SECTION 6.2
SPEED-VARYING DEVICES

6.2.1 EDDY-CURRENT COUPLINGS

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DESCRIPTION

The eddy-current coupling is an electromechanical torque-transmitting device installed between a constant-speed prime mover and a load to obtain adjustable-speed operation. Generally ac motors are the most commonly used pump drives, and they inherently operate at a fixed speed. Insertion of an eddy-current slip coupling into the drive train will allow desired adjustments of load speeds.

In most cases, the eddy-current coupling has an appearance very similar to that of its driving motor except that the coupling has two shaft extensions. One shaft, which operates at constant speed, is connected to the motor, whereas the other shaft, providing the adjustable-speed output, is connected to the load. A typical self-contained air-cooled eddy-current slip coupling is shown in Figure 1.

The input and output members are mechanically independent, with the output magnet member revolving freely within the input ring or drum member. An air gap separates the two members, and a pair of antifriction bearings maintain their proper relative position. The magnet member has a field winding that is excited by direct current, usually from a static power supply. Application of this field current to the magnet induces eddy currents in the ring. The interaction between these currents and magnetic flux develops a tangential force tending to turn the magnet in the same direction as the rotating ring. The net result is a torque available at the output shaft for driving a load. An increase or decrease in field current will change the value of torque developed, thereby allowing adjustment of the load speed. Field current, output torque, and load speed are usually not proportional. Therefore load torque characteristics and speed range must be known for proper adjustable-speed drive size selection.

Most eddy-current couplings have load speed control. An integral part of this system is a magnetic pickup that provides an indication of exact output speed and enables control of load speeds within relatively close tolerances regardless of reasonable variations in load

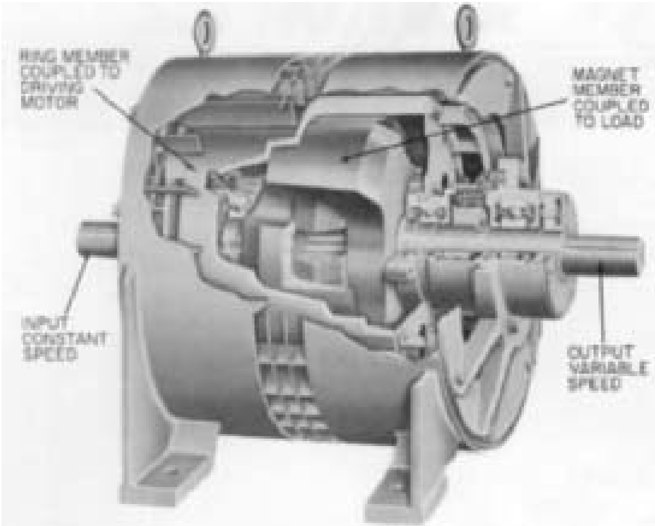

FIGURE 1 Cutaway of an Ampli-Speed eddy-current slip coupling (Electric Machinery Mfg.)

torque requirements. Slip-type adjustable-speed drives without load speed control will experience fluctuations in load speed when load torque requirements vary.

FUNDAMENTALS

The eddy-current coupling, like many other adjustable-speed drives, operates on the slip principle and is classified as a torque transmitter. This means that the input and output torques are essentially equal, disregarding frictional and windage losses. The motor input power is equal to the sum of load power and what is known as slip loss. This slip loss is the product of slip speed, which is the difference between motor and load speed, and the transmitted torque.

The various relationships may be expressed as follows:

In USCS units $$\text{Motor hp} = \frac{\text{rpm}_1 \times T}{5250}$$

In SI units $$\text{Motor kW} = \frac{\text{rpm}_1 \times T}{9545}$$

In USCS units $$\text{Load hp} = \frac{\text{rpm}_2 \times T}{5250}$$

In SI units $$\text{Load kW} = \frac{\text{rpm}_2 \times T}{9545}$$

In USCS units $$\text{Slip loss (hp)} = \frac{(\text{rpm}_1 - \text{rpm}_2) \times T}{5250} = \frac{\text{rpm}_3 \times T}{5250}$$

