Designing a Mechanically Adjustable Speed Drive for AC Motor Applications to Eliminate Vibrations Without Additional Harmonics

Philip Corbin III, Flux Drive Founder/CEO

1. INTRODUCTION:

With the advent of high performance permanent magnets, there is a new non-eddy-current option to achieving adjustable speed control when matching the AC motor output speed to the requirements of the load. This option is cheaper to install, maintain and operate without introducing damaging harmonic frequencies to the motor.

The Flux Drive® technology utilizes portions of induction motor theory and combines it with recent improvements in permanent magnets to develop a simple but unique magnetic adjustable speed drive (ASD) and soft-start coupling.

The following presentation will outline the technology and describe two applications in which this drive was installed.

2. TECHNOLOGY OVERVIEW:

This technology demonstrates the efficient use of the highest energy rare earth magnetic materials available (i.e., Neodymium-iron-boron). The robust design is characterized by a primary member populated by easily assembled permanent magnets, and a secondary member relying on casting techniques of an aluminum cage that have been highly refined over a century of induction motor development.

The Flux Drive® ASD, shown in Figure 1, achieves adjustable speed of the output shafting, by controlling the overlap of a "Can" containing an optimized array of rare earth magnets, as it spins around a magneto-conductive "Rotor". As the Can and Rotor are disengaged, the slip increases, and thus allows the output speed to decrease proportionally. The alignment between the Can and Rotor allows for greater transfer of torque and change in speed as the Rotor enters into the Can.

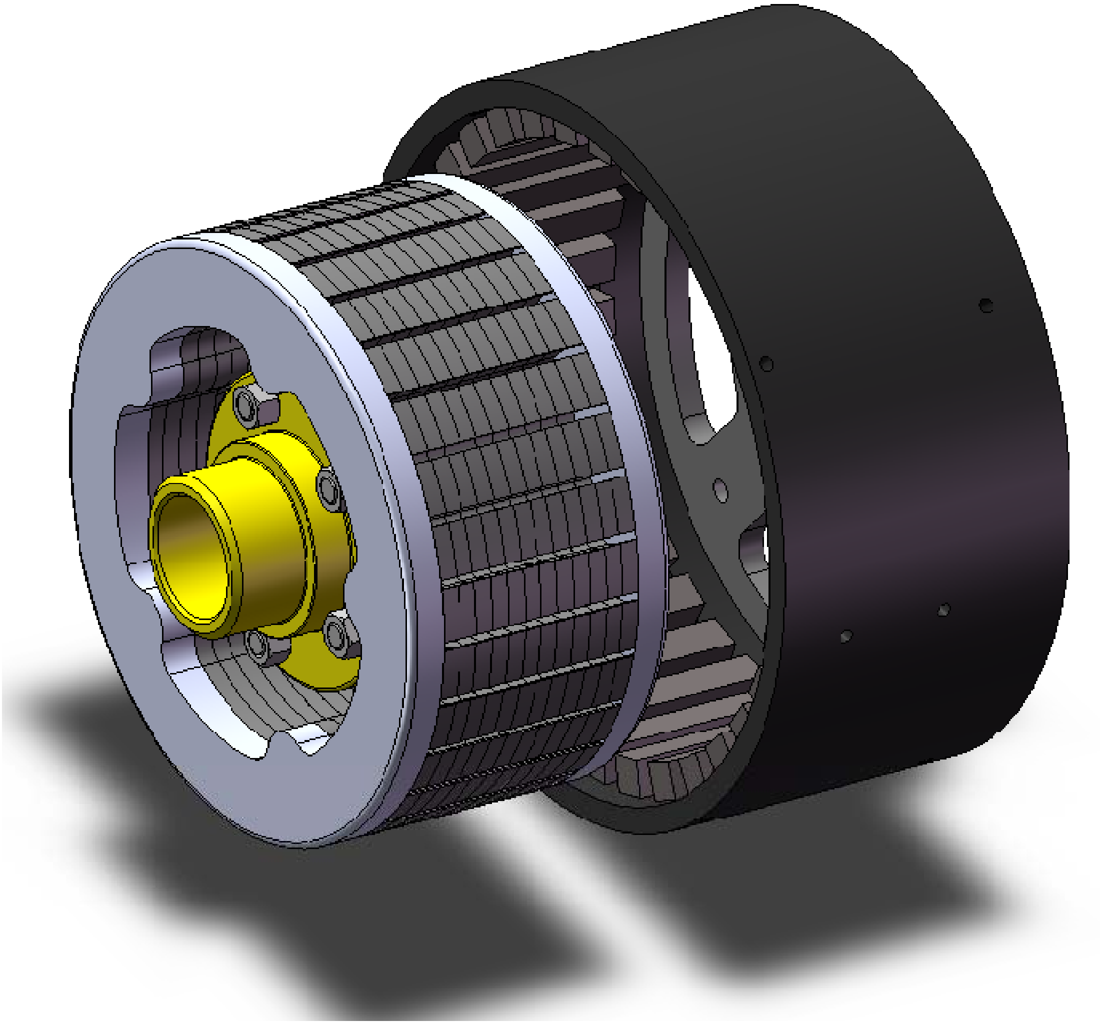


Figure 1 View of a Flux Drive® ASD

In Figure 2 a Flux Drive coupling is configured by simply leaving the Rotor fully engaged within the magnet Can. During the motor starting event, the motor shaft commences rotation before the start-up of the Flux Drive® coupling, thereby allowing the motor to breakaway from the load and accelerate to full motor speed without 'locked rotor' current. The motor only experiences reduced 'in-rush' current due to the absence of the load and the resulting 'locked rotor' current. This initial quick start of the motor prevents the 'locked rotor' currents from developing in the motor windings since the coupling is spinning freely at this point in time.

As a result of these two time-varying events, the motor current is limited to well below the 'locked rotor' value. Testing of the coupling on a 25 HP motor reported in Section 4 Figure 13a shows that the maximum torque developed is 76 ft-lb during the start-up event. In the event that the motor experiences a sudden obstruction to the output rotor, the maximum torque that it can develop would be no more than the maximum amount that the coupling can transmit. In this case, therefore, the motor torque (and consequently, the current) is limited to the safe value of 134% of its full load rating. This unique feature of the Flux Drive® coupling provides an added safety feature to installations that are susceptible to temporary overloads.

