

# FAN DRIVE SYSTEM EFFICIENCIES

ADAM CREERY, P.E.  
Universal Dynamics Limited  
100 - 13700 International Place  
Richmond, BC, CANADA V6V 2X8  
Tel. (604) 214-9248 Fax (604) 214-9249  
*e-mail: acreery@udl.com*

Presented at the

**NATIONAL LIME ASSOCIATION**  
**1999 OPERATING MEETING**  
Birmingham, Alabama  
September 27-29, 1999

## FAN DRIVE SYSTEM EFFICIENCIES

ADAM CREERY, P.E.  
Universal Dynamics Limited  
100 - 13700 International Place  
Richmond, BC, CANADA V6V 2X8  
Tel. (604) 214-9248 Fax (604) 214-9249  
*e-mail: acreery@udl.com*

**Abstract - Efficient use of our electrical resource is being championed by utilities throughout North America. The choice of large fan drive systems for new plants is an important one. Retrofits of dampered fan systems promise short payoffs. This paper examines four options for adjustable speed drive systems; eddy current clutch, fluid coupling, direct current drives and variable frequency drives. Selection criteria are discussed followed by an economic analysis of the cost of purchasing and operating the four different systems.**

### INTRODUCTION

Money is how efficiency is measured; the ratio of dollars out to dollars in is the bottom line. Concentrating on your electrical system can reap generous rewards. Adjustable speed drive system (ASD) options are plentiful. Drive systems examined are eddy current couplings, variable slip fluid couplings, direct current (DC) drives and alternating current (AC) drives.

Efficiency is the ratio of power out to power in. In electrical drive systems this represents the mechanical power produced at the motor shaft divided by the electrical power drawn from the power system. This is also expressed as:

$$EFFICIENCY = \frac{(POWER\ IN - LOSSES)}{POWER\ IN}$$

Losses appear as heat in the system. Electrical system heating losses vary with the square of the current. Efforts to reduce current levels through power factor correction, high efficiency motors and variable speed drive systems will pay rewards in reduced operating costs and increased life span of electrical equipment.

A number of factors affect the efficiency of your plant's electrical system:

- a) **Torque:** The load determines torque requirements. Motors are commonly designed to run at peak efficiency between 60% and 90% load [1]. Correct sizing of electrical system components is important. Oversized motors have poorer efficiency than their correctly sized counterparts.
- b) **Voltage:** Motor efficiencies are sensitive to voltage. Having the correct voltage available at the motor is important. A decrease in applied voltage results in a significant decrease in efficiency.
- c) **Power Factor:** The power factors of high efficiency motors are superior to standard motors. Higher power factors result in less line current and consequently fewer losses. Power factor drops off sharply under 75% load. Again, correct sizing of the motor is important.
- d) **Harmonics:** Harmonics cause additional higher frequency currents to flow, additional magnetic core losses and produce higher temperatures. Harmonic mitigation will produce system efficiency gains and longer equipment life.

### EDDY CURRENT COUPLINGS

Eddy current couplings (ECC) use a fixed speed motor connected to a drum and a wound rotor connected to the output shaft. A stationary coil is magnetized to vary the slip between the drum and the rotor. Increasing the excitation currents in the stationary coil increases the magnetic coupling between the drum and the output shaft. A tachometer is used to monitor the output speed and automatically adjust the current output of the exciter, providing 0.5 to 1% speed regulation, well within the requirements of the fan system. Typical power requirements of the exciter represent 2% of the total drive power [2].

