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Global energy consumption due to friction in paper machines

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ABSTRACT

Calculations on the global energy consumption used to overcome friction in paper machines in terms of friction in motors, transmissions, pumps, blowers, agitators, pipes and the roll systems are presented. The following was concluded:

- The energy consumed to overcome friction in a paper mill is in the range 15–25%.
- Globally there were 8525 paper and paperboard machines in operation in 2012. One paper machine uses on an average 140 TJ of electrical energy per year. Of this 32% is consumed to overcome friction, 36% is used for the paper production and mass transportation and 32% is other losses.
- The friction losses in an average paper machine are in total 44.8 TJ per year, and they are distributed as 32% due to friction in water-lubricated sliding in seals, doctor blades and fabric/support contacts, 23% due to friction in elastohydrodynamic rolling contacts, 22% due to friction in elastohydrodynamic rolling–sliding contacts, 15% due to friction in oil-lubricated seals and 8% due to friction in hydrodynamically lubricated contacts.
- Worldwide 105,000 GWh electrical power was used in 2009 to overcome friction in paper machines. This equals to 381,000 TJ of annual energy consumption.
- By taking advantage of new technology for friction reduction in paper machines, friction losses could be reduced by 11% in the short term (about 10 years), and by 23.6% in the long term (20–25 years). This would equal to annual worldwide economic savings of 2000 million euros and 4200 million euros; electricity savings of 36,000 and 78,000 GWh; and CO_2 emission reduction of 10.6 million and 22.7 million tonnes.

Potential mechanisms to reduce friction in paper machines include the use of low-friction and highly durable coatings, surface engineering including texturing, low-viscosity and low-shear lubricants and fluids, novel additives, new materials in seals, doctorblades and fabrics, as well as new designs.

1. Introduction

Improving energy efficiency has become a global megatrend within all industrial sectors as well as in the entire society. The overall aim is to minimise the greenhouse gas emissions, ensure the energy security and improve the industrial output and competitiveness. In the end part of the production chain, the conscious customers in the industrialised countries have woken up by the threats of global warming, changed their consuming habits and started to demand green and sustainable products and services. The uncertainty about global fossil energy reserves and their availability in the long run is increasing the awareness for the development of clean and renewable energy resources and optimised energy use to prevent waste. Furthermore, the increasing energy prices in recent years have created a greater demand for improved energy efficiency to reduce operating costs and support sustainable competitiveness. The current energy landscape, research opportunities and pathways that can lead to a prosperous, sustainable and secure energy future for the world were recently reviewed by Chu and Majumdar [1]. They consider that solar and water-based energy generation and engineering of microbes to produce biofuels represent good examples of the major renewable alternatives.

In a recent study Holmberg et al. [2] reviewed the economic and environmental impact of friction on energy consumption at global scale. They analysed in detail the energy loss sources and potential improvements in passenger cars and found that significant reductions in energy losses due to friction are possible. Advances in cost-effective technologies, such as tribological

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design, coatings, surface engineering, lubricant chemistry, tyres, braking and waste heat energy recovery, could potentially lead to fuel efficiency improvements of 20% in the short term (5–10 years) and more than 60% over the long term (15–25 years). In the present article we have chosen to focus on the energy losses due to friction in large, industrial process machines; here represented by the paper machine. We specifically focus on the electrical energy flow in a paper machine as this is largely used to overcome friction, whereas the heating in the paper making process relies on thermal energy from combustion processes.

The modern paper machines are very advanced and complex including numerous high technology solutions and resulting in paper production with a speed of up to 130 km/hour. However, in many parts of the world there are still more than 50 years old paper machines in operation today that are relying on much older and wasteful technology. The development of the technology from earlier days to today's modern machines has been presented by Lindberg [3]. An overview of the paper mill operations in the production of main paper and board grades is found in Sundholm [4] and several detailed presentations of the different sections and parts of the paper machine have been presented by Paulapuro [5] and Karlsson [6].

The pulp, paper and printing industry is the fourth largest industrial consumer of energy on a global level, with a consumption of 6.45 exajoules (EJ) of final energy, or 5.7% of total industrial energy use in 2004 [7]. Printing represents only a small share of the industry's energy demand. In the pulp and paper production field, the industry generates about half of its own energy needs from biomass residues and makes extensive use of combined heat and power technology. The energy efficiency in the paper and pulp industry has long been a major competitiveness-related issue [8–10].