This feature also reduces torque ‘spikes’ and torsional vibration that can often be created by the load and therefore protects the motor from damage that often results from a load shaft seizure event.

Figure 2 View of a Flux Drive® coupling

3. PERFORMANCE:

In order to achieve the optimum selection of the Flux Drive® products and the particular application, it is important to be familiar with the performance characteristics of this drive’s design. The following sections discuss various parameters that constitute the specifications of this adjustable speed drive or coupling.

i. Speed/torque characteristics:

Both the coupling and ASD have characteristics that are similar in appearance to induction motors but are unlike those of eddy-current couplings. Figure 3 shows the changes in maximum torque capability of these two drives with the slip-speed. The load speed is inversely proportional to the slip-speed since the motor is running at a constant speed. The speed/torque characteristics in Figure 4 were obtained from a test on a Flux Drive® coupling and show characteristics similar to those of induction motors. The starting and peak torque values are the familiar saddleback shape that can be modified with appropriate Rotor design changes, as is the case with induction motors.

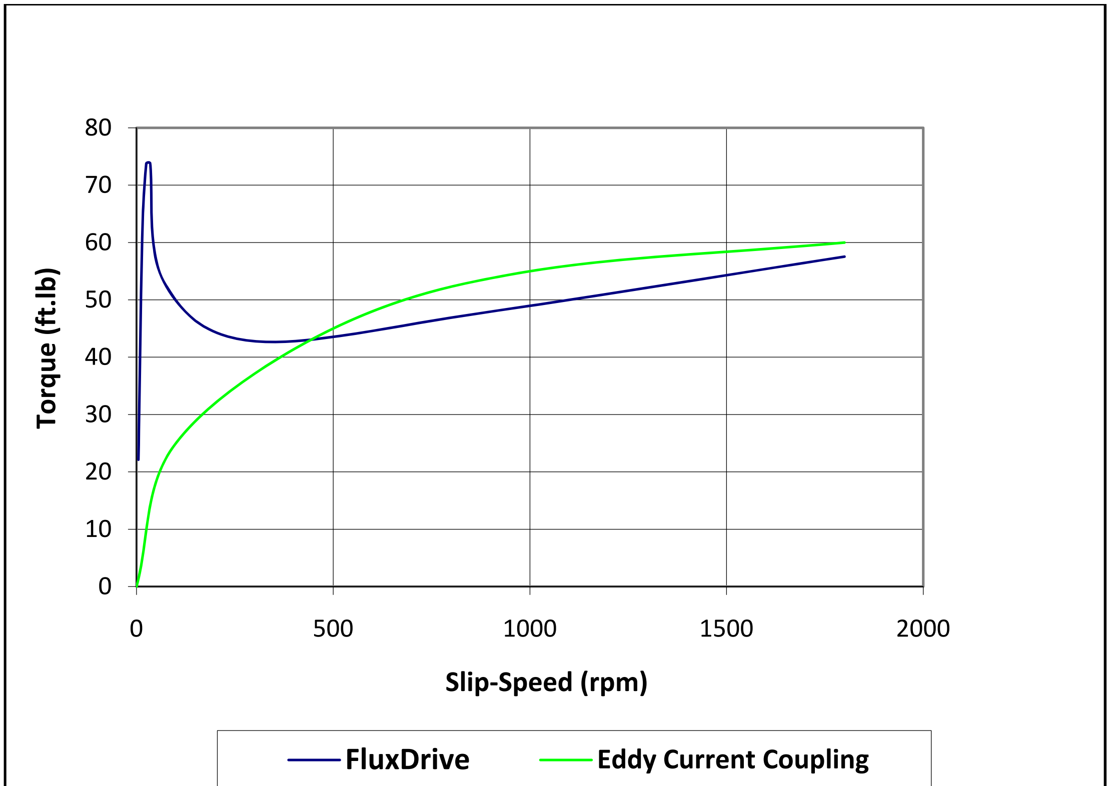


Figure 3 Calculated speed / torque characteristics of a Flux Drive® product

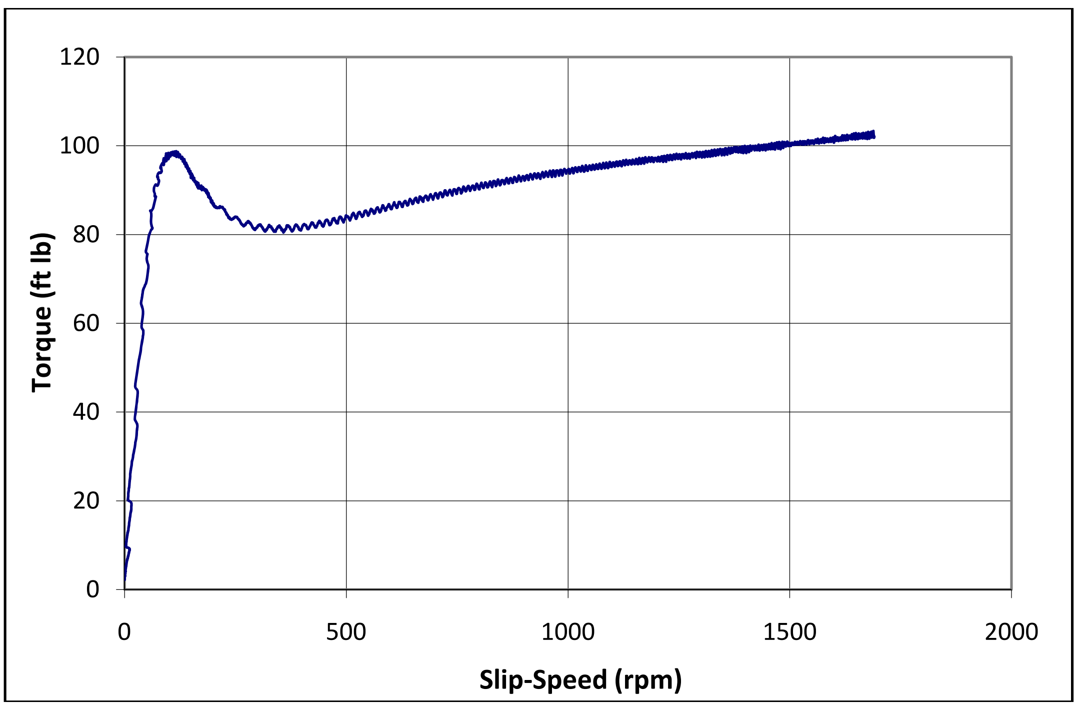


Figure 4 Experimental speed / torque characteristics of a Flux Drive® product

The percentage engagement (i.e., overlap) of the Can with the Rotor determines the amount of torque transmitted from the motor to the load and the speed at which the load shaft will operate. This is an adaptive situation in which the motor and load achieve a steady-state of operation at all engagement positions. The torque of the motor is transmitted without loss to the load via the Flux Drive® magnetic circuit at much higher torques and minimal slip.

