kW x 0.911) the 30kW machine can be replaced by a 22kW IE3 4 pole induction motor which has an efficiency of 93.1% according to the IEC60034-30 [5].

Especially with fan applications, one should take care when replacing older motors by newer, high efficient motors. One of the typical properties of induction motors with a higher efficiency label is the lower slip value compared to older motors due to the lower rotor resistance. Affinity laws claim a cubic relation between speed and power drawn by a centrifugal fan. This can result in considerably higher input power on motor side although the higher efficiency of the motor. In most cases this is not the intention and results in an even higher energy bill in comparison to the situation with the old motor. To take this effect into account, speed was measured before and after the replacement of the motor.

**Step 5: Energy logging no. 3**

After implementing the new 22kW IE3 4 pole motor a new energy logging resulted in an average active power of 17.3kW. In comparison to the 19.4kW before this is a reduction of about 11%. This result
shows the estimated 2% (93.1% - 91.1%) was indeed very conservative. The reason for this high energy gain can be found in several points:

- Estimations were made based upon measurements done on an IE1 induction machine in our lab which can be more or less compared to the old Eff2 efficiency class. Regarding the fact there was no information on the efficiency on the nameplate, it is very likely to assume the efficiency class of the old motor was even far below the old Eff3 efficiency class.

- The old motor was only loaded for 60%, which has a negative impact on the efficiency of the motor in that working point. The new motor is now loaded for about 75%. Measurements in our test lab show the efficiency often tends to maximize in that point [6] (Figure 4).

- The effect of a changed speed has to be considered too because of the cubic relation between power drawn and speed of a centrifugal fan. A speed measurement was done before the replacement and resulted in 1486 rpm. After installing the new 22kW the speed dropped slightly to 1482 rpm. Taking into account the cubic relation this results in a reduction of power drawn at grid side of about 1%.

Conclusion at this point is that the reduction in active input power of 11% due to the replacement of the 30kW motor is mainly due to the higher efficiency of the 22kW motor in it’s working point (+10%). Considering the total installation costs for the new motor, an energy price of 0.09 €/kWh and about 5800 working hours per year this investment has a payback of less than 1 year with a yearly saving potential of about €1000 per installed fan.

**Figure 4: 4kW motor and overall (motor-drive) efficiency at DOL and VSD operation with maximum efficiency typically reached around 75% [6].**

**Step 6 & 7: Implementing speed control**

When it comes to centrifugal loads, the step towards speed control to reduce the energy cost is often obvious. Again, because of the cubic relation between speed and power drawn, even a small drop in speed can result in substantially lower input power. Of course the quadratic relation between speed and pressure has to be considered regarding the fact the fan is used to extract dust for a shearing machine.

A speed control was implemented on the new 22kW motor and several speed setpoints were tested during a long time to ensure the dust was still sufficiently extracted from the shearing machine.
In a first trial, frequency was drastically dropped to 30Hz. In this case, according to the affinity laws, the input power theoretically drops to about 20% of the initial value. Very soon there was a visible loss of quality at this low speed so speed had to been increased again (Figure 5).

![Visible quality loss of the dust extraction performance of the fan at 30 Hz](image)

**Figure 5: Visible quality loss of the dust extraction performance of the fan at 30 Hz**

The frequency was then increased to 39Hz. Measurements show a reduction of measured input power of 50%, but this also resulted in a quality loss after a few hours. With a frequency of 45Hz, the input power dropped 20% in comparison to the DOL situation, but again there was a little quality loss after a few days (Figure 6).

![Average active power drawn by the motor fan at 39Hz and 45Hz](image)

**Figure 6: Average active power drawn by the motor fan at 39Hz and 45Hz**

Eventually, in consultation with the company, the frequency was set at 48Hz for this motor without any visible quality loss so far. The resulting average input power was now 15.9kW which is still a reduction of 8% in comparison to the DOL-situation of 17.3kW in step 5. This does not entirely match the theoretical affinity laws, which predicts a reduction of 11.5% with a pure centrifugal load.

When integrating a speed regulating drive into the system one should take into account the drive itself is responsible for an extra loss in energy efficiency of 2 to 3%. But even then this step in the optimization
process confirms again that speed control, especially at quadratic load profiles such as fans, is often a very energy saving solution, even for small reduction in fan speed.

Considering the total installation costs for the new drive, an energy price of 0.09 €/kWh and about 5800 working hours per year this investment has a payback of about 1.5 year with a yearly saving potential of about €730 per installed fan.

**Step 8 & 9: Maintenance: cleaning air ducts**

Prior to this step, the drive was removed from the system again so the fan motor operated again DOL.

The dust which is extracted from the shearing machine has the tendency to stick very easily to the side of the air ducts due to lubrication oil present in the dust. Every six months all the air ducts in the system and the fan itself are cleaned. The dust reduces in some cases the opening in the air duct by more than 50%. Measurements before and after the cleaning of the air ducts were performed to determine the effect on the overall energy performance.