A paper machine line typically consists of several sections, such as short circulation system including head box, wire section, press section, drying section, coating unit, machine calender and machine reels, see Section 3.1 for more details. A modern paper machine mainly uses electrical power to run pumps and drives and for water removal, which takes place by vacuum in the wire section and by nip contacts in the press section. The energy used in the drying section is excess thermal energy, obtained either from a thermo-mechanical pulp production process or from a recovery boiler. The total consumption of electrical power in a paper machine producing news grade paper is estimated to be 570–590 kWh/t [7,11,12]. The costs of the electrical power have been estimated to cover 14–22% of the total costs of news paper grades [13,14].

The consumption of electrical power in a newsprint paper machine has been estimated to be about 590 kWh/t (27%) and the consumption of steam to be about 1600 kWh/t (73%) [12]. Thus is the energy efficiency potential revealed when comparing the present, estimated energy consumption levels with the Best Available Techniques (BAT). The consumption of electrical power in a newsprint machine using BAT has fallen to 290 kWh/t (20%) and steam to 1170 kWh/t (80%) [12,15,16]. Masters estimated that 50% of the electrical power used today could be saved. VTT has concluded that the specific energy consumption in the production of paper still today is on an 85–97% level in comparison with the level in the 1970s [11].

According to a paper machine producer, most of the newsprint paper machine electricity consumption (31%) occurs in the press section [17,18]. Within the press section, the sectional drives use 60%, the vacuum system 20%, and the hydraulics 15%, of the total electrical power [18]. The electrical power needed for the sectional drives is mainly for overcoming the friction losses, which can be influenced by more efficient dewatering and optimised doctoring [17]. The vacuum dimensioning levels are often based on the worst case scenario and represent the maximum levels of vacuum in each position. Vacuum system audits and simple optimisations of the processes have cut down the electricity consumption in the vacuum systems by even up to 50% [19,20].

The wire section and the calendar and reel section use 19% each of the total electricity consumption of a newsprint paper machine, while the dryer section consumes 17% and the short circulation 12% [18]. Concerning the energy losses due to friction between the wire fabric and the dewatering elements, general estimates indicate that 15% is due to friction at the foils or blades and 80% due to sliding friction in connection to the high-vacuum boxes. The remaining 5% of the friction losses are of different origin, mainly due to friction in the rolling bearings [21]. New technologies in process design, pumping principles and variable-speed controlled electric drives can bring significant reduction in the pumping energy demand, which is the main electricity consumer in the short circulation system. The average potential for energy savings through replacing of worn pumps, downsizing of oversized equipment, and installation of variable-speed drives for big pumps has been estimated to be about 30%, on the basis of a number of audits in Scandinavian pulp and paper mills [8].

This study introduces a method for calculating the global energy consumption due to friction, and potential savings that can be achieved by friction reduction in paper machines. We have chosen to focus on paper machines as they represent a large and advanced industrial process machine in use worldwide.

2. Methodology

The methodology used in this study was developed by Holmberg et al. [2] recently. In the present work, our focus is on the electrical energy consumed by the paper machine. Thermal energy brought to the machine is not separately studied, as it is used for heating and not directly related to the frictional losses. The total energy flow in a paper machine is discussed in Section 3.1.

The present analysis is based on the physical phenomena resulting in energy consumption in paper machines. Previous analyses have been a mixture of functional and component-level studies and are often fragmented in scope. Our energy loss analysis includes five parts:

1. Paper machine energy consumption.
2. Operating cycle effects.
3. Global average paper machine and average operating conditions.
4. Energy loss sources in paper machines.
5. Tribocontact friction losses today and future.

The friction loss energy calculations, which are presented in greater detail in Appendices A–C, proceed as follows. We first chose the global paper machine stock for analysis [22]. The total energy consumption of all paper machines worldwide was calculated by using energy consumption statistics, paper machine statistics, and operating information [7,23–27]. What can be considered as a global average paper machine that is in average operation worldwide (in the following also called PM1980) was defined based on paper machine statistics [7,11,22,23,28]. We subdivided the total energy loss of the average paper machine into operational and frictional energy losses, using the best available estimates in published friction loss studies for paper mills, paper machines and its sub-sections (see Section 3.4). The friction losses were furthermore subdivided into the component level and tribocontact level; here defined as friction loss sources as illustrated in Fig. 1.