ELECTRIC MACHINES AND DRIVES

Edited by **Miroslav Chomat**

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Preface

This book focuses on a very important and diverse field of electric machines and drives. The history of the electric machine, which is the keystone of electromechanical energy conversion, dates back to the beginning of the nineteenth century. The names of famous scientists, such as Michael Faraday, Joseph Henry or Nikola Tesla, are associated with the invention of the rotating electric machine. Electric drives have quickly become an integral part of our everyday lives and we can hardly imagine our civilization without them. Electric drives play a vital part in industry, transportation as well as in modern households. If we counted the number of electric drives around every one of us today, we would certainly be surprised how big the number is.

Since the invention of the first electric machine, novel principles and designs have been appearing and the properties and parameters of electric machines have been steadily improving. The advent of power electronics and modern control circuitry at the end of the twentieth century caused a revolution in the field of electric drives. Nowadays, when modern technologies are available and advanced materials and techniques commonly utilized, formerly inconceivable results can be achieved in the field of modern electric drives.

The twelve chapters of the book written by renowned authors, both academics and practitioners, cover a large part of the field of electric machines and drives. Various types of electric machines, including three-phase and single-phase induction machines or doubly fed machines, are addressed. Most of the chapters focus on modern control methods of induction-machine drives, such as vector and direct torque control. Among others, the book addresses sensorless control techniques, modulation strategies, parameter identification, artificial intelligence, operation under harsh or failure conditions, and modelling of electric or magnetic quantities in electric machines. Several chapters give an insight into the problem of minimizing losses in electric machines and increasing the overall energy efficiency of electric drives, which is currently viewed as a priority.

I would like to express my gratitude to all the authors for their contributions, in which they shared their valuable experience and knowledge with the readers. It was their immense involvement that enabled the publication of this book. I would also like to thank the InTech staff for their great effort and support in preparation of the book. I hope it

will benefit the field of electric machines and drives, provide the readers with a new point of view on this interesting branch of electrical engineering and possibly initiate many inventions and innovations in the future.

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Premium Efficiency Motors

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1. Introduction

Despite its considerable potential for energy savings, energy efficiency is still far from realizing this potential. This is particularly true in the electrical sector (IEA, 2010). Why? There is no probably just one single answer to this question. A consequential response requires major multiform research and an analytical effort. No doubt that analysis of the interaction between energy efficiency policies and energy efficiency performance of economies accounts for a significant part of the effort.
In the future sustainable energy mix, a key role will be reserved for electricity, as GHG emissions reduction in this sector has to be drastically reduced. In this option, obvious conclusion is that large market penetration Premium motors needs a complex approach with a combination of financial incentives and mandatory legal actions, as industry doesn't invest according to least life cycle costs (DOE, 2010).
This present work illustrates the induced enormous energy saving potential, permitted by using high-efficiency motors. Furthermore, the most important barriers to larger high-efficiency motors utilization are identified, and some incentives recommendations are given to overcome identified impediments.
In the present work, experimental comparison of the performance characteristics of 3 hp Premium efficiency motors from three different manufacturers has been presented. The motors were tested according to Standard IEEE 112-B.

2. Energy, climate change and electricity

According to last report Intergovernmental Panel on Climate Change IPCC report (IPCC, 2007), the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations. Moreover, there is no doubt that discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns. Stabilizing atmospheric carbon dioxide concentrations at twice

the level of pre-industrial times is likely to require emissions reductions up to 90 % below current levels by 2100. Clearly, reductions of this magnitude can be achieved only by taking action globally and across all sectors of the economy. The electricity sector will undoubtedly need to assume a major share of the weight, according to its contribution to overall emissions estimated to be more 10 000 Mt (million tone) CO_{2eq} per year.
As can be seen in fig.1, the electricity generation is dominantly produced from fossil fuels (coal, oil, and gas), and today's situation is the same as forty years ago (DOE, 2010). In the last XXI world energy congress, it is highlighted that electricity generation will still depend on fossil sources. In the meantime, according to (IEA, 2010), industry accounts for more 40 % of the world 20 000 TWh (terawatt hours, or so called billion kilowatt hours) electricity consumption, weighting more 4 000 Mt CO_{2eq} per year. Within the industrial sector, motor driven systems account for approximately 60% to 65% of the electricity consumed by North American (RNC 2004, DOE 2010) and European Union industries. Implementing high efficiency motor driven systems, or improving existing ones just by 1 to 2 %, could save up to 100-200 TWh of electricity per year. This would significantly reduce the need for new power plants. It would also reduce the production of greenhouse gases by more 100 million CO_{2eq} per year and push down the total environmental cost of electricity generation.
The worldwide electric motors above 1 hp can be estimated to be nowadays more 300 million units, with the annual sales of 34 million pieces. Typically, one-third of the electrical energy use in the commercial sector and two-thirds of the industrial sector feed the electrical motors (DOE, 2010). Moreover, the low voltage squirrel cage induction motor constitutes the industry workhorse. In particular industrial sector such as the Canadian petroleum and paper industry, the share of the energy used by electrical motors can reach 90% (RNC 2004). Since induction motors are the largest electrical energy user, even small efficiency improvements will result in very large energy savings and contribute to reduce greenhouse gas emissions GHG. Furthermore, the declining resources combined environmental global warming concerns and with increasing energy prices make energy efficiency an imperative objective.

