NATIONAL
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PROGRAM

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Cathode-Disconnect Ballasts

Rapid-start electromagnetic ballasts that do not supply
electrode-heating voltage during lamp operation

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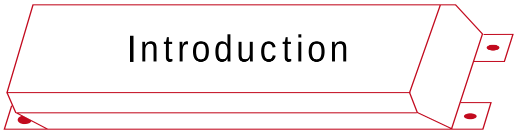

Introduction

One of the simplest ways to improve the energy efficiency of a fluorescent lighting system is to use an energy-saving ballast. The standard magnetic ballasts that were popular in the 1960s and 1970s consumed as much as 17 percent of a fluorescent lighting system's active power. The manufacture and sale of such high-loss magnetic ballasts for many types of lamps were banned in the United States by the National Appliance Energy Conservation Act (NAECA) of 1990. In Canada, although there is presently no national legislation, a similar ban on high-loss ballasts was enacted in 1992 in three Canadian provinces: British Columbia, Nova Scotia, and Ontario.

Today, several ballast options are available for replacing old ballasts or installing a new lighting system. Energy-efficient magnetic ballasts are usually the least-expensive option. They are similar to old high-loss ballasts, except that they use higher-grade materials, such as copper windings instead of aluminum, to reduce internal losses. More expensive, and more energy-efficient, are electronic ballasts, which use solid-state components to start and regulate lamp operation.

Cathode-disconnect ballasts fall between these technologies in both price and performance. They are also known as "heater-cutout ballasts," "cathode-cutout ballasts," "filament-cutout ballasts," and "hybrid ballasts." In this report, the term *cathode-disconnect ballast* is used to describe an electromagnetic ballast that disconnects the electrode-heating circuit after the lamps are started and that operates the lamps at 60 hertz (Hz).

For this issue of *Specifier Reports*, the National Lighting Product Information Program (NLPIP) collected performance data from all three of the major North American manufacturers of cathode-disconnect ballasts and also performed independent evaluations of product samples submitted by manufacturers and products purchased on the open market.

The production of this report involved important contributions from many people. LRC members who contributed include J. Barrett, P. Boyce, J. Ceterski, K. Conway, C. DeCusatis, D. Maniccia, M. Rea, K. Sasiadek, and Q. Wang.

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Methods of Starting Lamps

There are three main methods that ballasts use to start fluorescent lamps: preheat, rapid-start, and instant-start.

Preheat
In preheat operation, the lamp electrodes are heated for several seconds to a temperature of approximately 800°C (1470°F) to 1000°C (1830°F). When the proper electrode temperature is reached, a starter switch opens, allowing a voltage of approximately 200 volts (V) to 300 V (for 40-watt T12 lamps) to be applied across the lamp, striking the arc between the electrodes. Preheat operation is characterized by the lamp flashing on and off for a few seconds before finally staying lit. All early fluorescent lighting systems used preheat ballasts, but they are now used mostly with lower-wattage fluorescent lamps in applications such as under-cabinet lighting and desk lamps and in most magnetically ballasted compact fluorescent lamps. Preheat ballasts weigh less and are less expensive than other types of magnetic ballasts.

Rapid-start
Rapid-start ballasts have a separate set of windings that provide a low voltage (about 3.5 V) to the electrodes, heating them to a temperature of approximately 1000°C (1830°F) in 1 to 2 seconds. The starting voltage of 200 V to 300 V is then applied across the lamp. Except for rapid-start cathode-disconnect ballasts, the electrode heating voltage is supplied even after the lamp has started, which results in electrical losses of about 3 to 4 watts for each lamp that the ballast is operating. Rapid-start ballasts start lamps smoothly, without flashing. Some are dimmable. Rapid-start ballasts are the most popular option for 4-foot fluorescent lamps. All of the cathode-disconnect ballasts described in this report are rapid-start ballasts.

Instant-start
Rather than heating the electrodes prior to starting, instant-start ballasts supply a high initial voltage (over 400 V) to strike the arc. The high voltage is required to initiate the discharge between the unheated electrodes. Because the electrodes are not heated either before or during operation, instant-start ballast systems have lower electrical losses than rapid-start ballast systems. Instant-start ballasts are more expensive than other magnetic ballasts. They also reduce lamp life at short burning cycles, because the high initial voltage accelerates the degradation of the emissive coating on the electrodes. Lamps that are operated for an average of 3 hours per start may experience lamp life reduction of as much as 25 percent, compared with rapid-start operation. At longer burning cycles (such as 8 hours per start), however, the difference between instant-start and rapid-start lamp life may diminish. Instant-start ballasts typically are used for 8-foot lamps. Many electronic ballasts are instant-start.

Like ballasts, fluorescent lamps are also categorized by starting method, and they require a matching ballast for best performance. For example, an instant-start ballast will start a rapid-start lamp, but the lamp life may be shortened by the high starting voltage. Instant-start lamps are easily distinguished from other lamp types because most of them have only one pin at each end instead of two (the second pin is for the electrode-heating circuit). The table below shows the effects of using different ballast types with different lamp types.

Effects of Mismatching Ballast and Lamp Types

	Preheat ballast	Rapid-start ballast	Instant-start ballast
Preheat lamp	Normal operation	Unreliable starting	Unreliable starting; shortened lamp life
Rapid-start lamp	Normal operation	Normal operation	Shortened lamp life
Instant-start lamp	Will not start	Will not start	Normal operation

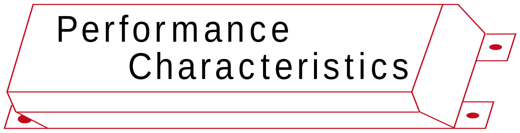
Another factor affecting lamp starting is ambient temperature. Ballasts that are designed for indoor operation, as are all of the ballasts that were tested for this report, are intended for use at an ambient temperature of about 25°C (77°F). At lower temperatures, a higher starting voltage is required to successfully strike the arc. Therefore, in cold temperatures, lamps may have difficulty starting or may not start at all.