In SI units $$\text{Slip loss (kW)} = \frac{\text{rpm}_3 \times T}{9545}$$

This may be further expressed as follows:

In USCS units $$\text{Slip loss (hp)} = \frac{\text{rpm}_3}{\text{rpm}_2} \times \text{load hp}$$

In SI units $$\text{Slip loss (kW)} = \frac{\text{rpm}_3}{\text{rpm}_2} \times \text{load kW}$$

Or

In USCS units $$\text{Slip loss (hp)} = \frac{\text{rpm}_3}{\text{rpm}_1} \times \text{motor hp}$$

In SI units $$\text{Slip loss (kW)} = \frac{\text{rpm}_3}{\text{rpm}_1} \times \text{motor kW}$$

where rpm_1 = motor speed at designated load
rpm_2 = load speed at designated load
rpm_3 = slip speed at designated load
T = load torque, ft · lb ($N \cdot m$)

An eddy-current coupling must slip in order to transmit torque. The normal minimum value of slip for a centrifugal pump application is usually 3%, but values from 1 to 4% are common. The above formulas hold true regardless of the type of load involved.

The efficiency of an eddy-current coupling can never be numerically greater than the percentage that the output speed is of the input motor speed. This effectively takes into consideration only the slip losses, and a true efficiency value must also include frictional, windage, and plus excitation losses. The frictional and windage losses are constant for a fixed motor speed and therefore increase in significance with speed reduction. Excitation losses, on the other hand, decrease with reduction in output speed. The overall effect of these losses is an efficiency versus speed relationship that is somewhat linear with efficiency values anywhere from 1 to 4 points less than the output speed percentage.

LOAD CHARACTERISTICS

In the application of slip couplings for continuous pump loads, both variable- and constant-torque requirements are encountered.

Variable-Torque Loads Variable-torque loads are those where the torque increases with the speed and varies approximately as the square of the speed while the load power varies approximately as the speed cubed. The centrifugal pump fits into this classification. To be specific, the above torque-power-speed relationship exists only where the friction head is the total system head, as would be the case if a centrifugal pump were pumping from and to reservoirs having the same liquid levels or in a closed loop.

The various relationships of load power, motor power, and slip loss applying to a typical variable-torque load are shown in Figure 2—again frictional and windage losses have been disregarded.

Static heads, which usually exist in centrifugal pump systems, do not significantly affect the selection of a suitable slip coupling for a specific requirement. Pump efficiency, on the other hand, can be quite an important factor when it decreases significantly with speed reduction. Pumps with relatively flat efficiency curves are most desirable for adjustable-speed duty.

Centrifugal pumps usually operate against some static head. This causes the pump torque to follow a closed discharge characteristic until sufficient speed is reached to cause the resultant discharge head to equal or exceed the static head. This is equivalent to a closed discharge or normally unloaded condition. The pump load then follows a different curve to the full-load condition at minimum slip. These characteristics are illustrated in Figure 3. Curve *OAB* indicates the closed discharge power. At point *A* the static head is overcome, and

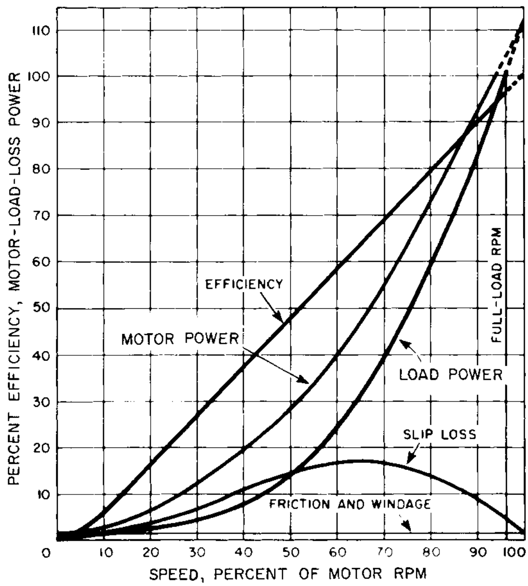

FIGURE 2 Load, power, and slip characteristics for a friction-only pumping system