The rating of a Flux Drive® ASD or coupling is based on the combination of two major parameters: 1) the maximum torque transmitted, and 2) the slip-speed corresponding to that torque. Figure 5 shows a family of speed/torque curves of a typical ASD drive at various amounts of engagement between Can and Rotor. The general shape of the curves in Figures 3, 4 and 5 differ from each other because they describe the performance of drives with different Rotor cage designs.

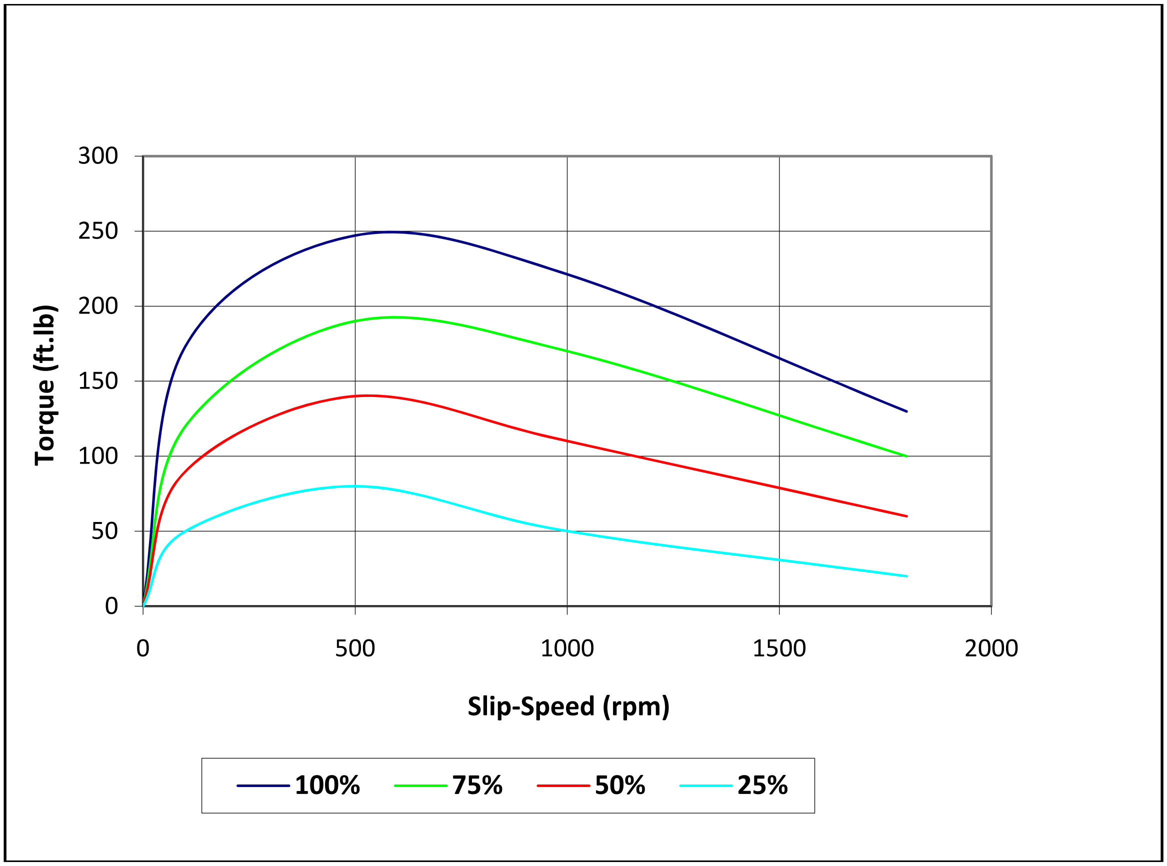


Figure 5 Calculated speed / torque characteristics at various % engagements

ii. Soft-start characteristics:

As mentioned in Section 2 above, the Flux Drive® coupling or ASD can be used to soft-start a motor's load as well as to adjust its speed. Various parameters were recorded as a 25 HP motor was started with the Flux Drive coupling compared to a standard flexible coupling. Figure 6 shows that the duration of the high start-up current is reduced substantially and is only a fraction of the time experienced with a rigid coupling. The power input to the motor is also reduced to approximately a third of its value, as seen in Figure 7. This is primarily because of the lower amounts of current necessary to accelerate the output shaft to full speed. The power factor is also improved as seen in Figure 8. Figure 9 shows that for this motor, even though the energy transferred with the Flux Drive® coupling takes more than twice as long to complete than with a rigid coupling, the startup power is reduced during most of that time.