Background

The first ballasts for fluorescent lamps were “core-and-coil” electromagnetic ballasts, which used a heavy magnetic core of several laminated steel plates wrapped with copper windings. To reduce manufacturing costs, aluminum windings eventually replaced the copper, and lower grades of steel were used for the core. These standard magnetic ballasts were inexpensive to manufacture, and even though they consumed as many as 16 watts in the process of operating two 40-watt T12 lamps (96 total watts), fluorescent lighting was much more energy-efficient than incandescent lighting. Later, in an effort to reduce the heat output of ballasts, manufacturers returned to using copper windings and high-grade steel cores. In addition to reducing heat output, these higher-quality materials increase the energy efficiency of the ballast, saving about 8 watts (when operating two 40-watt T12 lamps; 88 total watts). The 1990 NAECA requires all ballasts for commercial fluorescent lighting systems to have efficiencies greater than or equal to those of energy-efficient magnetic ballasts. As a result, standard magnetic ballasts are no longer sold for commercial applications in the United States, although they still are in use in many older buildings.

In North America, all magnetic ballasts, including cathode-disconnect ballasts, operate lamps at a frequency of 60 Hz. This means that the phosphors are refreshed 120 times per second, which is fast enough to give the appearance of a steady light source even though the light pulses rapidly. Shortly after the 1938 introduction of the fluorescent lamp, it was discovered that when fluorescent lamps were operated at significantly higher frequencies (above 20 kHz), they produced 10 to 15 percent more light than at 60 Hz. For many years it was not technologically feasible to use high-frequency operation, but recent advances in solid-state technology allowed ballast manufacturers to replace the core and coil with electronic components that operate lamps at 20 to 60 kHz. These high-frequency electronic ballasts can provide a wattage reduction of 18% (16 watts) compared to an energy-efficient magnetic ballast operating two 40-watt T12 lamps, with a light output reduction of about 6 percent (see Table 1 on p. 5). Another advantage of electronic ballasts is that some models can operate up to four lamps; energy-efficient magnetic ballasts usually can only operate either one or two lamps. This issue of *Specifier Reports* discusses electronic ballasts only as they compare with cathode-disconnect ballasts. For more information about electronic ballasts, including manufacturer-specific performance data, see Volume 1, Issue 1 of *Specifier Reports*, published December 1991.

To further refine the energy-efficient magnetic ballast, manufacturers added components that disconnect the electrode-heating voltage after the lamp has started (see sidebar, "Lamp Starting Methods"). Although cathode-disconnect ballasts cost more than energy-efficient magnetic ballasts, they are not as expensive as electronic ballasts, as shown in Table 1 on p. 5. Compared with energy-efficient magnetic ballasts, rapid-start cathode-disconnect ballasts maintain the same light output and can save approximately 6 to 8 watts when operating two 40-watt T12 lamps (80 to 82 total watts). For additional energy savings (69 to 71 total watts), cathode-disconnect ballasts also are available that operate lamps at a light output that is reduced by 10 to 12 percent, compared with energy-efficient magnetic ballasts. Both full-light-output and reduced-light-output cathode-disconnect ballasts are discussed in this report. Active power and initial light output for several lamp/ballast combinations are shown in Table 1 on p. 5.



Performance Characteristics

Lamp Operation and Lamp Life

For all ballast types, the lamp voltage can be decreased from the high starting voltage to around 100 V once the arc is established. Rapid-start energy-efficient magnetic ballasts then continue to provide about 3.5 V to heat the electrodes during lamp operation. Combined with the electrode heating that results from the arc discharge, the average temperature of the electrode is approximately 1100°C (2010°F) during lamp operation (Verderber *et al.* 1985).

Conversely, a cathode-disconnect ballast stops heating the electrodes once the lamp is operating. The resulting average electrode temperature during lamp operation is approximately 600°C (1110°F) (Verderber *et al.* 1985). Although the evaporation of the emissive coating is reduced at this lower temperature, lamp electrode sputtering may increase, possibly resulting in reduced lamp life (see sidebar, "Lamp Sputtering").

Interaction Effects

Ambient temperature and input voltage both affect the performance of fluorescent lighting systems. Temperature affects both the light output and power consumption of fluorescent lamps by altering the pressure of the mercury vapor inside the lamps. If lamps are either too cold or too hot they will not produce their full rated light output. The cold-

Electrodes, Cathodes, and Anodes

Electrodes are located inside a fluorescent lamp at both ends of the glass tube. Electrons are emitted from one electrode, called the cathode, and gathered at the other electrode, called the anode. Fluorescent lamps are operated by alternating current, so both electrodes alternate serving as cathode and anode. Therefore, throughout this report the term *electrode* is used to describe both the cathode and the anode.

Lamp Sputtering

To assist in lamp starting, the tungsten filaments of lamp electrodes are coated with a material that easily emits electrons when heated. The material may contain barium, strontium, or calcium oxide. With preheat or rapid-start ballasts, including cathode-disconnect ballasts, voltage is first applied to heat the electrodes prior to lamp starting. The emissive coating releases electrons that ionize the mercury vapor surrounding the electrodes. The starting voltage is then applied across the lamp electrodes to strike the arc that ionizes the mercury vapor throughout the lamp. Ions strike the electrode filament with such force that part of the electron-emitting coating can erode. If the electrodes are heated before the starting voltage is applied, a relatively low voltage of 200 to 300 V can be applied to strike the arc with a minimum of erosion. If the electrodes are not heated prior to the lamp starting, for example, with instant-start operation or when there is poor contact between the lamp and lamp holders, then a higher starting voltage is required to successfully strike the arc. At higher starting voltages, ions strike the electrodes with greater force, which increases the erosion of the emissive coating in a phenomenon known as lamp electrode sputtering. Lamp electrode sputtering during starting is the chief cause of shortened lamp life. Lamp electrode sputtering also can occur during normal lamp operation and may increase at reduced electrode temperatures, such as those that occur with cathode-disconnect ballasts.