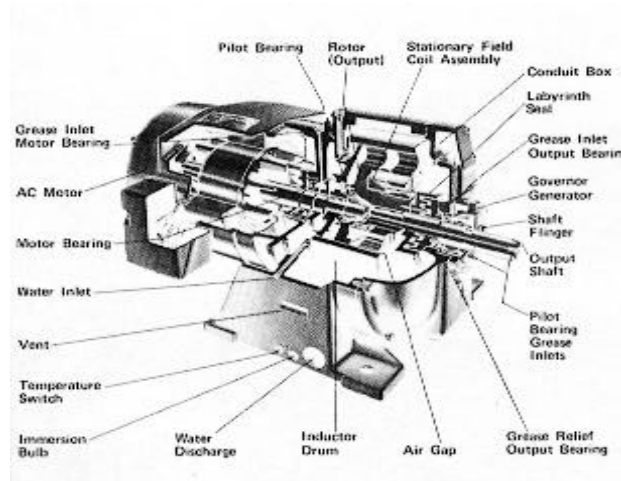


Fig. 1. Eddy Current Coupling

More recent models have used slip rings to connect to the winding, reducing the magnetic coupling between the drum and the rotor winding to a single air gap. This “salient pole” arrangement results in higher efficiency, but the slip rings are not suitable for dusty environments.

Efficiency of this and other “Slip” type couplings is linear with speed. For a centrifugal fan, the required horsepower varies as the cube of the speed. This causes the power loss of a fluid coupling on a fan application to be at its worst at 2/3 speed and climb back up to 100% efficient near zero speed. Slip coupling efficiencies for fan applications are often quoted this way, incorporating the fan affinity laws. Care must be taken when comparing these efficiency values to those of DC and AC systems.

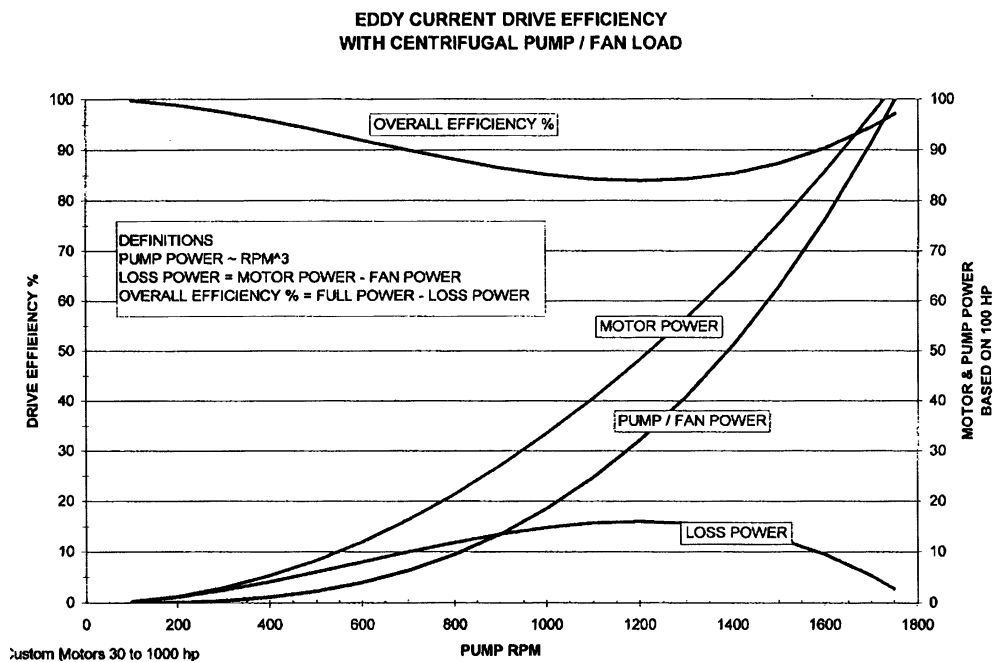


Fig. 2. Eddy Current Coupling Fan Efficiency Curve

The principal maintenance item of the ECC is the internal pilot bearing that maintains the air gap between the two rotors [3]. This bearing is difficult to access and service. Fluid coupling vendors quote this issue as the most common reason for replacing eddy current couplings.

	Cons
<ul style="list-style-type: none"> <li>• Relatively inexpensive</li> <li>• Torque coupling is via magnetic field</li> </ul>	<ul style="list-style-type: none"> <li>• Require liquid cooling to dissipate heat</li> <li>• Low efficiency at low speeds</li> <li>• Large drive footprint</li> <li>• May be difficult to start motor on weak systems</li> </ul>

### FLUID COUPLINGS

A variable slip fluid coupling uses a fluid to engage the coupling between the motor and the load. Sophisticated couplings are available with reasonably high efficiencies. Cooling system costs must be factored in as large amounts of heat must be dissipated from the coupling.