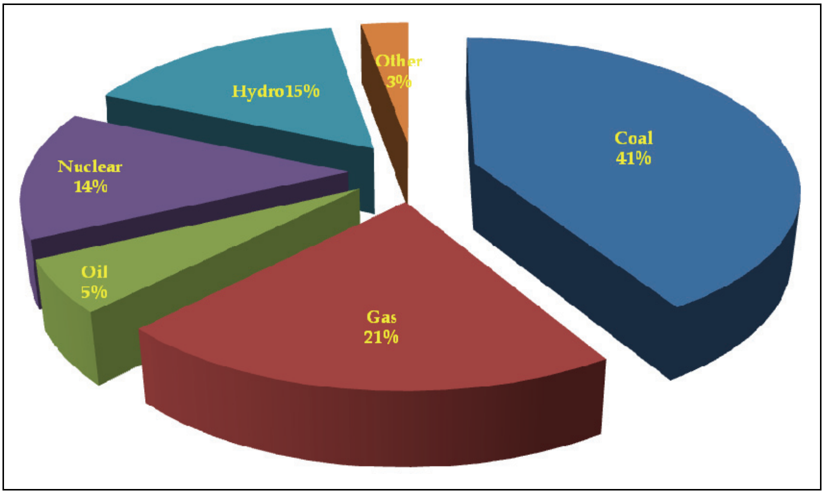

Fig. 1. Electricity generation by fuel

3. Motor losses segregation and efficiency

The impact of a motor in terms of energy and economical costs depends on its performance during its lifetime. The motor performances are characterized by the efficiency with which it converts electrical energy into mechanical energy.
In Standard IEEE 112-B the losses are segregated and the efficiency is estimated by the following formula:

$$\Delta P_{str} = P_{in} - P_{out} - (\Delta P_{el1} + \Delta P_{el2} + \Delta P_{core} + \Delta P_{mech}) \qquad (1)$$

Where the electric input power, P_{in}, is measured with a power analyser and the output power, P_{out}, with a torque meter. The overall precision of efficiency assessment mainly depends on the torque estimation, and with the improved accuracy of recent power analysers and torque meters, this method can be considered accurate and reliable.
Motor efficiency is defined as a ratio motor mechanical output power and electrical input power. Hence in order to have a motor perform better, it is important to reduce its losses. The major motor losses are resistive losses in the stator and the rotor windings, and magnetic losses (hysteresis and eddy current losses) in the cores. Other losses include mechanical (bearing friction and ventilation), and stray load losses. High efficiency motor losses relative distribution is not so different at low efficiency one's; it's more dependent on the power. Their general distribution is illustrated in fig.2.

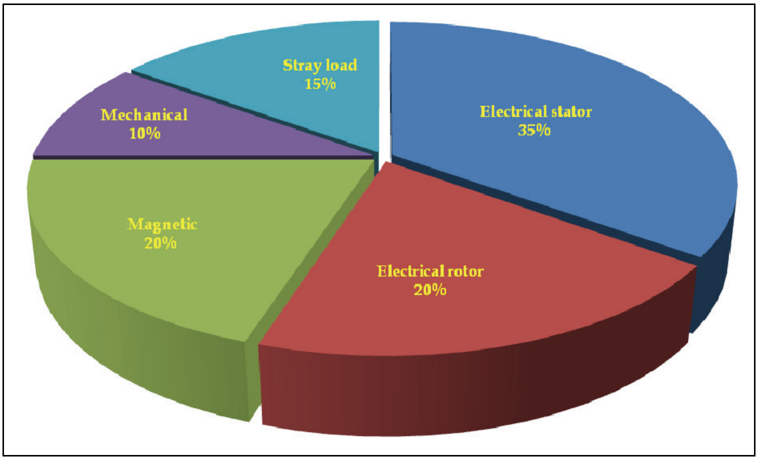

Fig. 2. Induction motor losses distribution

There are many ways to improve electric motor efficiency; the majority of them make the motor larger in diameter or overall sizes and, of course, more expensive.

- Winding stator (ΔP_{el1}) and rotor (ΔP_{el2}) losses are due to currents flowing through the stator windings and rotor bars. These losses can be reduced by decreasing the conductor current density in the stator windings, in the rotor bars and in the end rings. Using larger conductors lowers stator resistance, while the use of copper instead of aluminum reduces rotor losses (Parasiliti et al. 2002). Another way of decreasing stator losses is by reducing the number of turns. Unfortunately, this increases the starting current and maximum torque, as worsen the power factor.