Another way that the emissive coating can degrade is through evaporation, which can occur either during lamp starting or during lamp operation, when electrodes are heated to temperatures exceeding 1000°C (1830°F). Cathode-disconnect ballasts do not heat the electrodes during lamp operation, so evaporation of the emissive coating during lamp operation is minimized.

est spot on a lamp's bulb wall is where the mercury vapor will tend to condense, because the pressure is lowest there. A 40-watt T12 fluorescent lamp produces the most light when this minimum bulb wall temperature is approximately 38° C (100° F).

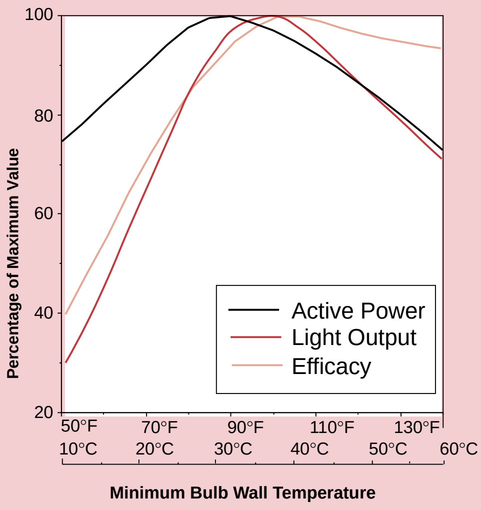
Figure 1 illustrates how ambient temperature affects light output, active power, and system efficacy. For indoor applications, overheating of lamps is more common than underheating, because lamps are often enclosed in luminaires that trap heat. Light output reductions of as much as 20 percent are common for lamps operated in 2- foot by 4- foot lensed luminaires. Because cathode-disconnect ballasts draw less power than energy-efficient magnetic ballasts, they generate slightly less heat. Also, the lamps themselves are cooler because the electrodes are not heated during operation. This increases the likelihood that lamps will operate closer to their optimal performance in an enclosed luminaire. Reduced-light-output cathode-disconnect ballasts operate at even lower power, possibly further increasing thermal efficacy gains.

Fluctuations in supply voltage can also affect light output by either overdriving or underdriving the lamps. The cathode-disconnect ballasts covered in this report are all designed to operate at either 120 V or 277 V. Nearly all ballasts are designed to operate lamps while the supply voltage is within ±10 percent of the designed operating voltage. Outside of this range, lamps may not operate properly. Within this range, the light output from lamps that are operated by magnetic ballasts (including cathode-disconnect ballasts) will decrease when the voltage is low and increase when it is high. Some electronic ballasts are designed to adjust lamp current to compensate for voltage fluctuations, thereby maintaining a constant light output.

Root-Mean-Square (rms)

The term *root-mean-square* refers to the procedure used to calculate the average value of a periodic waveform, such as voltage or current. Mathematically, it is the square root of the mean of the squared values, volts or amps, taken over one complete cycle. Thus, the term *rms voltage* expresses the average voltage.

Figure 1. Effect of Temperature on Performance Characteristics



As the temperature of a fluorescent bulb increases, both the light output (red curve) and the active power consumption (black curve) also increase. However, as the temperature rises above 32°C, the power consumption gradually begins to decrease. The light output continues to increase until the temperature reaches approximately 38°C, at which point it begins to drop dramatically. The system efficacy (pink curve), defined as light output divided by active power, is therefore maximized at approximately 40°C. (Adapted from the *IES Lighting Handbook: 1984 Reference Volume.*)

Lamp Current Crest Factor

Lamp current crest factor (CCF) is the ratio of peak lamp current supplied by the ballast to the root-mean-square (rms) current; rms current is the average value of the current. A high lamp CCF indicates that the current wave shape has high peaks, or "spikes," that can reduce lamp life. A lower lamp CCF generally indicates a smoother current wave shape. The CCF for a sine wave is 1.41. As lamp CCF rises, lamp life may decrease. A lamp CCF of 2.0 may reduce lamp life by 50 percent. Most lamp manufacturers void their warranties when lamps are operated on ballasts with lamp CCFs greater than 1.7. Many ballast manufacturers do not report lamp CCF in their product catalogs, but they will provide the information upon request. Table 2 on p. 11 shows lamp CCF values for cathode-disconnect ballasts as reported by manufacturers and as measured by NLPIP.

Ballast Factor

Ballast factor is the measured ability of a particular ballast to produce light from the lamp(s) it powers. It is the ratio of the light output of a lamp or lamps operated by a specific ballast to the light output of the same lamp(s) operated by a reference ballast. Lamp manufacturers report initial light output based on measurements that are performed under standard conditions that were established by the American National Standards Institute (ANSI): operation in still, 25° C (77° F) open air with a reference ballast. Generally, ballasts have ballast factors less than 1.0 because they do not perform as well as the reference ballast. Some new electronic ballasts, however, have ballast factors that exceed 1.0 for certain lamp types. Ballast factor is dependent upon the lamp/ballast combination; therefore, a single ballast can have several ballast factors, depending upon the specific type of lamps that it is operating. Thus, ballast factors of different ballasts should only be compared if the ballasts are operating the same number and type of lamps. Ballast factor is used in calculations for fluorescent lighting system designs to obtain the actual light output of a specific lamp/ballast combination.