Fig. 3. Fluid Coupling Installation

The fluid coupling's efficiency varies linearly with speed and is marginally lower than the eddy current coupling's efficiency. The coupling is a transmission system which can be more familiar to maintenance staff than the other options described here.

	Cons
<ul style="list-style-type: none"> <li>• Relatively inexpensive</li> <li>• Purely mechanical concept</li> <li>• Familiar to maintenance staff</li> </ul>	<ul style="list-style-type: none"> <li>• Liquid cooling</li> <li>• Less efficient than eddy current coupling</li> <li>• Large drive footprint</li> <li>• May be difficult to start motor on weak systems</li> </ul>

### DC DRIVES

DC drive systems have long been used for large horsepower operations. AC power is rectified and applied to a direct current motor. The field (stator) winding is stationary, while the armature winding rotates. Brushes allow a magnetic field to be built up in the armature (rotor) winding. The magnetic poles formed on the field are repulsed from the poles formed on the armature, causing the rotating motion. DC drives are relatively simple but the motors are complicated. The brushes are a high maintenance item and are difficult to protect from a dusty environment.

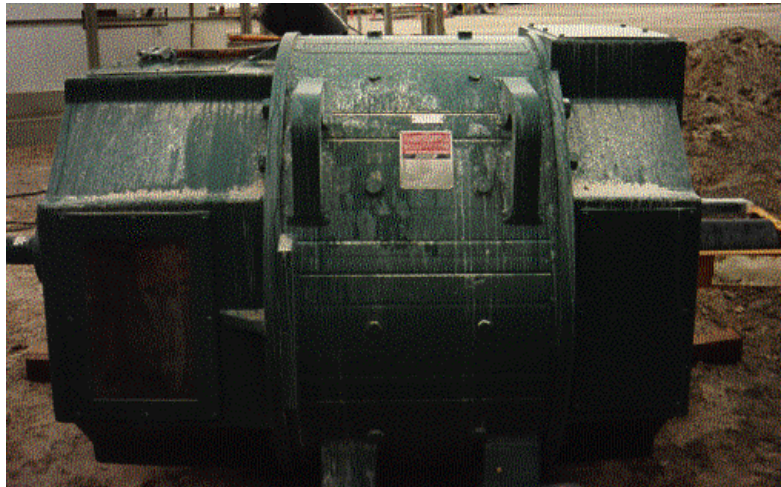


Fig. 4. DC Motor

The DC drive uses power semiconductors to convert the AC power to a variable DC voltage applied to the motor. One characteristic of the DC drive is that it has low power factor at low speed operation, increasing the losses in the supply system.

	Cons
<ul style="list-style-type: none"> <li>• Wide range of speed operation</li> <li>• High starting torque</li> <li>• Relatively simple controller</li> <li>• Good efficiency at higher speeds</li> <li>• Overspeed capability</li> </ul>	<ul style="list-style-type: none"> <li>• Low power factor at low speeds</li> <li>• Not well suited to hostile environments</li> <li>• Constant brush and filter maintenance</li> <li>• Expensive motor to spare</li> <li>• Harmonics</li> </ul>

### AC DRIVES

In the AC drive the incoming power is converted to DC and then switched by power transistors (inverter) to produce an AC output voltage at the motor. The drive is more complicated than its DC counterpart due to the addition of the inverter section. AC motors on the other hand are much simpler than DC motors and ideal for use in dusty environments.

