Energy Efficiency in Motor Driven Systems

Shares of electricity consumption in industry (EU-15)

Motor systems account for about 65% of electricity consumption in industry in the European Union
Overview of saving potentials in motor driven systems

<table>
<thead>
<tr>
<th>Measures</th>
<th>economic saving potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improvement of drive by</td>
<td></td>
</tr>
<tr>
<td>- use of high efficiency motors</td>
<td>3 %</td>
</tr>
<tr>
<td>- use of variable speed drives</td>
<td>11 %</td>
</tr>
<tr>
<td>Improvement of the system</td>
<td></td>
</tr>
<tr>
<td>- for compressed air supply</td>
<td>33 %</td>
</tr>
<tr>
<td>- for pump systems</td>
<td>30 %</td>
</tr>
<tr>
<td>- for refrigeration systems</td>
<td>18 %</td>
</tr>
<tr>
<td>- for HVAC and fan systems</td>
<td>25 %</td>
</tr>
<tr>
<td>Motorsystems Total</td>
<td>25-30 %</td>
</tr>
</tbody>
</table>

Many measures are highly economic, as energy costs account for about 80% of the life cycle cost.
Electric Motors

Saving Potentials for drives

<table>
<thead>
<tr>
<th>Measures</th>
<th>Saving Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>System installation or replacement</strong></td>
<td></td>
</tr>
<tr>
<td>high efficiency motors (HEM)</td>
<td>2-8 %</td>
</tr>
<tr>
<td>correct sizing</td>
<td>1-3 %</td>
</tr>
<tr>
<td>energy efficient motor repair</td>
<td>0.5-2%</td>
</tr>
<tr>
<td>variable speed drives</td>
<td>10-50 %</td>
</tr>
<tr>
<td>efficient gear boxes</td>
<td>2-10 %</td>
</tr>
<tr>
<td>quality of power supply</td>
<td>0.5-3 %</td>
</tr>
<tr>
<td><strong>System operation and maintenance</strong></td>
<td></td>
</tr>
<tr>
<td>greacing, adjusting and fine tuning</td>
<td>1-5 %</td>
</tr>
</tbody>
</table>
Improved efficiency of motors

- As smaller the power of the motor as worse is the efficiency of it and hence as larger the saving potential
- Also small improvements for large motors could deliver significant total savings

<table>
<thead>
<tr>
<th>Power (kW)</th>
<th>Cost Savings (€/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 kW</td>
<td>69 €/a</td>
</tr>
<tr>
<td>90 kW</td>
<td>266 €/a</td>
</tr>
</tbody>
</table>

High Efficiency Motors (HEM)

- Efficiency requirements for motors
- Cost savings calculated based on the power of the motor
- Small improvements for large motors yield significant savings.
Share of efficiency classes on motor sales in Europe

Total motor-sales in the scope of the Voluntary Agreement of CEMEP

Comparison of EFF 1 and EFF 2-motors by infrared photographs

EFF 1

EFF 2
Pumps

Mission 6.2: Energy Efficiency

Energy efficiency of pump systems

(a) STANDARD MOTOR (Efficiency=90%)  COUPLING (Efficiency=90%)  PUMP (Efficiency=77%)  PIPE (Efficiency=90%)

(b) VARIABLE-SPEED DRIVE (Efficiency=90%)  ENERGY EFFICIENT MOTOR (Efficiency=90%)  COUPLING (Efficiency=90%)  MOST EFFICIENT PUMP (Efficiency=90%)  LOW-FRICTION PIPE (Efficiency=90%)
Energy Saving Potentials in Pump Systems

<table>
<thead>
<tr>
<th>Measure</th>
<th>Saving potential [%-points]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction of surface roughness</td>
<td>10 %</td>
</tr>
<tr>
<td>Reduction of internal leakage (gap losses)</td>
<td>6 %</td>
</tr>
<tr>
<td>Optimised geometry of impellers</td>
<td>3%</td>
</tr>
</tbody>
</table>