It is possible for a lamp/ballast system with a low ballast factor to have a high system efficacy, which is the ratio of total light output (in lumens) to the total active power (in watts). For example, some cathode-disconnect ballasts are designed to produce less than the rated light output from lamps, which results in a low ballast factor. However, the system may be more efficacious than one with a ballast designed for full light output, because it requires less active power. Table 2 lists ballast factors for cathode-disconnect ballasts operating 40-watt T12, 34-watt T12, 40-watt T10, and 32-watt T8 lamps as reported by manufacturers, and ballast factors measured by NLPIP using 40-watt T12 lamps.

Ballast Efficacy Factor

Ballast efficacy factor (BEF), sometimes called ballast efficiency factor, is the ratio of the ballast factor to the active power. It is used as a relative measurement of the system efficacy of the fluorescent lamp/ballast combination. As with ballast factor, BEF depends on the type and number of fluorescent lamps that a ballast is operating. Comparisons of BEF should be made only among ballasts operating the same type and number of lamps. When operating two rapid-start 40-watt T12 lamps, the standards established by NAECA require 120 V ballasts to have a minimum BEF of 1.060, and 277 V ballasts to have a minimum BEF of 1.050. Some states extend the federal BEF standards to include other lamp and ballast types. Canada has no national legislation regulating ballasts, but some provinces use requirements similar to those in NAECA. Table 2 shows BEF values for cathode-disconnect ballasts as reported by manufacturers and as measured by NLPIP. All cathode-disconnect ballasts that were tested by NLPIP meet the NAECA BEF requirements for operating two rapid-start 40-watt T12 lamps.

Efficacy and Economics

A common way to describe how efficiently a lamp/ballast combination converts electricity into light is system efficacy. This lumen-per-watt (LPW) ratio ranges from about 60 LPW to 100 LPW for fluorescent lighting systems.

Table 1 lists typical system efficacies, ballast factors, and annual energy costs for several lamp and ballast combinations. As the table shows, cathode-disconnect ballasts and electronic ballasts perform better than energy-efficient magnetic ballasts, in terms of both efficacy and operating costs.

Table 1. Typical Efficacies and Annual Energy Costs of Different Lamp/Ballast Combinations

	Active power (watts) (1)	Initial light output (lumens)	Ballast factor (1)	Efficacy (lumens/watt)	Increase in ballast price (2)	Annual energy costs (3)
Ballast and two 4-foot 40-watt T12 lamps						
High-loss magnetic	96	N/A	N/A	60	Not sold	$33.60
Energy-efficient magnetic	88	6016	0.94	68	Base case	$30.80
Cathode-disconnect, reduced light output	69	5312	0.83	77	$2	$24.15
Cathode-disconnect, full light output	80	6080	0.95	76	$2	$28.00
Electronic	72	5632	0.88	78	$6	$25.20
Ballast and two 4-foot 32-watt T8 lamps						
Energy-efficient magnetic	70	5452	0.94	78	Base case	$24.50
Cathode-disconnect	61	4988	0.86	82	$2	$21.35
Rapid-start electronic	62	5104	0.88	82	$6	$21.70
Instant-start electronic	63	5510	0.95	87	$6	$22.05

Except where indicated, all ballasts are rapid-start.

(1) These data are based on information from the California Energy Commission and assume operation under ANSI test conditions.

(2) Increase in ballast price is with respect to the cost of an energy-efficient magnetic ballast. These figures are based on price quotations from an Albany, New York-area distributor. Actual prices will vary depending on volume purchased, local market conditions, and distribution channel.

(3) Annual energy costs assume 3500 operating hours per year and an energy cost of $0.10/kWh; annual energy cost = [active power (watts) x operating hours x $/kWh] ÷ 1000. No lamp replacement or other maintenance costs are included.

Power Quality

Power quality is the extent to which current and voltage waves conform to a sinusoidal shape and are in synchronous phase with each other. Current and voltage wave forms can be distorted or shifted out of phase with each other by electronic equipment such as variable-speed drives, uninterruptible power supplies, personal computers, and fluorescent lighting systems. Poor power quality can interfere with efficient and reliable operation of an electrical system. Two power quality concerns exist for fluorescent lighting systems: power factor and electromagnetic interference.

Power factor. Power factor is defined as a ratio:

$$\text{Power factor} = \frac{\text{Active power (watts)}}{\text{Apparent power (rms voltage x rms current)}}$$

A power factor of 1.0 means that the volt-amperes supplied (apparent power) are equal to the watts used (active power) and indicates that the voltage and current wave forms are sinusoidal and in phase. When the power factor is less than one (apparent power is greater than active power), the customer pays only for the active power used and not for the volt-amperes that the electric utility company must supply.

Many utilities penalize customers whose facilities have power factors lower than 0.80 to 0.90 because supply equipment (including conductors, transformers, and switchgear) must be oversized to handle loads with low power factors. All of the cathode-disconnect ballasts that were tested for this report had power factors above 0.90.

The power factor is reduced by systems that shift the phase of the current with respect to the voltage and by systems that distort the sinusoidal wave shape of the input current. A phase shift between the current and voltage can be corrected with an appropriate inductor or capacitor in the line or distribution system. However, distortions in the current wave shape presently are difficult and expensive to correct.

A distorted wave shape is composed of a pure sine wave added to other sine waves that are at frequencies that are multiples of the first sine wave. To illustrate, if you and another person each held an end of a long rope and you began to shake your end of the rope up and down once per second, a sinusoidal wave would travel though the rope toward the other person. If that person began to shake the end of the rope three times per second, the resulting wave shape would no longer be sinusoidal, but would be a distorted shape equal to the sum of both your wave (the fundamental frequency) and the other person's wave (in this case, the third harmonic). A similar phenomenon occurs with current wave shapes. An electrical device drawing current, like a fluorescent lighting system, can send harmonics at many frequencies back onto the supply line.