After cleaning the installation and performing a new energy measurement during several days, the average active power was 18.7kW which is a rise of 1.4kW in comparison to the DOL operation before the cleaning.

This is a typical phenomenon which is sometimes underestimated in industry. Because of the cleaned system, a new working point becomes active in the system curve with a higher pressure drop and a higher flow. This also means the fan needs more power at the shaft side (Figure 7). Of course in most cases the higher flow is not needed because the installation was working fine before the cleaning and in fact we now have an installation which is over dimensioned.

![Figure 7: Typical fan characteristics [BEE India, 2004]](image)

This confirms again the need for a drive to regulate the speed of the fan according to the system demands. The fan speed can automatically be adapted using a flow sensor in the air ducts as feedback for the speed control of the system.
Step 10: Redimensioning the drive train

At this point in the process, the entire drive train concept is questioned and the possibility of leaving out the belt drive concept is considered (Figure 9). Using input information of measurements done at our facilities, the possible impact on the efficiency was estimated.

In the original set up, the fan is driven by 3xSPB 2000 V-belts. Using belt calculation software at a service factor of 1.4, the power which can be transmitted with these three belts is 57kW! With an average input power of 16kW after implementing the speed controlled high efficiency motor this means an over dimensioning of more than 70%.

Measurements done at our test lab on a SPA 1682 with a ratio of 0.56 have shown an efficiency of 96% at about 30% of the nominal torque. As can be seen on the iso-efficiency contour, speed has no real impact on the efficiency of the belt [7]. The output torque is the determining factor for the efficiency (Figure 8).

Figure 8: Iso-efficiency contour of 1xSPA 1682 V-belt [7]

By omitting the driving belts, an estimated energy saving of about 4% can be predicted based on these measurements. Also maintenance costs are reduced by leaving out the belts out of the drive train.

Belts are often used at industrial fan installations for mechanical safety reasons. At startup, the belt can shortly slip to reduce the mechanical stress on the drive train. In case of a stalled fan, the belt again can act as a mechanical safety factor. By implementing a drive however, the startup is now established by providing an adapted ramp-up time and a stalled motor will quickly be shut down by the drive itself because of the overload of the output bridge of the drive.
By omitting the belts however, the motor has to turn 1.47 times faster at a speed of about 2178rpm by using the drive. Experience has shown this is not a problem for the motor itself and the mechanical effects on the motor are negligible. On the contrary; measurements done at our test facilities indicate that the overall efficiency of a speed regulated induction motor does not reach maximum efficiency at nominal load and speed, but always around 120% of nominal speed and 60% of nominal load [6](Figure 10). In this case, the motor will run at a speed of 147% of nominal speed and about 66% of nominal torque. Relying on our experience and based on the contour beneath (Figure 10) the efficiency should stay at about the same level as at nominal speed and load.

This last step has not yet been implemented by the publishing date of this paper, but energy logging results of this last step will be presented at the Eemods 2013 conference.

Conclusions

Regulations on energy efficiency tend to evolve to a total system approach to reach a certain minimum overall system efficiency. The EU-directive 327/2011 for industrial fans is an example of such a total system approach. This case was set up as an example to determine the possible measures to rise the overall system efficiency of an industrial fan installation. Regarding the several steps which have been taken during the optimization process, the following conclusions can be made:

1. In this case, maintenance performed on the belts using adequate equipment resulted in a negligible effect on the energy efficiency. The belt tension was already correct and the correction of the misalignment did not result in a change of input power. The cleaning activities on the air ducts and fan however resulted in a higher flow and pressure, but also in a not
intended input power rise of 8% which shows the need for a speed regulated system to adapt the speed to the system condition.

2. Older motors (without any efficiency labeling at all) should be replaced by newer, high efficient alternatives. In this case, an energy saving of 10% was reached with a payback of less than a year. Take care however when replacing the motor to maintain same speed of the fan.

3. Speed regulation has shown again to be an interesting step with industrial fans. Even a small reduction in speed of the fan can result in substantial energy savings because of the affinity laws. In this case an energy saving of 8% was reached by reducing the frequency by 2 Hz. To optimize the savings, a flow sensor feedback has to be installed which controls the speed regulator of the drive.

4. Reconsider the whole drive train. As in many industrial fan applications, belts were used to drive the fan. The applied belts were over dimensioned by 70%. By omitting the belts and drive the shaft of the fan directly using a frequency convertor, an extra 4% in energy savings can be expected in this case. Also, the overall maintenance costs go down by leaving the belts away.

After performing these optimization steps, an overall system efficiency gain was reached of 22% (-24MWh/year). With an average of 5800 working hours a year and an energy price of € 0.09/kWh this equals about €2150 of yearly savings per installed fan in the company and a payback time of around 1 year.
References