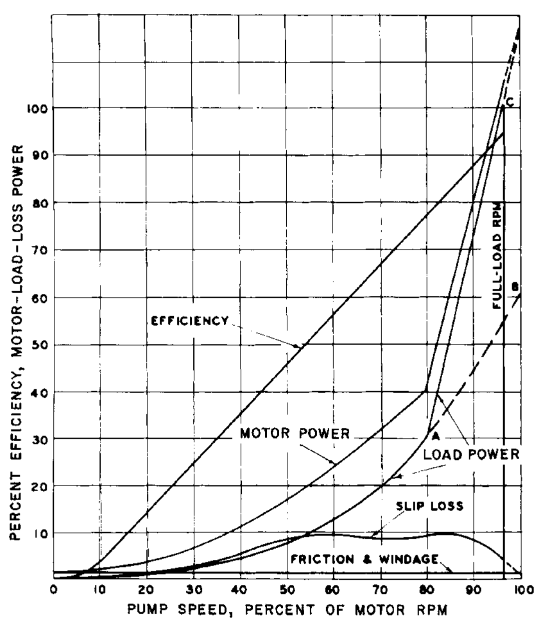

FIGURE 3 Percent efficiency, motor load loss power versus pump speed in percent of motor speed for a static head and friction pumping system

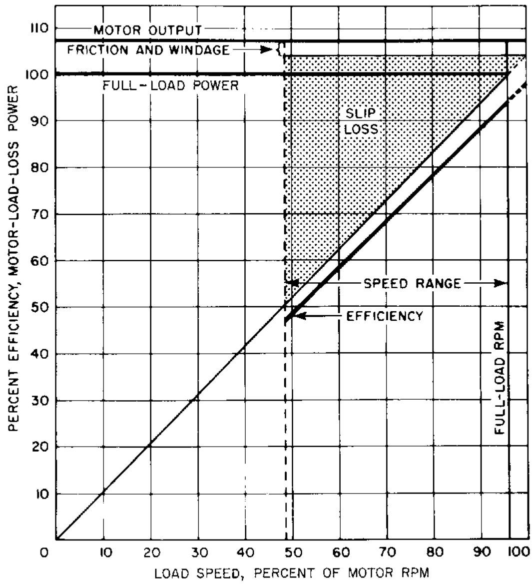

FIGURE 4 Power, torque, and losses for a constant-torque load

the pump load then rises along curve *AC*; this causes a significant difference in slip loss as shown. Under conditions as indicated, where static head is not exceeded and water does not start to flow until 80% of full speed is reached, the slip loss never exceeds 10% of the full-load rating. In general, this is true of a pump with high static head.

Constant-Torque Loads Constant-torque loads are those requiring essentially constant torque input regardless of operating speed. Positive displacement pumps generally are of this type. The load characteristics showing the division between slip loss and load power are illustrated in Figure 4. Note that the driving motor output does not change, regardless of load speed and power.

The slip loss characteristics make slip couplings undesirable for large power loads if any appreciable speed range is required. However, in relatively small units, the simplicity and ease of speed control will frequently justify the use of slip couplings instead of more efficient but more complex speed-control systems.

The constant-torque-load capacity of a slip coupling is largely limited by slip loss and, to a lesser degree, by breakaway torque and minimum slip. Because slip loss is directly proportional to slip, the desired speed range will definitely limit the torque, and therefore the power, that can be transmitted. In some cases, breakaway torque is important as the static friction may be quite high. It is usually recommended that at least 150% of starting torque be available for any constant-torque load.

CONSTRUCTION

Eddy-current couplings are available in both horizontal (Figure 5) and vertical (Figure 6) configurations as might be required for any pump mechanical arrangement. Horizontal machines in smaller sizes are frequently close-coupled to the drive motor in what is known as *integral construction.* Larger sizes are usually flexibly coupled to the drive motor and pump load.