Current total harmonic distortion (THD) is a measure of the degree to which a sinusoidal current wave shape is distorted by harmonics, with higher values of THD indicating greater distortion. Mathematically, current THD is the rms summation of the non-fundamental harmonic components expressed as a percentage of the fundamental component. Harmonics that are odd triple multiples of the fundamental frequency (third, ninth, fifteenth, etc.) have the greatest potential impact on electrical systems, because the current from these harmonics flows on the neutral conductor and may cause an overload on this conductor. See sidebar for other effects of harmonics.

NLPIP's evaluations found current THD for cathode-disconnect ballasts operating two 40-watt lamps to range from 12 to 20 percent, which is similar to THD for other rapid-start magnetic ballasts. Current THD for electronic ballasts typically ranges from 5 to 32 percent. By comparison, current THD for personal computers is often above 100 percent. Although the ANSI-recommended THD limit for fluorescent lighting systems is 32 percent, utilities often set 20 percent THD as the limit for lighting products that are covered under their rebate programs.

Electromagnetic interference (EMI). EMI is caused when unwanted electromagnetic signals interfere with desirable signals. EMI may be transmitted in two ways: radiated through the air or conducted by wiring. The Federal Communications Commission (FCC) limits the amount of conducted EMI that fluorescent lighting systems may produce (FCC Part 18); all fluorescent lighting systems must meet this limit. Both cathode-disconnect ballasts and electronic ballasts may generate EMI, but in order to be sold in the United States, the levels of conducted EMI must be below the FCC requirement. In Canada, the Department of Communications investigates complaints about EMI problems but presently does not specify limits.

Effects of Harmonics

Problems that harmonics may cause include

- Interference with the operation of electronic equipment (both nearby and remote);
- Improper operation of power grid protective devices (fuses, circuit breakers, and relays);
- Interference with nearby communications circuits; and
- Overheating of motors, transformers, capacitors, and neutral conductors.

Flicker

Flicker is caused by the modulation of the light output from fluorescent lamps. In North America, cathode-disconnect ballasts operate lamps at a frequency of 60 Hz, which results in the same level of flicker that other magnetic ballasts produce. At this frequency, the phosphors are refreshed 120 times per second. Between each refresh, the phosphors dim rapidly, resulting in 120 Hz light output oscillation. Flicker index is the industry-recognized measure for light modulation. The index ranges from zero for a steady light source to 1.0 for a source that goes instantaneously from light to dark (and then back again). Flicker index values for fluorescent lamps operated by magnetic ballasts, including cathode-disconnect ballasts, range from about 0.05 to 0.12. Electronic ballasts operate lamps at significantly higher frequencies, thereby refreshing the phosphors so often that their flicker index values are almost zero. Flicker is sometimes a suspected source of worker complaints of eyestrain and headaches.

THD Standards

Although no standards are in place for acceptable levels of current THD from fluorescent lighting systems, the ANSI Fluorescent Lamp and Ballast Committee recommends a limit of 32 percent. This recommendation is based on existing magnetic ballast performance and proposed International Electrotechnical Commission (IEC) standards. The proposed IEC 555-2 Standard has a THD limit of 33.8 percent. The Institute for Electrical and Electronics Engineers (IEEE) is updating the IEEE-519 Recommended Practice to include maximum THD for electric utility voltage (5 percent) and customer current (5 to 20 percent, depending upon the electrical demand of the customer’s facility), both measured at the “point of common coupling,” which is usually the place of metering. Some utilities base their harmonic distortion standards on IEEE-519. Many utilities that rebate ballasts will do so only for ballasts with current THD less than 20 percent. The United States Department of Energy, as part of its Federal Relighting Initiative, has proposed a current THD limit of 20 percent on all retrofit lighting equipment.

Both IEEE and IEC use the term *harmonic factor*, also known as *distortion factor,* to describe the ratio of the harmonic content to the rms value of the fundamental component; NLPIP calls this ratio, expressed as a percentage, *total harmonic distortion.* IEEE and IEC define *THD* differently, as the ratio of the harmonic content to the rms value of the periodic current (which includes the fundamental and all the harmonic components). The Canadian Standards Association also uses the term harmonic factor in CSA-C22.1, No. 0.16-M92. NLPIP uses the term *THD* to describe what these organizations call harmonic factor or distortion factor, because *THD* is the term commonly used in the lighting industry and used by most utilities in their rebate specifications.

Sound

In quiet spaces, people may hear a humming sound coming from ballasts. This is caused primarily by vibrations emanating from the laminated magnetic core. If a ballast is not properly mounted in a luminaire, the vibrations may be transmitted to the luminaire itself, amplifying the sound. Both energy-efficient magnetic and cathode-disconnect ballasts have cores that can cause the ballast to hum. Potting material, which is located inside the ballast case and is used to protect the ballast components, reduces this hum but does not completely eliminate it. Electronic ballasts use solid-state electronic components instead of a core and coil and operate at higher, inaudible frequencies, which results in significantly reduced ballast hum. Ballasts are sound rated from “A” to “F” based on the level of hum. “A”-rated ballasts are for indoor applications such as offices, and noisier “B”-rated ballasts are intended for outdoor applications or indoor spaces such as warehouses where quietness is not as important. All the cathode-disconnect ballasts that were tested for this report have a sound rating of “A.”

Ballast Life

Under normal operating conditions, (operating, on average, 12 hours per day), cathode-disconnect ballast life should be roughly 10 to 12 years, which is the same as that of energy-efficient magnetic ballasts. All of the cathode-disconnect ballasts that were tested for this report carry three-year manufacturers’ warranties. Ballast life is very dependent upon ballast operating temperature. Underwriters Laboratories (UL) specifies a maximum ballast case temperature of 90° C (194° F) for fluorescent ballasts operating in luminaires in an ambient temperature of 25° C (77° F). Rated ballast life assumes these conditions. An increase of 10° C (18° F) over this temperature can reduce ballast life by as much as 50 percent. Conversely, operating the ballast at a temperature 10° C (18° F) below the limit might double the ballast life. For example, as shown in Table 2, some manufacturers’ ballasts are rated for much longer life than other manufacturers’ ballasts but specify maximum temperatures that are much lower.