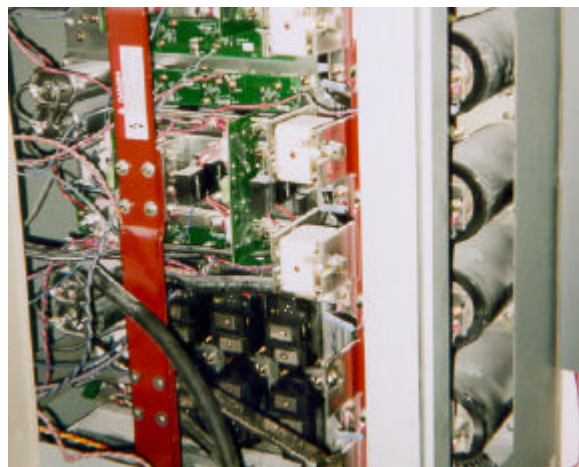


Fig 5. Variable Frequency Drive Electronics

Efficiency of the system is relatively constant when the voltage/frequency ratio is kept constant as is the case in today's drives. This results in a high efficiency throughout the operating spectrum.

Modern drive systems are microprocessor controlled and offer automatic tuning of motor parameters for optimum operation. Another benefit of the microprocessor is enhanced diagnostics that allow rapid troubleshooting.

	Cons
<ul style="list-style-type: none"> <li>• Simple motor, easily spared</li> <li>• Flexible control</li> <li>• Easy to start</li> </ul>	<ul style="list-style-type: none"> <li>• Most complicated controller</li> <li>• Requires large footprint in electrical room</li> <li>• Harmonics</li> </ul>

### SELECTION CONSIDERATIONS

The choice of drive system must be evaluated with a number of factors in mind. Horsepower loading, starting torque, full load torque, speed range, cooling, environment, space and maintenance all must be considered. Economic factors such as capital investment, installation and maintenance costs play a large role as well.

#### a) *Horsepower*

The drive system must be able to produce the required horsepower of the fan. Close attention must be paid to the selection of maximum required horsepower as this will determine the size of the drive.

#### a) *Speed Range*

Fan speed range is important as fan horsepower increases as the cube of the speed. Minimum speed requirements will determine the type of motor required for AC systems. Operation at minimum speed is often required for curing the refractory and the drive system must be able to run for hours at these low speeds. Due to their power output wave forms, older VFD designs restricted standard motors to a 4:1 turndown ratio due to harmonic heating and the inability of the fan to dissipate these losses at low speeds. Newer drive systems produce near sine wave output power and 10:1 turndown ratios are easily achieved.

#### a) *Environment*

The environment at the motor and in the electrical rooms must be considered. Not much can be done at the motor location, nor is any required for AC motors. Filtered air is usually piped into the DC machine but these systems rarely keep out the brush destroying dust. AC and DC drives require well-maintained environments to operate in, free of dust and excessive heat. Note that the AC drive requires substantial space in the electrical room due to its inverter section, while the slip couplings require additional foundation room at the motor.

#### a) *Maintenance*

An important issue is the maintenance staff. Mechanical slip couplings can easily be maintained by in-house personnel. AC drives are seen by the maintenance departments as requiring little attention and maintenance is usually performed by outside contractors. DC drives, less complex than AC, can be maintained in-house; however, care must be taken when replacing the brushes. This procedure should be performed by trained personnel. All systems, including AC and DC systems, must receive scheduled attention during shutdowns to ensure reliable operation.

### COMPARISON

The application under consideration is an induced draft (ID) fan with a brake horsepower requirement of 1250 hp. The units of power we are concerned with are kilowatts (kW) and the units of energy are kilowatt hours (kWh). Assumed cost of energy is \$0.05 per kWh, typical for industrial users.

Additional losses are found in the mechanical systems attached to the motor shaft, belt couplings, gear reducers, fixed couplings and in the driven machinery, fans, pumps, conveyors, etc. These additional losses are common in all drive systems and will not be included in the analysis.

Running conditions have been assumed as follows:



TABLE 1  
DUTY CYCLE

Hours of Operation: 8,000 h/yr		
Speed (Flow)	% Time	Hours
100%	5%	400
90%	10%	800
80%	50%	4,000
70%	25%	2,000
60%	10%	800

Capital costs, auxiliary cooling system costs and maintenance costs must be included. Approximate costs for the different systems are shown below.