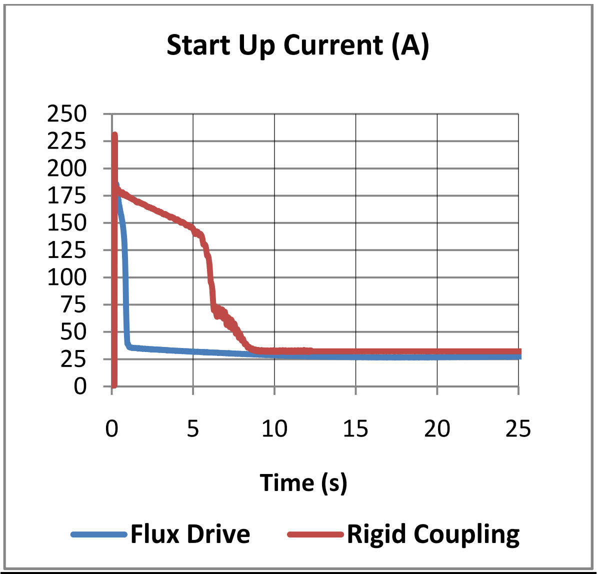


Figure 6 Start-up current with two couplings

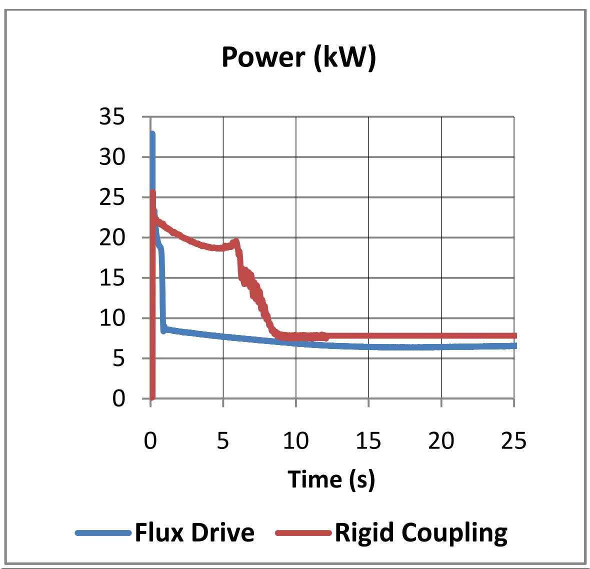


Figure 7 Input power with two couplings

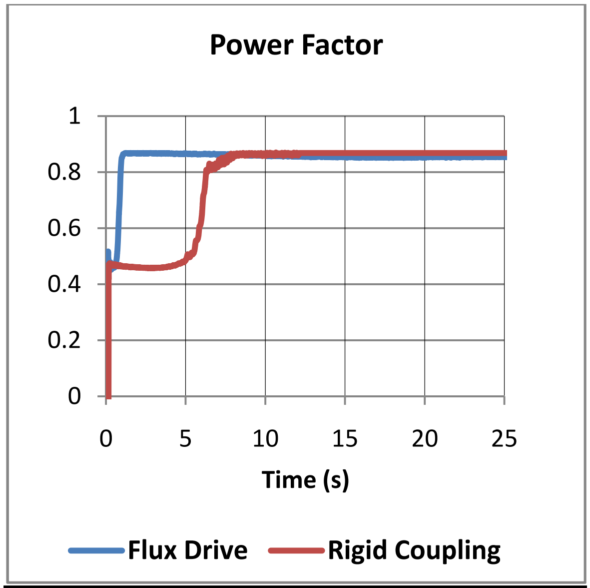


Figure 8 Power factor with two couplings

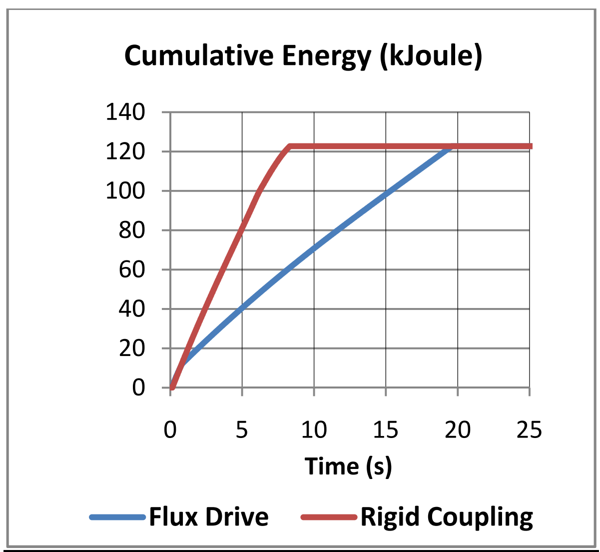


Figure 9 Shaft energy required to start load

iii. Efficiency:

The two types of loss discussed above constitute the total losses of the Flux Drive® products. There are no additional losses (i.e., mechanical or electronic) usually found in other types of drive (i.e., eddy-current or VFDs). This fact allows the Flux Drive® products to operate at higher efficiencies than other drives with similar loads. The following Figure 11 shows typical efficiency plots for three types of drive. This information was collected from published reports and studies (Ref. 1 & 2). It is clear from these reports and our tests that the Flux Drive® products, particularly when used as couplings, have the highest efficiency of all types of coupling, including VFDs and the most modern types of eddy-current coupling. There are of course, many disadvantages associated with the other drives as noted and discussed in Section 6 below.