Class “P” Ballasts

In the United States, Section 410-71(e) of the 1965 National Electrical Code required that ballasts for indoor use must incorporate protective devices that prevent the hazardous situation of ballast overheating. Underwriters Laboratories (UL) established the Class “P” standard for indoor ballasts to implement this safety requirement. When a Class “P” ballast’s case temperature reaches 110°C (230°F), a heat-sensitive device opens a switch that interrupts power to the ballast, thereby preventing overheating and possible fires. When the ballast case cools to a temperature below 85°C (185°F), the switch closes and the ballast resumes operation. Under normal operation, the maximum ballast case temperature for UL-listed ballasts should not exceed 90°C (194°F). The 1984 National Electrical Code requires that all ballasts for indoor use be Class “P” ballasts.

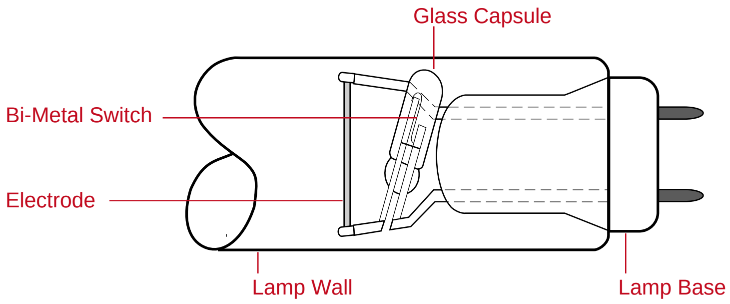
Product Availability

In acquiring product samples for this report during the first quarter of 1993, lead times for delivery from the distributor were approximately four weeks. Cathode-disconnect ballasts are manufactured on existing magnetic ballast production lines; thus manufacturers have little difficulty in meeting the present market demand. By contrast, lead times for most electronic ballasts were 12 to 20 weeks during the same period.

Alternatives

In addition to the energy-efficient magnetic ballasts and electronic ballasts already discussed, another alternative technology to consider is cathode-disconnect lamps. Cathode-disconnect lamps are energy-saving 34-watt T12 rapid-start lamps that contain small, thermally activated switches at each end. As illustrated in Figure 2, the switch is enclosed in a small glass capsule. Once the lamp has started, the switch disconnects the electrode-heating current. This results in a rating of 2 watts less per lamp while reducing the light output by 2 to 5 percent as compared with 34-watt energy-saving lamps. These lamps are compatible with most one-lamp and two-lamp magnetic ballasts, but are not compatible with electronic ballasts. They are not recommended to be used with cathode-disconnect ballasts. A significant drawback to these lamps is that they require approximately 1 minute to restart if they are switched off or if the power is interrupted. As with lamps that are operated by cathode-disconnect and electronic ballasts, cathode-disconnect lamps may be susceptible to shortened life due to the reduced operating temperature of the electrodes. Some manufacturers rate them for 15,000-hour life, compared with 20,000-hour rated life for standard 34-watt energy-saving lamps.

Figure 2. Cutaway View of a Cathode-Disconnect Lamp



(Adapted from Hernandez and Mullen 1984.)

Performance Evaluations

There are three major manufacturers of cathode-disconnect ballasts in North America (Advance Transformer Co., MagneTek, Inc., and Valmont Electric); all three participated in this project and supplied product information to NLPIP in November 1992. According to the manufacturer-supplied data, the dimensions of all of the ballasts are the same: 9.5 inches (24.13 cm) long, 2.4 inches (6.03 cm) wide, and 1.5 inches (3.81 cm) high. The weights of these ballasts range from 3.5 to 3.9 pounds (1.6 to 1.8 kg). All products have a sound rating of "A." The warranty period for ballasts from all three manufacturers is three years. The minimum filament preheat times reported by manufacturers range from 0.5 to 1.0 second. All products were reported to have power factors above 0.90; this was confirmed by NLPIP's testing.

NLPIP Testing Procedure

Three samples of each ballast were requested from manufacturers and three of each were purchased through a distributor. All product samples were acquired between November 1, 1992 and March 2, 1993. The NLPIP-measured data in Table 2 are the averages of the six samples, except for two products. For one product, the data are based only on the three samples that NLPIP purchased because samples of that product were not received from the manufacturer in time for the testing. For another product, the data are based on five samples because one of the samples that NLPIP purchased was defective and could not be replaced in time for testing. For all of the performance characteristics that were tested, no substantial differences were noted between the performance of the products that were submitted by manufacturers and the products that NLPIP purchased.

NLPIP did not test ballast performance for the operation of 40-watt T10 lamps or 34-watt T12 lamps. Two ballasts that operate 32-watt T8 lamps were tested, but ballast factor was not tested for these products due to the inavailability of a ballast that was calibrated for T8 lamps. Measured data for ballast factor and ballast efficacy factor are therefore not reported for T8 lamp operation.

The apparatus for NLPIP's testing is illustrated in Figure 3. The two test lamps that were used were F40 RE70 lamps and were seasoned for at least 100 hours. Prior to collecting data, lamp/ballast systems were operated for at least 20 minutes. The temperature within the integrating sphere was maintained at 25°C ± 1°C (77°F ± 1.8°F).

