UPDATE ON THE NEW FLUORESCENT BALLAST DESIGNS

Joseph R. Knisley, Senior Editor

The selection of a ballast should be made on the basis of its operation in the total lighting system.

THE AVAILABILITY of high-efficiency ballasts (and new types of lamps and fixtures) allows for many choices in the design of a fluorescent lighting system. But the key problem is that while many of these combinations are physically and electrically interchangeable, the actual performance of one lamp/ballast system can be different than the performance of another system. So, while new products help to make energy-efficient design easier, they can present an overwhelming and possibly confusing array of choices.

In planning a modern fluorescent lighting system, a designer/specifier should consider a number of factors. For example, the effect that a ballast may have on expected lamp life and lumen maintenance is an important consideration. And the lumen maintenance characteristics of the lamp are important because illumination levels are normally calculated with reference to "maintained footcandles" (the fc level after lamps have been operating for a specific time).

Lamp types and starting modes

Before discussing ballast operational characteristics, it is important to understand the three types of lamps (and thus ballasts) that have traditionally been used in general illumination fluorescent lighting systems.

Rapid-start lamps use cathodes or filaments at each end of the tube that are heated from transformer windings in the ballast for about one second prior to lamp starting. The cathodes remain heated after starting. Operating current for the F40 T-12 lamp is 430mA.

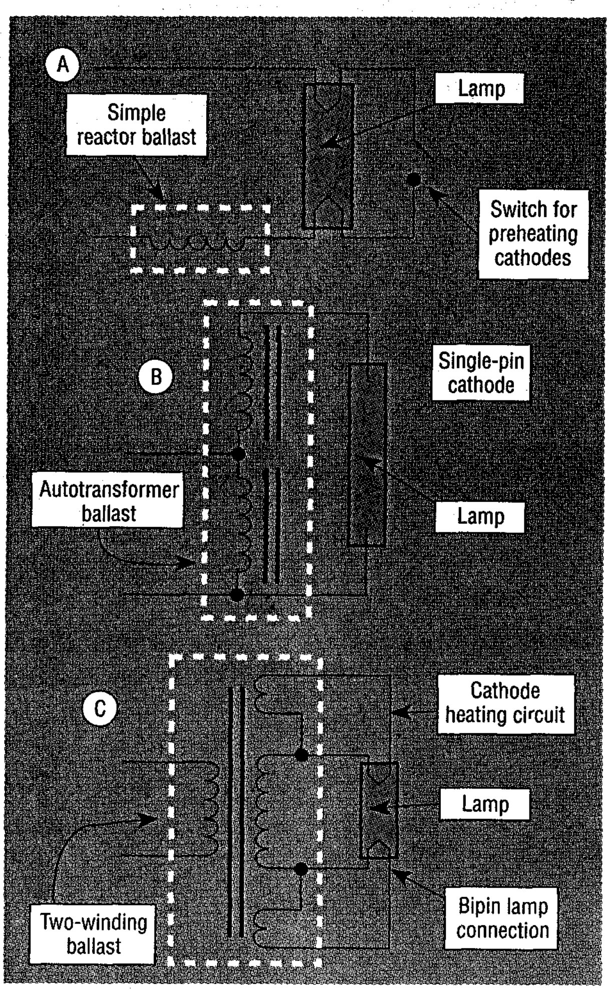


Fig. 1 Three fluorescent lamp starting modes presently used today are discussed in this article. (A) The preheat starting mode (the original fluorescent system) uses a starter with a time delay of 1 to 2 seconds to heat the filaments (cathode) before arc conduction begins. (B) The instant start mode applies a high voltage pulse for about 50 ms, to begin arc conduction, and filament heating is not used. Single-pin slimline lamps are designed for instant starting. (C) The rapid-start mode applies a filament or cathode heating voltage through a separate ballast winding for less than a second before arc conduction.

High output (HO) lamps use the same starting procedure as the rapid-start lamps, but operate at higher currents (800 to 1000mA). With its higher current loading, a 4-ft HO lamp provides about 40% more light than a 430mA lamp of the same length.

Instant-start (slimline) lamps do not have their cathodes preheated before starting and thus these lamps require the use of a higher voltage between the unheated cathodes for about 50 ms to start the lamp. The ballast must provide an open circuit voltage about three times the normal lamp operating voltage to initiate the arc. Two-lamp slimline ballasts are available in two circuit types: lead-lag and series sequence.

These two starting modes, and the preheat starting mode, are depicted in **Fig. 1**. The preheat circuit was the original system developed for operation of fluorescent lamps. This circuit uses a separate starting switch in series with the ballast to help start the lamp. At turn on, the switch allows current to pass through the electrodes of the lamp for several seconds to heat them before voltage is applied between the electrodes to strike the arc. The preheat circuit is generally used for low wattage linear lamps (4 to 20W).