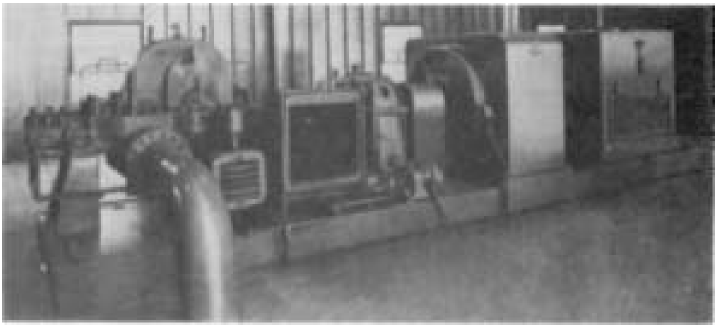

FIGURE 5 Horizontal centrifugal pump driven by a 1000-hp (746-kW), 1780-rpm induction motor through a stepup gear and an eddy-current coupling (Electric Machinery)

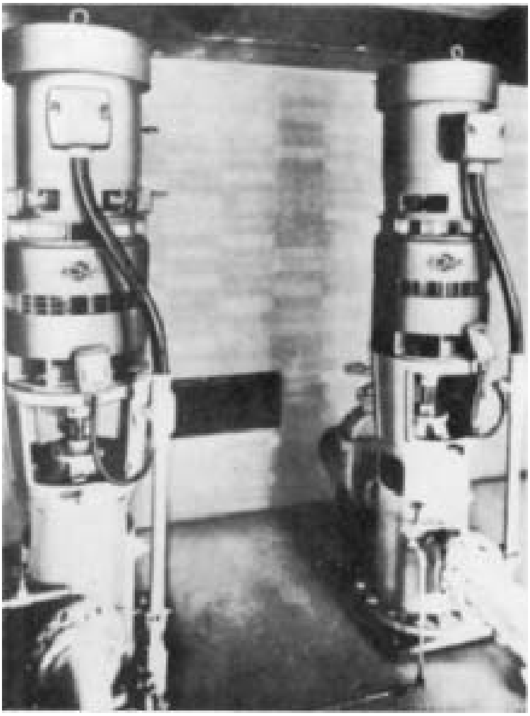

FIGURE 6 Vertical centrifugal pumps driven by 40-hp (30-kW), 1750-rpm induction motors and eddy-current couplings (Electric Machinery)

Vertical motors and slip couplings are close-coupled to limit overall height and to prevent vibration problems. Pump hydraulic thrust requirements can be accommodated, when necessary, in much the same way as in constant-speed motor applications. Because of mechanical limitations, thrust bearings are frequently located in the bottom of the adjustable-speed drive.

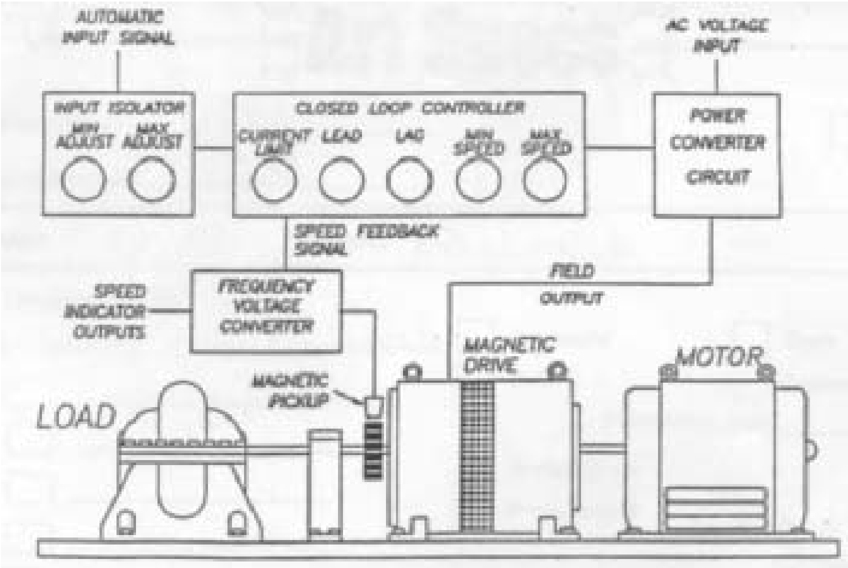

FIGURE 7 Interconnection block diagram of eddy-current clutch and speed control

Enclosures available will vary depending on the type of cooling involved. Obviously water-cooled types need little if any enclosure adaptation for virtually any installation. However, caution should be exercised in outdoor use where freezing can occur. Also, vertical installations utilizing water cooling may require special considerations.