### Pumpsystem

**Measure** | **Energy Saving Potential Systems (EEP)** | **Possible Market uptake (MDD)** | **Efficiency factor (1 - EEP*MDD)** |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>speed control</td>
<td>70 %</td>
<td>20 %</td>
<td>86.0 %</td>
</tr>
<tr>
<td>operating hours</td>
<td>10 %</td>
<td>15 %</td>
<td>98.5 %</td>
</tr>
<tr>
<td>high efficiency motors</td>
<td>4 %</td>
<td>40 %</td>
<td>98.4 %</td>
</tr>
<tr>
<td>system design</td>
<td>15 %</td>
<td>4 %</td>
<td>99.2 %</td>
</tr>
<tr>
<td>reduced pressure losses in the pipework</td>
<td>8 %</td>
<td>15 %</td>
<td>98.8 %</td>
</tr>
</tbody>
</table>

\[
\prod_{n=1}^{i} (1 - EEP_{n} \cdot MDD_{n}) = 81.9 \%
\]

Energy Saving Potential

\[
1 - \prod_{n=1}^{i} (1 - EEP_{n} \cdot MDD_{n}) = 18.1 \%
\]

### Energy Saving with Pumps

- Pumps often work away from their best efficiency Point (BEP) based on
  - Over dimensioning during planning
  - Changes compared to design conditions
  - Significant reduction of efficiency of the pump
  - Changed volume flows

- Aging of pumps:
  - Loss of efficiency by 10 to 15 %-points based on poor maintenance
Maximum efficiency improvement by surface smoothening

Surface roughness before smoothing: 
\( k_s = 0.4 \text{ mm} \)

- whole pump: \( < 20\% \)
- whole impeller
- volute: \( < 5\% \)
- casing: \( < 5\% \)
- outer surface: \( < 7\% \)
- inner surface: \( < 5\% \)

The specified values of efficiency gain are per cent points.

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Peter Radgen, Dr., STE
Fraunhofer Institute System and Innovation Research, Karlsruhe
Ljubljana, 13-15 March 2006

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Fans
### Industrial Fans

- **Fan for steel works**
- **Mine ventilation fan**
- **Induced draught fan for 600 MW Power station**
- **Fan for sinter plant**

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### Building Ventilation

- Diagrams and images of building ventilation systems.
Distribution of electricity consumption for fans by motor size (SIC 20-39 Overall Manufacturing)


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Energy flow in a fan system

\[ \eta = \frac{\text{useful fan energy}}{\text{energy input}} = 54\% \]

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Fan Electricity Consumption in the European Union (EU-15)

Total consumption 197 TWh

Fan Electricity Consumption by Sector

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Ljubljana, 13-15 March 2006
Emission and Cost Savings

- Electricity saving potential totals 43.2 TWh per year
- Overall emission reduction is 18.8 Million Tones of CO₂ per year
- Overall cost savings are about 1.7 to 3.5 Billion Euro per year

Electricity consumption for fan systems in the EU-15 by sector up to 2020

• BAU (Business As Usual) no measures and improvements are implemented
  • IA (Improved Awareness) only technical improvements at fan will be implemented
• GT (Global Thinking) technical measures and system measures will be fully implemented
Factors Influencing Fan System Efficiency

- Difference between peak and low efficiency of a fan can be up to 30%.
- Small differences in fan peak efficiency are of much less importance than the poor matching between the fan and the system.
- The fan has to be correctly designed, but all the effort in correctly designing a fan can be wasted, if all the other steps of the choice/design procedure are not carefully examined. Specifically:
  - The fan operating point must be properly selected on its characteristic curve
  - The fan and the system have to be properly matched
  - The system has to be correctly designed to reduce as much as possible energy requirements and energy losses
  - The system has to be properly installed
  - The regulation system should be selected to limit energy losses

Energy saving potentials and additional costs for fans

<table>
<thead>
<tr>
<th>Fan type</th>
<th>Efficiency gain</th>
<th>Additional cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propeller fans</td>
<td>15 – 20 %</td>
<td>2 – 12 %</td>
</tr>
<tr>
<td>Tube-axial</td>
<td>2 – 10 %</td>
<td>4 – 10 %</td>
</tr>
<tr>
<td>Jet fans</td>
<td>4 – 8 %</td>
<td>5 – 7 %</td>
</tr>
<tr>
<td>Forward curved</td>
<td>5 – 15 %</td>
<td>7 – 10 %</td>
</tr>
<tr>
<td>Radial tip</td>
<td>10 %</td>
<td>6 – 10 %</td>
</tr>
<tr>
<td>Backward curved</td>
<td>2 – 5 %</td>
<td>8 – 12 %</td>
</tr>
<tr>
<td>Radial fans</td>
<td>5 %</td>
<td>4 – 7 %</td>
</tr>
<tr>
<td>Other fans</td>
<td>5 – 10 %</td>
<td>8 – 10 %</td>
</tr>
</tbody>
</table>

Each point of efficiency gain will increase fans first cost by about 1 %.