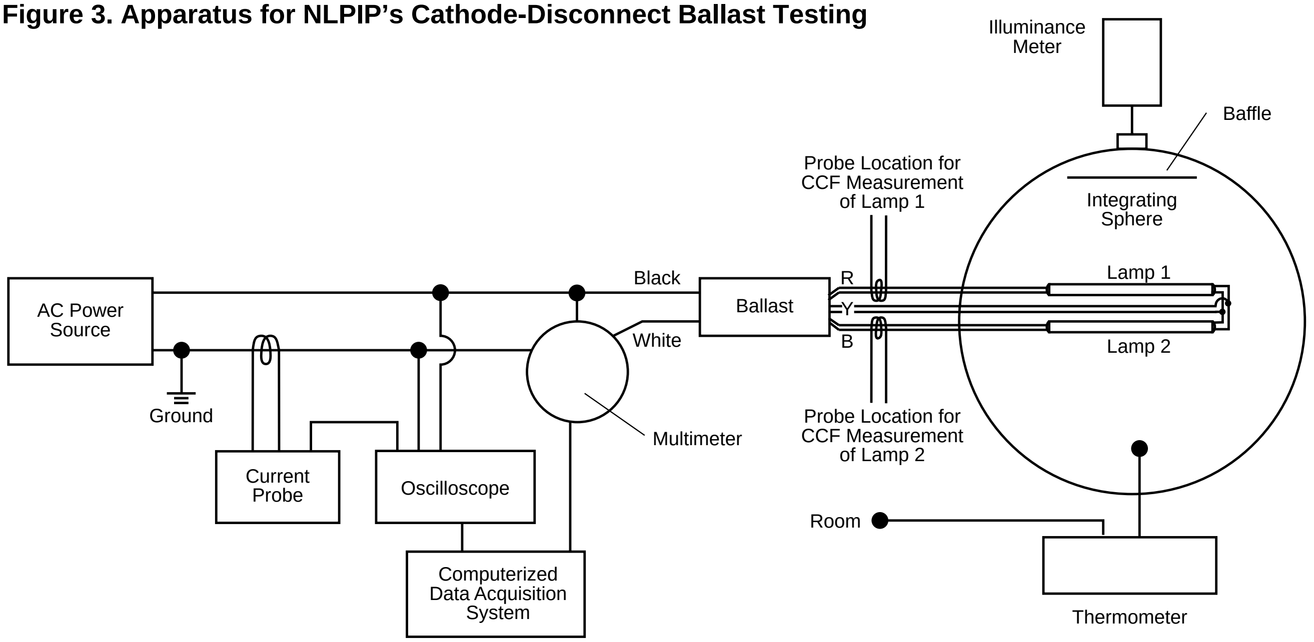
Data Table

Table 2 presents product information that was supplied by manufacturers to NLPIP and data collected through NLPIP tests. The column headings in Table 2 are explained in this section in the order in which they appear.

Input voltage. This value is the designed operating voltage of the ballast, as reported by manufacturers. In the United States, ballasts are designed to operate at either 120 or 277 V. In Canada, 347 V operation also is used. Only 120 and 277 V ballasts are included in Table 2. Nearly all ballasts for fluorescent lighting systems are specified to operate in a range of ±10 percent of the designed operating voltage.

Ballast life. The manufacturer-supplied rated ballast life and the maximum ballast case temperature are reported in this column. Ballast life may be reduced if the temperature of the hottest spot on the ballast case exceeds the manufacturer's recommended maximum. Ballast life is discussed on p. 7.

Figure 3. Apparatus for NLPIP's Cathode-Disconnect Ballast Testing



Electrode-heating voltage. This is the manufacturer-reported range of the minimum and maximum electrode-heating voltage as measured using a standard dummy load resistor. These data indicate the voltage used to heat the electrodes prior to lamp starting. The dummy load resistance is defined for different lamp types by ANSI. For example, for a 40-watt T12 rapid-start lamp, the dummy load is a resistance of 9.6 ohms ± 0.1 ohms. ANSI recommends 3.4 V as a minimum and 4.5 V as a maximum electrode-heating voltage for 40-watt T12 and 32-watt T8 lamps. All ranges that were reported by manufacturers meet the minimum voltage recommendations; however, some exceed the maximum recommendations. If the ANSI recommendations are exceeded, less lamp voltage will be required to start lamps, but lamp life may be reduced if the high electrode-heating voltage is not disconnected after lamp starting, because the electrode operating temperature will be increased. However, with cathode-disconnect ballasts, because the electrode-heating voltage is disconnected after starting, some manufacturers assert that higher electrode-heating voltages may not reduce lamp life. Therefore, to improve starting, some manufacturers of cathode-disconnect ballasts exceed the ANSI recommendation. After starting, the electrode-heating voltage for all cathode-disconnect ballasts was reported to be zero.

Active power. This value indicates the system input watts for a lamp and ballast combination. Both manufacturers' data and NLPIP's test data are included in the table. The variation in measured active power among the samples of each product that were tested was less than 5 percent. The NLPIP-measured active power values reported in Table 2 are adjusted based on the performance of a calibrated ballast (Advance Mark III, catalog number R-2S40-1-TP) that was used in the testing procedure. The active power for the calibrated ballast was reported at 89.4 W. NLPIP performed 17 measurements of the calibrated ballast with the test lamps and found an average active power of 91.4 W, 2.2 percent higher than that reported at calibration. This difference can be accounted for by the lamps used in the testing, which were not reference lamps. Therefore, all reported active power values are 2.2 percent less than measured values.

Although the same two test lamps were used for all the reported data, NLPIP also tested the calibrated ballast with different 40-watt lamp types and found a variation of ± 3 watts in active power. Similar variances can be expected in actual applications.

Total harmonic distortion (THD). Both manufacturers' data and NLPIP's test data are included in the table. Current THD for all products was lower than 20 percent. Harmonic distortion and other power quality concerns are discussed on p. 6.

Lamp current crest factor (CCF). Both manufacturers' data and NLPIP's test data are reported in the table. NLPIP's testing confirmed that lamp CCFs for all tested cathode-disconnect ballasts were below 1.7. Lamp CCF is discussed on p. 4.