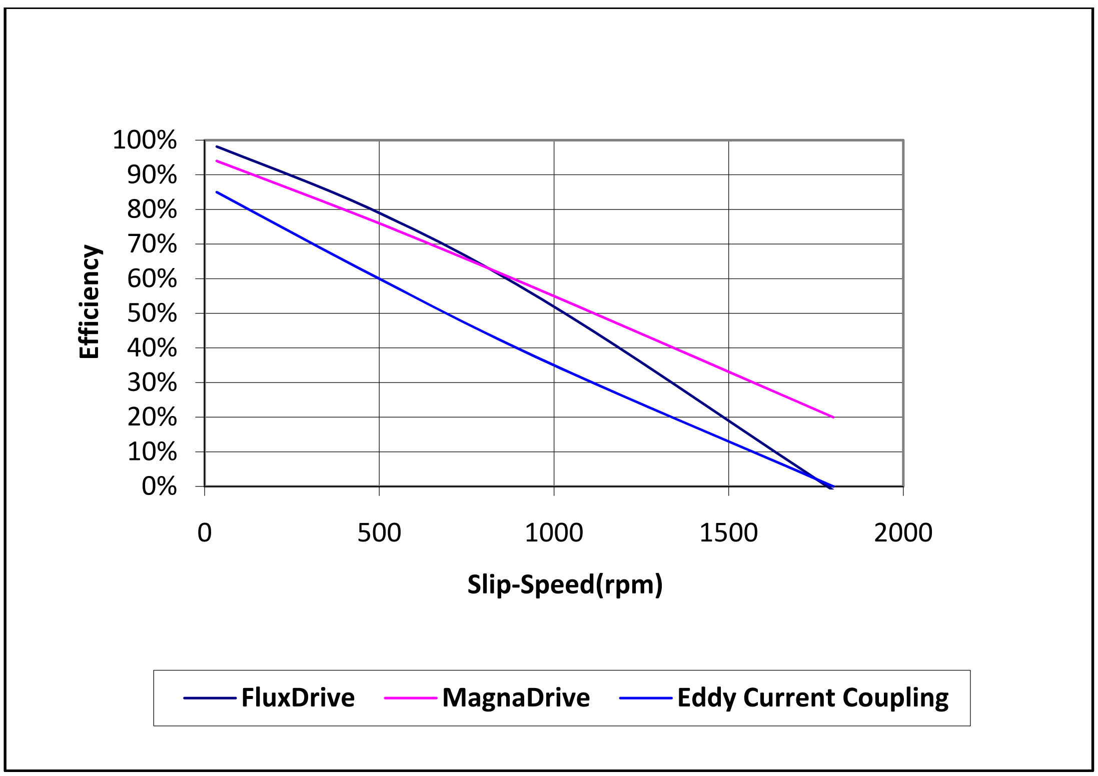


Figure 11 Efficiency plots of ASDs

iv. Affinity Laws:

Centrifugal loads follow what are called ‘affinity laws’. According to these laws, the changes in fluid-flow are proportional to speed. However, the required torque is proportional to the square of the change in speed and the horsepower is proportional to the cube of the change in speed. These relationships are confirmed by test as part of the performance of a Flux Drive® product as seen in the following Figure 12.

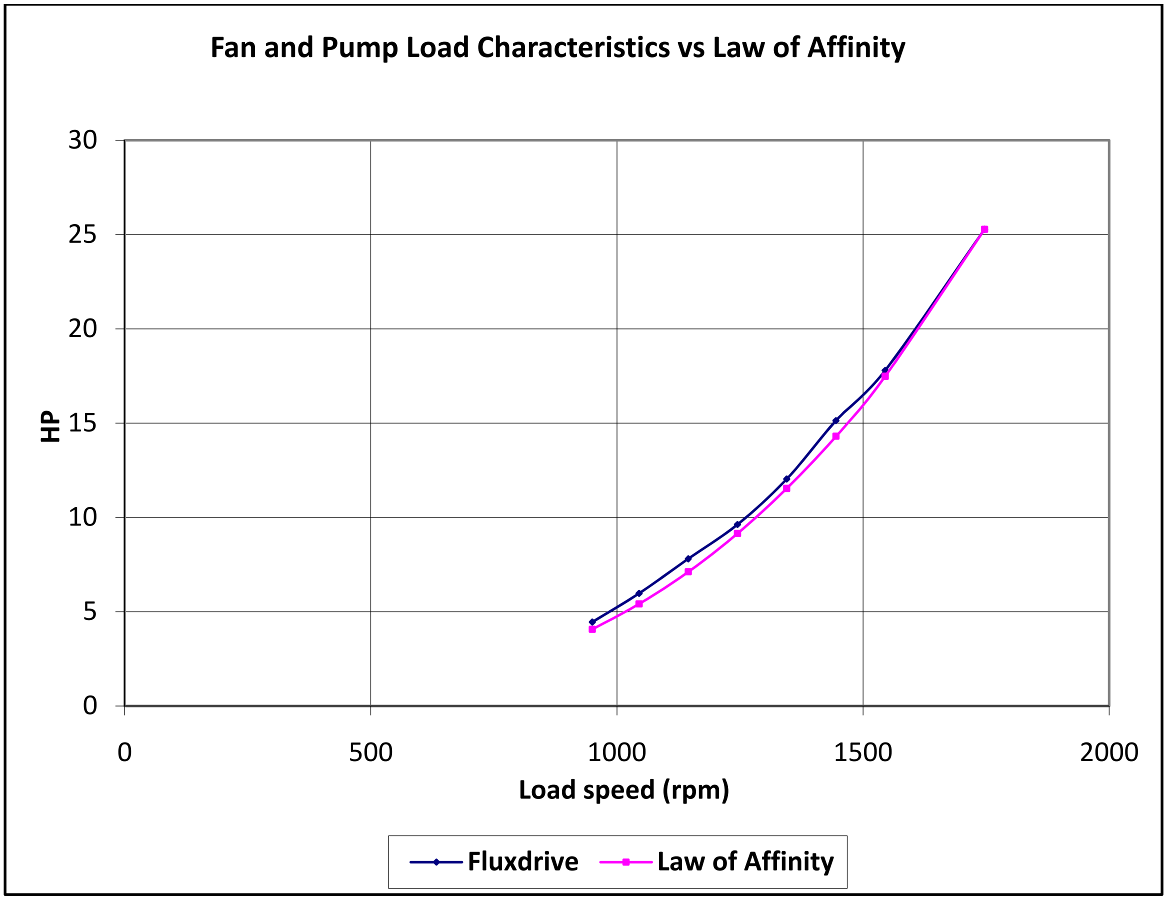
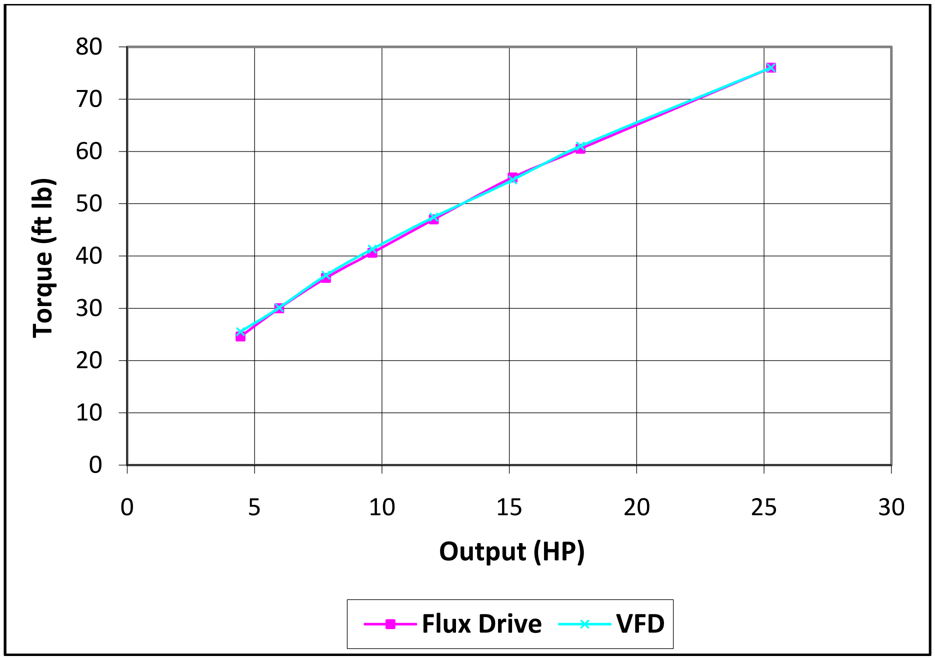