For each Euro spent about 4 Euro will be saved (based on LCC)
Efficiency Measures for Fan Systems and their Improvement Potential

<table>
<thead>
<tr>
<th>Management Action</th>
<th>Efficiency Gain Factor (EGF) System</th>
<th>Market Penetration Factor (MPF)</th>
<th>1-EGF*MPF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation Schedule</td>
<td>30 %</td>
<td>20 %</td>
<td>94.0 %</td>
</tr>
<tr>
<td>HEM</td>
<td>5 %</td>
<td>20 %</td>
<td>99.0 %</td>
</tr>
<tr>
<td>Correct Sizing of Motor</td>
<td>15 %</td>
<td>5 %</td>
<td>99.3 %</td>
</tr>
<tr>
<td>Optimising Transmission</td>
<td>8 %</td>
<td>60 %</td>
<td>95.2 %</td>
</tr>
<tr>
<td>Optimising Ducting</td>
<td>15 %</td>
<td>30 %</td>
<td>95.5 %</td>
</tr>
<tr>
<td>Additional Savings</td>
<td>12 %</td>
<td>15 %</td>
<td>98.2 %</td>
</tr>
</tbody>
</table>

Product of (1-EGF*MPF) factors 82.5 %
Energy Savings 17.5 %

Energy savings depending on control system

Power consumption [%]

Volume flow [%]

Quelle: LfU, Stuttgart, 2002
Strategy for Improving the Energy Efficiency of a Fan Installation

**Carry out a performance test**
Carry out a performance test to determine the actual flow rate, fan pressure and power absorbed. Many fans are not working at the specified duty point, often the pressure requirement is overestimated. It may be possible to alter the fan speed to a lower value and still achieve the required flow. This in any case should be reviewed as the design flow may only be required 3 or 4 days per year.

**Check the vee belt drive**
Vee belt drives are frequently ‘over-engineered’. Maintenance engineers often specify more belts than necessary as this extends their life. It is however at the expense of drive efficiency and consequent power consumption. Remove a belt at a time and re-check the amperage.

**Check the motor selection**
Many motors are oversized to give a margin. Check the new power absorbed by means of voltage, amperage and power factor readings. Determine if a new motor (possibly of higher efficiency) will give reduced energy consumption, and if power factor correction is warranted. HEM have typically a much broader high-efficiency operating range.

**Check if an impeller change is warranted**
Many fan manufacturers have a range of impellers to suit a particular fan casing / drive assembly. It may be that a change of impeller and/or inlet cone will reduce the energy consumption e.g. changing a forward curved bladed impeller for a backward airfoil bladed impeller on a centrifugal fan or changing the solidity (number and chord of blades) or hub to tip ratio on an axial fan.

**Check if a complete change of fan is warranted**
For best efficiency backward bladed fans are larger than forward curved fans for the same duty. The additional first cost may however be more than recovered over the life of the fan. Sometimes fans are found to be oversized for the duty and a smaller fan will then be more efficient. A change in width may also be beneficial.

**Check the control type of the fan**
Where the fan is fitted to a constant orifice system, an inverter speed control is preferred for varying the flow rate. If the system requires constant pressure, a variable geometry fan is suggested. A soft start should be incorporated wherever possible.

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Pay back time for fan replacements depending on power and number of operating hours

![Pay back time graph](image_url)
Compressed Air

Motor driven systems - much more than a motor (the compressed air example)
Refrigeration Systems

Refrigeration compressor

Ab-/Adsorption cooling

Often refrigeration systems are responsible for peak power demand

- Power Total
- Power w/o cooling
- Power cooling
The European Motor Challenge-Program

- Program of the European Commission with voluntary participation
- Target: Improvement of energy efficiency of motor driven systems in industry
- Aim of the Programme:
  - Reliability
  - Quality
  - Costs of system to be improved

Structure of the MCP-Program

- Partner Guidelines
  - User of Motor Systems
- Endorser Guidelines
  - Manufacturers, ESCO's and other supporting institutions

- Compressed Air Module
- Pump Module
- Refrigeration Module
- Energy Management
- Fans Module
- Drives Module
- Distribution Module
- In preparation
Module-Guidelines

• The module descriptions helps the partners to identify possible measures for the participation in the MCP Program.