TABLE 2  
CAPITAL COSTS

System	Motor	Controller	Cooling	Spares	Total
Eddy current coupling	\$75,000	\$100,000	\$50,000	\$10,000	\$235,000
Variable fluid coupling	\$75,000	\$100,000	\$50,000	\$10,000	\$235,000
DC Drive System	\$120,000	\$120,000	\$30,000	\$20,000	\$290,000
AC VFD Drive System	\$75,000	\$170,000	\$20,000	\$30,000	\$295,000

Efficiency estimates vary widely and are subject to interpretation. Care must be taken to include all losses associated with the system under scrutiny. Efficiency estimates of existing equipment can be made in the field [4]. The following table lists conservative efficiencies used in the study.

TABLE 3  
EFFICIENCIES

Fan speed	ECC	FLUID	DC	AC
100%	88%	85%	90%	85%
90%	78%	75%	89%	84%
80%	70%	65%	88%	83%
70%	60%	56%	85%	82%
60%	50%	46%	78%	80%

Using the load profile (duty cycle) shown in Table 1, capital costs from Table 2 and efficiencies shown in Table 3 the cost of purchasing and operating these drives over a five-year period is detailed in Table 4.

TABLE 4  
COST SUMMARY

Speed (Flow)	Hours	Load hp	Load kW	ECC kWh	FLUID kWh	DC kWh	AC kWh
100%	400	1,250	933	424,000	439,000	415,000	439,000
90%	800	911	680	697,000	725,000	611,000	648,000
80%	4,000	640	477	2,726,000	2,935,000	2,168,000	2,299,000
70%	2,000	429	320	1,067,000	1,143,000	753,000	780,000
60%	800	270	201	322,000	350,000	206,000	201,000
Annual kWh				5,236,000	5,592,000	4,153,000	4,367,000
Annual energy cost				\$261,800	\$279,600	\$207,650	\$218,350
Maintenance costs				\$20,000	\$20,000	\$25,000	\$10,000
Total annual costs				\$281,800	\$299,600	\$232,650	\$228,350
Capital costs				\$235,000	\$235,000	\$290,000	\$295,000
Total Five-year cost				\$1,644,000	\$1,733,000	\$1,453,000	\$1,436,000
Total Ten-year cost				\$3,053,000	\$3,231,000	\$2,616,000	\$2,578,000

## CONCLUSION

As Table 4 shows, the annual energy costs are by far the largest costs. The results are very dependent on the efficiency estimates. The efficiency estimates used in this study were gathered from vendors and from the technical literature. Efficiency of AC drives and motors operating as a unit is a subject of ongoing debate as very little factual evidence is available. Efficiency estimates for AC systems usually quote the drive and motor separately. Efficiencies for slip couplings do not take into account the cooling equipment required. Care must be taken in comparing options for your plant.

The results are close enough that all systems, not surprisingly have a comparable cost after five years of operation. However, if a longer term approach is used, the AC and DC options win out economically. The DC option is not favored due to its brush maintenance requirement. The AC option is the preferred choice provided the drive purchased provides reliable operation.

## FURTHER CONSIDERATIONS

A comprehensive study commissioned in July 1995 [5] covering users' and manufacturers' experience with medium-voltage AC drives revealed a high degree of satisfaction among the users. The users overwhelmingly stated that criteria for drive selection were reliability, energy efficiency and process efficiency. While it may seem odd that over 66% of users reported failures within the first 12 months, more than 75% of the failures were corrected for less than \$5,000 and with less than one day of downtime.

## REFERENCES

- [1] BC Hydro, Guides to Energy Management, High Efficiency Motors, GEM M-104, pp 4, April 1996.
- [2] Dynamatic Corporation, <http://www.dynamatic.com/ec-principles.html>, August 1999.
- [3] Clarence Phipps, Variable Speed Drive Fundamentals, Fairmont Press, pp 8-9, 1994.
- [4] Gilbert McCoy and John Douglass, Energy Management for Motor Driven Systems, US DOE Motor Challenge Program, Chapter 4, June 1997.
- [5] R.A Hanna and S. Prabhu, Medium-Voltage Adjustable-Speed Drives, Users' and Manufacturers' Experiences" IEEE Transactions on Industry Applications, Vol 33, pp 1407-1415, Nov/Dec 1997.