Figure 12 Flux Drive® vs. Laws of affinity

4. COMPARISONS:

A 3-phase, 1770 rpm, 25 HP induction motor driving a blower was utilized during extensive testing of a Flux Drive® ASD. A commercially available VFD of the similar power rating was also tested when connected without the Flux Drive ASD, using the same blower load. The test conditions were similar for both drives as shown in Figures 13 a&b. Torque and percentage slip were plotted against output power indicating that the load characteristics were constant.



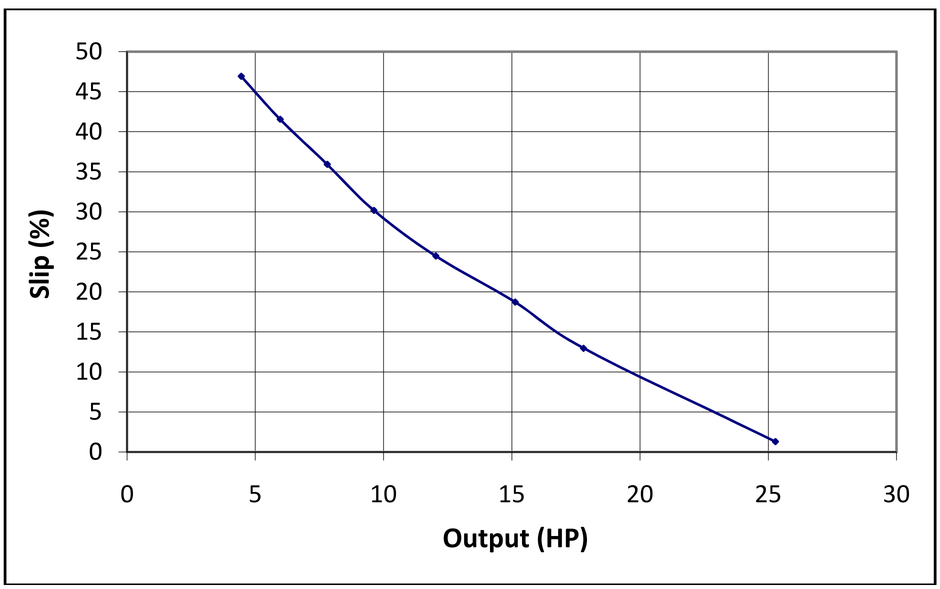


Figure 13 a&b Load conditions for both drives

The VFD rms current plotted in Figure 14 was measured with and without line reactors. The effect of improving the power factor by the line reactors is reflected in the lower values of current. This is confirmed by the comparison in power factor data plotted in Figure 15. When using a Flux Drive® ASD, the addition of power factor correction equipment is totally at the discretion of the user.

The Flux Drive® ASD provides an alternative advantage to the system: the preservation of low % total harmonic distortion (%THD). This is seen in Figure 16. The %THD is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency (Ref. 3). It is understood that the power factor is primarily influenced by the motor inductance, in contrast with the %THD which is a description of the harmonic content of the waveform. The measurement technique of these parameters is a complex task and is admittedly beyond the scope of this presentation.