Ballast factor (BF). Both manufacturers' data and NLPIP's test data are included in the table. A calibrated ballast (Advance Mark III, catalog number R-2S40-1-TP, ballast factor = 0.973) was used to determine the ballast factor of cathode-disconnect ballasts operating two 40-watt T12 lamps. Ballast factor was calculated as follows:

$$BF = BF' \times (E1/E2)$$

where: BF is the ballast factor for the test ballast,
BF′ is the ballast factor for the calibrated ballast (BF′ = 0.973),
E1 is the illuminance reading in the integrating sphere for the test ballast/test lamp system, and
E2 is the illuminance reading in the integrating sphere for the calibrated ballast/test lamp system.

A high BF indicates a full-light-output ballast. A low BF indicates a reduced-light-output ballast. Ballast factor is discussed on p. 4.

Ballast efficacy factor (BEF). Both manufacturers' data and NLPIP's test data are included in the table. NLPIP's test data are based on adjusted active power values (see "Active Power"). Ballast efficacy factor is discussed on p. 5.

Table 2. Performance Data for Cathode-Disconnect Ballasts

			Manufacturer-Reported Data										NLPIP-Measured Data (Averages)			
				Ballast Life		Electrode-Heating Voltage (V)										
Manufacturer	Trade Name	Catalog Number	Input Voltage (V)	Rated (years)	Max. Temp. (°C)	Min.	Max.	Active Power (W)	THD (%)	CCF	BF	BEF	Active Power (W)	THD (%)	CCF	BF
Two 40-Watt T12 Lamps																
Advance Transformer Co.	PowrKut	RK2S34-TP	120	10	90	3.4	4.5	71	18.5	1.40	0.85	1.17	73	19.4	1.50	0.83
Advance Transformer Co.	PowrKut	RK2S40-TP	120	10	90	3.4	4.5	80	14.8	1.55	0.93	1.15	83	14.9	1.51	0.93
Advance Transformer Co.	PowrKut	VK2S34-TP	277	10	90	3.4	4.5	71	16.2	1.50	0.85	1.15	73	19.4	1.43	0.82
Advance Transformer Co.	PowrKut	VK2S40-TP	277	10	90	3.4	4.5	80	12.8	1.45	0.93	1.13	84	14.6	1.48	0.92
MagneTek, Inc.	Universal Plus	420-L-TC-P	120	20	65	4.0	6.0	71	19.1	<1.7	0.85	1.20	71	18.3	1.54	0.83
MagneTek, Inc.	Universal Plus	427-L-TC-P	277	20	65	4.0	6.0	71	19.7	<1.7	0.85	1.20	71	19.5	1.44	0.82
MagneTek, Inc.	Universal Plus	530-L-TC-P	120	20	65	4.0	6.0	80	12.6	1.50	0.95	1.16	80	15.8	1.57	0.93
MagneTek, Inc.	Universal Plus	537-L-TC-P	277	20	65	4.0	6.0	80	16.1	1.50	0.93	1.13	83	13.2	1.51	0.93
Valmont Electric	Opti-Miser	M28-120	120	20	65	4.0	5.3	70	16.0	1.50	0.81	1.14	70	17.4	1.37	0.80
Valmont Electric	Opti-Miser	M28-277	277	20	65	4.0	5.3	70	16.4	1.50	0.80	1.13	70	17.5	1.39	0.79
Two 40-Watt T10 Lamps																
Advance Transformer Co.	PowrKut	RK2S34-TP	120	10	90	3.4	4.5	71	18.5	1.42	0.85	1.16	NLPIP did not measure ballast performance for operation of 40-watt T10 or 34-watt T12 lamps.			
Advance Transformer Co.	PowrKut	RK2S40-TP	120	10	90	3.4	4.5	80	15.3	1.60	0.93	1.10				
Advance Transformer Co.	PowrKut	VK2S34-TP	277	10	90	3.4	4.5	71	18.4	1.50	0.85	1.09				
Advance Transformer Co.	PowrKut	VK2S40-TP	277	10	90	3.4	4.5	80	16.4	1.50	0.93	1.09				
Two 34-Watt T12 Lamps																
Advance Transformer Co.	PowrKut	RK2S34-TP	120	10	90	3.4	4.5	58	16.5	1.68	0.85	1.37				
Advance Transformer Co.	PowrKut	RK2S40-TP	120	10	90	3.4	4.5	66	12.4	1.60	0.91	1.31				
Advance Transformer Co.	PowrKut	VK2S34-TP	277	10	90	3.4	4.5	58	15.1	1.75	0.82	1.37				
Advance Transformer Co.	PowrKut	VK2S40-TP	277	10	90	3.4	4.5	66	12.5	1.68	>0.9	1.29				
Valmont Electric	Opti-Miser	M28-120	120	20	65	4.0	5.3	60	17.9	1.50	0.81	1.34				
Valmont Electric	Opti-Miser	M28-277	277	20	65	4.0	5.3	61	15.6	1.50	0.80	1.32				
Three 34-Watt T12 Lamps																
Advance Transformer Co.	PowrKut	RK3S34-TP	120	10	90	3.4	4.5	90	16.7	1.50	0.82	0.91				
Advance Transformer Co.	PowrKut	VK3S34-TP	277	10	90	3.4	4.5	90	19.1	1.50	0.82	0.91				
Valmont Electric	Opti-Miser	M28-120-3	120	20	65	4.0	5.3	87	11.8	<1.7	0.82	0.94				
Valmont Electric	Opti-Miser	M28-277-3	277	20	65	4.0	5.3	87	11.5	<1.7	0.79	0.89				
Two 32-Watt T8 Lamps																
Advance Transformer Co.	PowrKut	RK2S32-TP	120	10	90	3.4	4.5	62	12.4	1.35	0.87	1.39	60	14.4	1.37	—
Advance Transformer Co.	PowrKut	VK2S32-TP	277	10	90	3.4	4.5	62	14.6	1.35	0.87	1.41	61	14.6	1.35	—

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