Air-cooled couplings are more universally used for centrifugal pump loads but do require attention on enclosure design. Indoor installations in clean atmospheres need only open or drip-proof enclosures where heat rejection is not a problem. In some cases, intake and discharge covers for connection to ductwork may be necessary for environmental isolation.

Weather-protected enclosures are available for outdoor installations, A NEMA Type I rating is normally adequate because of the slip coupling's inherent mechanical design and relatively low field winding voltage levels.

CONTROLS

The speed control is designed to operate with a magnetic drive equipped with a magnetic pickup. The controller contains a signal isolator to allow precise speed adjustment from an automatic 4–20 ma (milliamperes) of 0–10 VDC (volts DC) control signal. The control has a closed loop control circuit, field firing circuit, current feedback loop, and SCR (silicon-controlled rectifier) power stage for controlling the output speed of the magnetic drive. The control also has an acceleration/deceleration ramp circuit that is an integral part of the control circuit for smooth acceleration of the load—especially important for many types of pump loads.

The input signal is fed through an isolation circuit or from the manual speed adjustment pot to the controller circuit. The controller circuit outputs a regulated voltage and current to the field firing circuit. This voltage/current output is also regulated by the current feedback sensed by the resistor network and the speed signal from the magnetic pickup to assure precise speed regulation. The field firing circuit regulates the firing timing of the SCRs. By using multiple loopback feedback circuits, speed regulation is held with .2% of the set speed.

The controller circuit has a current limiting adjustment that controls the maximum current from the SCR circuit to the drive field to eliminate any excess current in the drive coils. This protects from overpowering the drive and causing unnecessary heating.

The controller power circuits convert 120–480 VAC (volts AC) into DC voltage. The DC voltage is converted to the required voltage of the drive field by the SCR firing circuit using pulse width modulation. The circuits are protected by circuit breakers and metal oxide varistors.

APPLICATIONS

Slip couplings are applied to centrifugal pumps for water and waste-water pumping in municipal installations, for boiler-feed pumping, for circulating water and condensate pumping in power plants, for fan and stock pumping in paper mills, and for reciprocating pumping in a multitude of applications and industries.

In the water and waste-water fields, slip couplings are used extensively for raw- and finished-water pumping, lift-station pumping, raw-sewage pumping, and effluent and sludge pumping. Almost any pumping problem, where cyclic constant-speed pumping or throttling or other means of flow control are alternate considerations, can be conveniently solved with the use of an eddy-current slip coupling as the adjustable-speed flow controlling device.

Potable water treatment and distribution facilities are continually confronted with substantial fluctuations in demand through daily, weekly, and even seasonal periods. Distribution systems that depend on direct pumping usually must utilize total or partial adjustable speed operation for high-service and booster requirements. The quick response of eddy-current slip couplings makes them extremely well suited for this duty.

Waste-water collection systems, where inflow conditions to lift stations and treatment plants vary widely throughout the day, can realize many advantages when designs are based on adjustable speed with eddy-current slip couplings.

RATINGS AND SIZES

Eddy-current couplings are available in a wide range of ratings and sizes, from fractional power units up through 10,000 hp (7500 kW) and beyond. The type of cooling employed is an important consideration; some manufacturers use either water or air exclusively and others use a combination of the two. In addition, the type of load is a factor because thermal capability will vary significantly between water- and air-cooled units.