- Magnetic losses ΔP_m occurring in the stator and rotor laminations are caused by the hysteresis and eddy current phenomena. These losses can be decreased by using better grade magnetic steel, thinner laminations and by lowering the flux density (i.e larger magnetic cores). The better grade of laminations steel are still relatively very expensive. Cheaper manufacturing methods other than stamping are expected to become available in the near future.
- Mechanical losses ΔP_{mec} are due to bearing friction and cooling fan air resistance. Improving the fan efficiency, the air flow and using low friction bearings result in a more efficient design. As these losses are relatively small, the efficiency gain is small too, but every improvement is welcome.
- Stray load losses ΔP_{st} are due to leakage fluxes induced by load current, non-uniform current distribution, mechanical air-gap imperfection…These losses can be reduced by design optimisation and manufacturing method improvements.

As can be deducted, one of the most established methods of increasing motor efficiency is to use higher quality materials, inexorably increasing the motor cost, as most high performance materials are expensive materials. In a recurrent manner, the same problem of increased cost holds true for better construction techniques, such as smaller air gaps, copper rather than aluminum in the rotor construction, higher conductor slot fill, and segmented core stator construction. The resulting increase in motor cost is evaluated to be between 15 % and 30 %.

4. Testing standards

In North America, the prevailing testing method is based on direct efficiency measurement method, as described in the Institute of Electrical and Electronics Engineers (IEEE) "*Standard Test Procedure for Polyphase Induction Motors and Generators*" IEEE 112-B and in its Canadian CSA 390 adaptation. The standard first introduced in 1984 and updated in 2004, requires the measurement of the mechanical power output and the electric input, and provide a value for the motor losses, where the additional stray load losses are extrapolated from their total by the following formula (1). So, the efficiency is extrapolated by:

$$\eta = \frac{Pout}{Pin} = \frac{Pout}{Pout + \Delta Pel1 + \Delta Pel2 + \Delta Pm + \Delta Pmec + \Delta Pst} \tag{2}$$

In Europe, the prevailing testing method is based on an indirect efficiency measurement as defined in IEC 34-2 standard "Rotating electrical machines – Part 2: Methods for determining losses and efficiency of rotating electrical machinery from tests". The standard first introduced in 1972 and updated in 1997, attribute a fixed value, equal to o.5 % of input power to the additional stray load losses.

These standards differ mainly by the method used to take into account the additional load losses (Aoulkadi & Binder, 2008, Boglietti et al 2004, Nagorny et al. 2004, Elmeida et al. 2002…). Many papers have been published and some authors have illustrated, that IEC 34 – 2 has drawback with a noticeable influence on the testing of high efficiency motors, as the efficiency of this motor type is overestimated, particularly in the small motor size cases. Ultimately, standard IEC 34 – 2 was found to be unrealistic with its 0.5 % P_{in} value for stray losses (Aoulkadi & Binder, 2008, Renier et al. 1999, Boglietti et al 2004…). That is why, in 2007, IEC published a revised standard for efficiency classification no. 60034-2-1 which includes a test procedure largely comparable to IEEE 112-B or CSA C390. Newly harmonized standards for energy efficiency testing IEC 60034-2-1 can contribute to lowering barriers in global trade for energy efficient motor systems.

5. Minimum energy performance standard MEPS and efficiency motor classification

There are many different worldwide definitions for energy efficient motors, as until these last years, there was no consensus on what really represents an energy efficient motor. Technical barriers include non harmonized testing standards and efficiency classification. In reality, the key mandatory instrument is minimum energy performance standards (MEPS).

5.1 MEPS in North America

On October 1992, US Congress voted law, Energy Policy Act EPAct, which mandates strict energy efficiency standards for electrical appliances and equipment, including electric motors. Motor MEPS were for the first time introduced in 1992 when all partners were finally persuaded that voluntary measures are too slow, and no significant market transformation towards more efficient motors was possible otherwise.

EPAct requires that the general purpose electric motors meet the higher nominal efficiency requirements defined in the table of National manufacturer association NEMA Standard, and the implementation of the motor MEPS went into effect in 1997.

The Canadian Standard association developed a Canadian standard in 1993, and updated it in 1998. CAN/CSA C-390 set the requirement for minimum efficiency for new motors made or sold in Canada at the same value as the NEMA energy-efficient level.

The Energy Policy Act EPAct-92 motors covered are:

- General purpose
- Definite or special purpose in a general purpose application
- Continuous duty
- 2, 4 & 6 Pole
- 1-200 HP
- 230/460/, 60 Hz

The Canadian standard was furthermore extended to 575 V and IEC motors, and included 75 % full load to reach maximum efficiency.

Some motors were not covered:

- Definite or special purpose in a non-general purpose application
- Slower speeds
- Inverter duty
- Multi-speed
- Totally enclosed air over TEAO, and totally enclosed not ventilated TENV

As a result of the mandatory standard that was endorsed as part of the EPAct-92, North America had a motor standard foundation that leads the new century world.

In 2002, NEMA and Consortium for energy efficiency CEE established a voluntary NEMA Premium level of efficiency, and the manufacturers began the next step in evolution with the implementation on voluntary basis MEPS NEMA Premium efficiency motors. NEMA premium efficiency standards (CEE 2007) have remained voluntary for a long period of 10 years. In spite of this, NEMA premium motors have been progressively gaining market share, as the overall benefits of Premium motors is incommensurable (more reliable, last