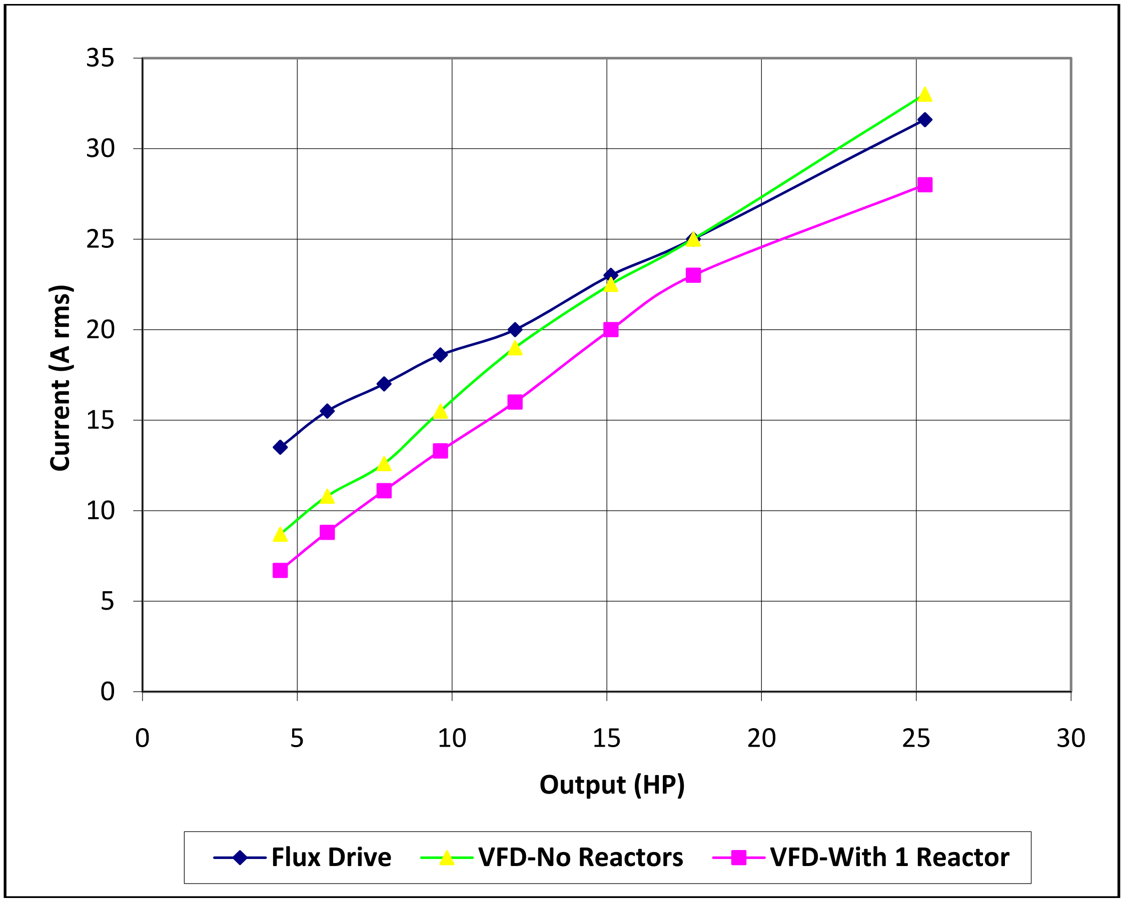


Figure 14 RMS current of both drives

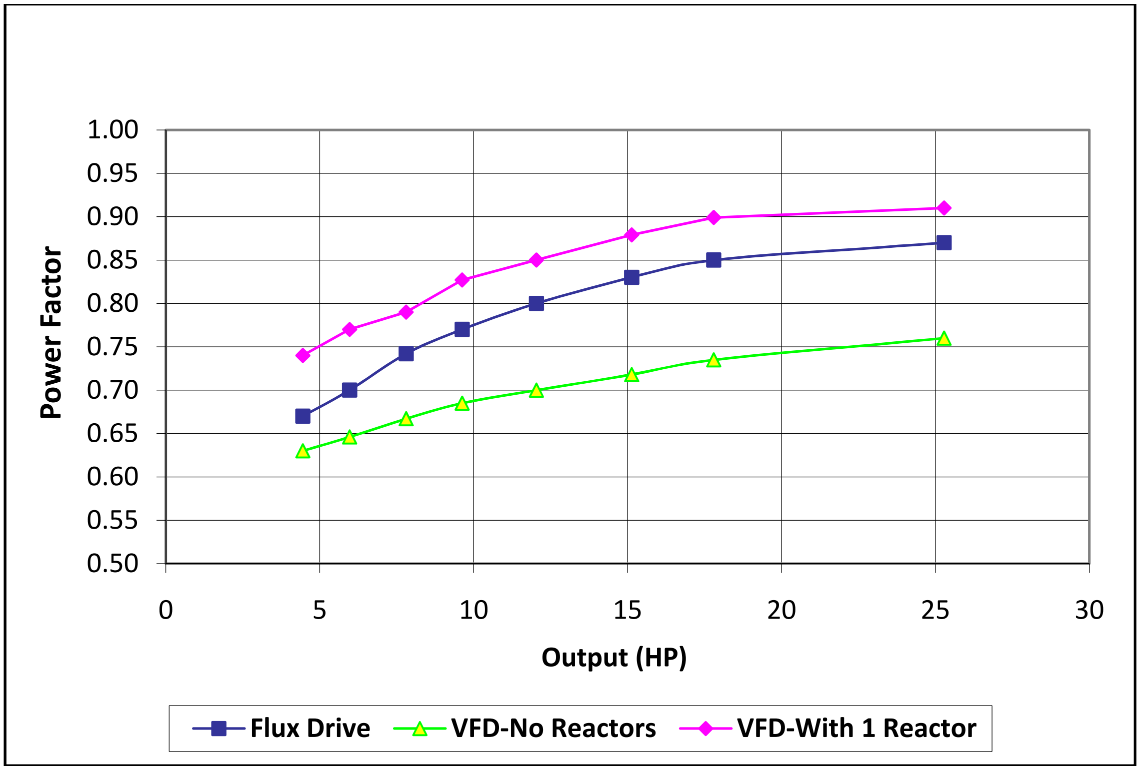


Figure 15 Power factor of both drives

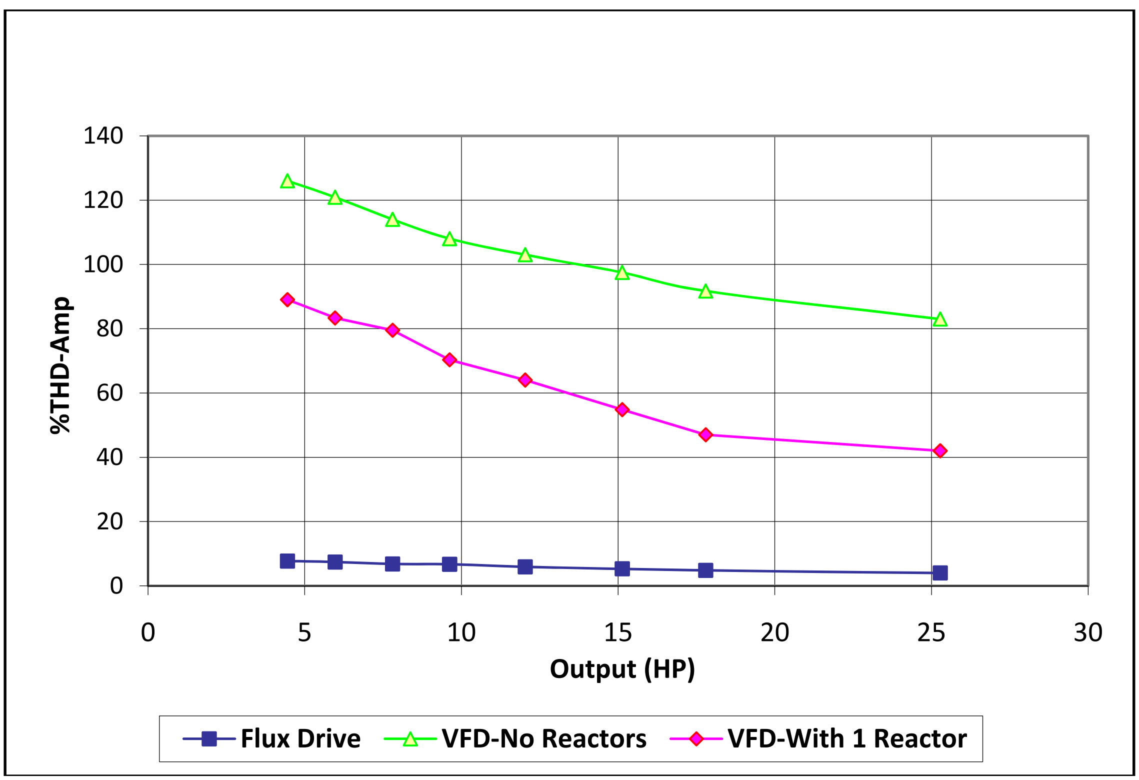


Figure 16 % THD of both drives

The major pieces of equipment used are as follows:

1. Motor: WEG Model 02518EP3E284T, 284T Frame, 25 HP, 1760 RPM, 460 V, 29.6 A, .85 PF
2. Load: Penn and Barry Blower, Size 021-61-AH, Class 15, APR- 10CW, Sheave Ratio 1.38:1
3. Torque Transducer: Binsfield Engineering Inc., Transmitter Model TX10K-S Receiver Model RX10K
4. VFD: Automation Direct - Dura Pulse Drive, Model GS3-4025, Rating 0-480 V, 25 HP, 38 amp, 28.9 KVA, 3 Phase, Frequency Range 0.1 to 400 Hz
5. Line Reactors: Automation Direct, Model GS-4025-LR, Type JR, 3 Phase, Dry Type, Iron Core Reactor
6. Dranetz: Model PowerXplorer PX5 Meter

5. CASE STUDIES:

Flux Drive® products have been installed in locations where they are relied upon for continuous operation after having shown measurable improvement in the performance compared to previously installed drives.

i. Blower Application:

A Flux Drive® coupling was installed between a 20 HP motor and a blower in a 30-year-old boiler room. Figures 18 a&b below show the old fluid drive coupling and the replacement Flux Drive® installation, respectively. This application is a 20hp, 1750 rpm motor driving a Forced Draft Fan for a small boiler through a fluid drive for speed control. The fluid drive is controlled by a pneumatic actuator that regulates the fan speed and airflow to the boiler.

Figure 18a old boiler coupling

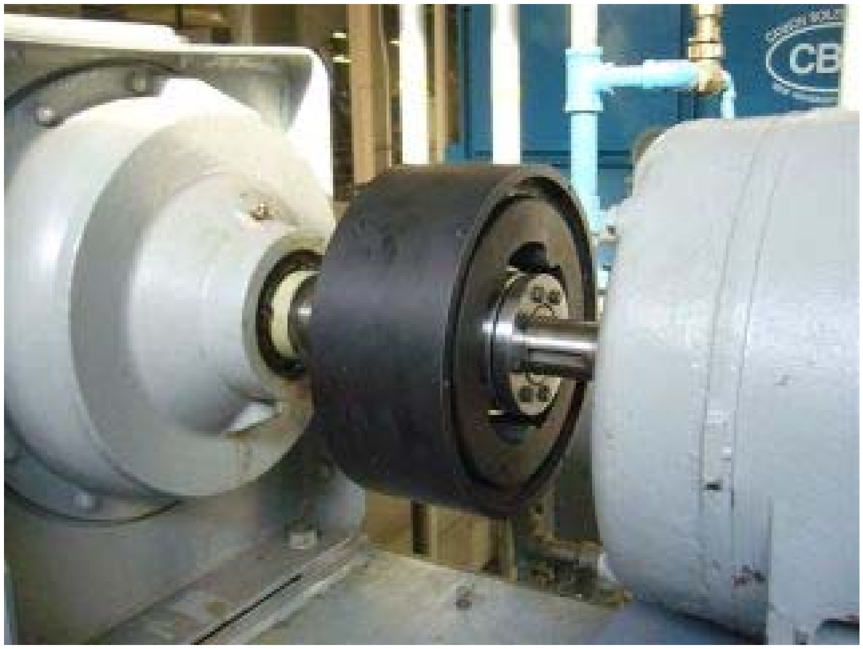


Figure 18b Flux Drive® coupling

ii. Pump Application:

A Flux Drive® coupling was installed between a 20 HP motor and a pump at an aquarium. Figures 19 a&b below show the old flexible coupling and the replacement Flux Drive® installation, respectively. The pump serves to circulate saltwater to an underwater dome exhibiting marine life that requires reliable operation.

Figure 19a old aquarium coupling

Figure 19b Flux Drive® coupling

6. CONCLUSION:

The goal in developing the Flux Drive® technology was to provide an alternative to current speed control options with similar or better performance. The result is a coupling and ASD with the following features:

- Reduce power required to operate machinery at variable speeds compared to VFDs and eddy current couplings,
- Eliminate introducing harmonic frequencies that cause distortion in the electrical systems
- Eliminate the need to install complex electronic filtering systems to reduce %THD to acceptable levels
- Reduce the ambient noise associated with VFDs and other competitive products,
- Reduce the life cycle costs of replacing and repairing expensive electronic components of other drives,
- Reduce peripheral costs (e.g., separate Filter rooms and air conditioning) involved with introducing a single (or multiple) VFDs to a system requiring speed control,
- Provide cost effective operations in harsh environments (saltwater, gases, etc.).
- Allow medium and high voltage applications to have an ASD that does not increase in price dramatically due to the higher voltage requirement of electronic drive products.

7. REFERENCES:

[1] *Product Testing: Magna Drive*, Motor Systems Resource Facility, Oregon State University, Report #00-048, March 2000.

[2] *Technology Demonstration of Magnetically-Coupled Adjustable Speed Drive Systems*, Pacific Northwest National Laboratory, PNNL-13879, June 2002.

[3] *Power Quality – Look Beyond the Symptoms*, Plant Engineering Web cast, event was broadcast on December 11, 2008