Centrifugal pump variable-torque loads are usually best handled by air-cooled couplings having high-torque capabilities at low slip values and limited heat-dissipating capabilities. The selection chart shown in Table 1 is representative of one manufacturer's line of couplings designed specifically for centrifugal pump loads. Where full-torque capabilities are realized at 3% slip below motor speed, thermal loads at two-thirds of motor speed will be 16.2% of rated speed load power. Sizes starting at 3 to 5 hp (2.2 to 3.7 kW) and extending up through 3000 to 5000 hp (2240 to 3730 kW) are generally available.

Eddy-current couplings for pump loads requiring constant-torque drives have rather limited usage. In small sizes where thermal capabilities are proportionately greater than the 6:1 ratio encountered on large units, constant-torque loads can be adequately handled by air-cooled couplings. Beyond 100 hp (75 kW), air-cooled units can be impractical because of thermal and starting-torque requirements.

Water-cooled eddy-current couplings have somewhat different characteristics, making them more suitable for constant-torque and large-power variable-torque loading. High starting torque, high minimum slip, and high thermal capabilities all tend to lead to those conclusions. Thermal capabilities are frequently equal to or greater than full-load power ratings. The starting torque is usually the maximum torque, and as a result low slip values are limited.

TABLE 1 Eddy-current coupling selection chart for centrifugal pumps, horsepower output (1hp = 0.746 kW)

		Percent of motor full-load speed			
Drive motor input speed, rpm	Unit Size	99	98	97	96
1750	S209	370	420	405	395
	S238	630	610	597	579
	S276	820	800	775	750
	S326	1150	1100	1065	1030
	S376	1800	1750	1700	1650
1150	S209	160	290	305	295
	S239	400	470	455	442
	S276	440	615	600	580
	S326	910	870	844	818
	S376	1300	1270	1230	1190
870	S209	100	170	225	240
	S239	250	336	375	364
	S276	300	355	490	480
	S326	650	718	696	675
	S376	1100	1080	1050	1000
700	S209			160	185
	S238			200	210
	S239	170	250	316	316
	S276	250	310	365	375
	S326	420	580	597	579
	S376	950	920	900	860
585	S209			110	135
	S238			140	160
	S239			223	270
	S276		240	270	280
	S326	300	510	520	507
	S376	430	610	600	576
495	S209				100
	S238				135
	S239				200
	S276			205	235
	S326	220	380	410	460
	S376	740	710	700	670
435	S209				80
	S238				115
	S239				167
	S276				190
	S326	170	310	330	390
	S376	640	670	650	630
385	S276				150
	S326			275	320
	S376	530	600	585	565
	S448	650	950	1000	980
	S529	1650	1790	1750	1680

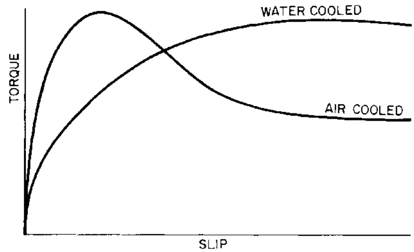

FIGURE 8 Speed-torque curves for variable-torque air-cooled and constant-torque water-cooled couplings

TABLE 2 Typical eddy-current coupling downthrust capabilities, lb[a]

	Motor speed, rpm					
Unit size	1,750	1,150	870	700	585	495
S209	2,920	3,530	4,080	4,580	4,860	5,180
S239	2,240	2,860	3,410	3,910	4,190	4,500
S276		3,900	4,605	5,170	5,670	6,150
S326		2,545	3,260	3,810	4,290	4,780

[a] 1 lb = 4.45 N.

Figure 8 illustrates the differences in the speed-torque curves of variable-torque air-cooled and constant-torque water-cooled couplings.

THRUST CAPABILITIES FOR VERTICAL UNITS

Most vertical eddy-current couplings have limited external downthrust load capabilities when provided with standard bearing arrangements. Typical values are listed in Table 2 for the sizes listed in Table 1. Bearing life is an important factor, and the values shown are based on a minimum life of five years in accordance with manufacturer's standards at an average output speed of 85% of input speed. Bearings are angular-contact ball type with grease lubrication. Where higher thrust values are encountered or where longer bearing life or adherence to ABMA life standards must be met, spherical roller bearings or plate-type hydrodynamic thrust bearings with oil lubrication can be furnished.