• Basic description of the system. (simple data collection of type, power and use).
  – Required measurements (e.g. Electricity consumption, load distribution)
  – Basic data
  – Planned efficiency measures

How to become an MCP Partner

A 5 Step Procedure

• Partner
  – Company starts with a motor system inventory.
  – Company proposes action plan, which contains type and size of the commitment and the list of measures to be undertaken
  – EU-Commission approves action plan and grants Partner Status.
  – Partner follows the Action plan and reports annually to the Commission
  – EU-Commission checks annual report and renew the „Partner“-Status.

• Endorser
  – Company starts with an inventory of ’s energy saving activities.
  – Company proposes action plan, which contains type and size of the commitment and the list of measures to be undertaken
  – EU-Commission approves action plan and grants Endorser Status.
  – Endorser follows the Action plan and reports annually to the Commission
  – EU-Commission checks annual report and renew „Endorser“-Status.
Mission 6.2: Energy Efficiency

ProMot Toolbox (Refrigeration, Pumps)
Mission 6.2: Energy Efficiency

Barriers and Resistance
Killer phrases instead of killer applications

- We’ve never made it that way.
- We’ve tried that already in the past.
- This may be right in theory, but...
- Others have tried already and failed.
- If it was that easy, the concurrence would have done it before.
- Therefore we haven’t got the funds.
- It’s not worth to do it.
- We know exactly what our customers want.
- Draw up all the details first before we do anything.

Not only one but many reasons for investing in energy efficient motor driven systems

<table>
<thead>
<tr>
<th>Decrease (energy) costs</th>
<th>Reduce pollution of the environment</th>
<th>Facilitate Repairs</th>
<th>obtain a general idea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce personal cost</td>
<td>Improve Quality</td>
<td>Prepare for increasing energy cost</td>
<td>Stabilization of company situation</td>
</tr>
<tr>
<td>reduce maintenance cost</td>
<td>Guarantee jobs</td>
<td>Achieve PR-effects</td>
<td>Simplify regulation/manipulation</td>
</tr>
<tr>
<td>Increase/stabilize turnover</td>
<td>Increase efficiency</td>
<td>Improve service</td>
<td>Improve industrial safety</td>
</tr>
</tbody>
</table>

Mission 6.2: Energy Efficiency

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Ljubljana, 13-15 March 2006
Why energy efficiency is a difficult task?

Multiple Actors
with multiple reasons for investing have to select between multiple different technologies from multiple suppliers
need to get an integrated energy efficient solution

Market barriers to energy efficiency

Major Barriers
- Reluctance to change a working process
- Pay back time required below two years
- Investment and operation cost are not dealt equally at same time (split budgets)

Medium Barriers
- Missing motivation
- Energy efficiency not seen as priority at the management level
- missing definition of motor system efficiency
- Oversizing of equipment due to unknown load characteristics

Moderate Barriers
- Other functional specifications conflict with energy efficiency
- Shortage of capital

Management
Financial
Technical
Interpreting Barriers

Many barriers of all types show up often due to a lack of information

➢ Pay back time seen as a tool for profit analysis and not as an risk indicator.
   (Note: Investments with a payback time of 4 years can have easily internal rates of return above 15 %)

➢ First cost seems to dominate the total cost
   (Note: Typically energy costs of motor driven systems make up more than 2/3 of the life cycle cost.)

➢ Efficiency improvements are related to single components
   (Note: The component with the lowest efficiency in the system limits the maximum efficiency)

The key to efficiency are the people behind it

If you want to build a ship then do not gather men to
- collect wood,
- divide tasks
- and to arrange the work.

Teach them the desire for the endless oceans.

Antoine de Saint-Exupéry
Helpful resources on the web

- http://europa.eu.int/comm/energy/index_de.html
- http://energyefficiency.jrc.cec.eu.int (Energy)
- www.motor-challenge.de (Motor systems)
- www.druckluft-effizient.de (Compressed Air)
- www.druckluft.ch (Compressed Air)
- www.eu-promot.org (ProMot; Pumps, Motors, ASD)
- www.energy.wsu.edu/software/imssa/ (EURODEEM Int.)
- www.bayern.de/lfu/bestell/index.html (Energy efficiency)