TERMS TO KNOW

ANSI: American National Standards Institute. A standards making body for American industry.
Ballast: A device that modifies incoming voltage and current to provide the circuit conditions necessary to start and operate electric-discharge lamps.
Ballast factor: The ratio of light output obtained by a commercial ballast to that obtained by a reference ballast.
Crest factor: The ratio of the peak (maximum value) to the rms (root mean square) value of a voltage or current waveform. For a pure sine wave, the crest factor is 1 divided by 0.707 or 1.414.
Electric discharge lamp: A light source that produces light or energy near the visible spectrum by the passage of an electrical current through a gas. An electric discharge lamp may be designated by using one or more descriptive terms. For example, the fill gas that provides most of the light energy; mercury, sodium, neon; the physical dimensions or operating parameters, short arc, high pressure, low pressure; or by its application, such as plant growth, bactericidal, or black light. *See Fluorescent Lamp.*
Fluorescent lamp: A low-pressure mercury, electric discharge lamp that uses a fluorescing coating (phosphor) to convert ultraviolet light energy into visible light.
Lamp: The term used in the electrical industry to indicate the light source itself; the bulb that produces the light.
Lumen (L): SI unit of luminous flux. It is the luminous flux (light energy) emitted within a unit solid angle of one steradian by a point source having a uniform intensity of one candela. SI is the abbreviation for International Standards.
Lumen-per-watt (LPW) ratio: A numerical figure used to express the luminous efficacy of a light source. It is a combination of two different units—lumens and watts—and is similar to the miles-per-gallon rating for a car.
Luminaire: A complete lighting fixture including one or more lamps and sockets and a means for connection to a power source. It may also include one or more ballasts and elements to position and protect lamps and distribute the light.
Power factor (PF): The ratio of the circuit power (watts) to the circuit volt-amperes. The ratio of the active power to the apparent power.

In the past, the two-lamp, F40 electromagnetic (EM) ballast along with F40 T12 cool-white, rapid-start lamps was the standard system for many interior spaces, such as offices. For other areas, such as supermarkets and warehouses, the HO and slimline lamps were used. By following a few tables and a simple equation, a specifier could determine the power density required to meet the illumination levels for a space.

But, since ballast losses are a significant portion of any lighting system's power consumption, federal legislation now requires minimum efficiencies for ballasts that operate the most common fluorescent lamps. The National Appliance Energy Conservation Amendment of 1988 (Public Law No. 100-357) covers 1- and 2-lamp ballasts for 4-ft T12 rapid-start (F40 RS, as well as two-lamp ballasts for 8-ft high output (F96 T12/HO), and 8-ft slimline (F96T12).

This amendment to the previously enacted Energy Policy and Conservation Act eliminates "commodity type" EM ballasts with iron core laminations and aluminum windings. EM ballasts are still used with the lamps mentioned above but they must be of an energy-saving construction. Generally, this means steel core laminations and copper wire.

Energy-saving EM ballast

Specifically, an energy-saving, 2-lamp F40 T12 EM ballast has 6 to 8W of internal heat loss versus a 16 to 20W internal heat loss for the commodity type ballast. And because of its 20% cooler operation, the energy-saving EM ballast can have an average life expectancy at least twice that of a commodity EM ballast.

The EM ballast is available in at least three different designs. The first design is described above. The second design uses the same materials as the first design, but in addition cuts power to the lamp filament once the lamps are started, offering a further savings in power use compared to the standard ballast, although reducing light output from 8 to 10%, compared to an existing system. The third design also cuts power to the lamp filaments once the lamps are started; however, it has circuit refinements that reduce energy consumption by 17% without sacrificing light output, compared to an existing system. In an F40 T12 2-lamp system, power consumption is about 80W.

An EM ballast must be designed with the proper number of core laminations and coil windings to operate lamps of a specific size and type. Thus, while the EM ballast can be a valid selection where minimum initial equipment costs are important, its single-use restriction limits its flexibility.

Electronic ballasts

An electronic (EL) ballast offers even greater opportunities for energy savings, while boasting many operational advantages over the EM ballast. An EL ballast converts the 60-Hz line frequency of the input power to direct current, and then inverts this current back to an alternating power system at frequencies between 20 and 60 kHz to drive the lamp. The EL ballast provides energy savings in two ways. First, it has lower internal losses than an EM ballast, and secondly, the light output is increased due to the excitation of the lamp phosphors with high frequency power. If the period of the frequency of excitation is smaller than the deionization time constant for the gas inside the lamp, the gas will stay ionized continuously and, thus, maintain the arc stream continuously. This factor, along with the continued persistence of the phosphors at high frequency, can increase light output from 8 to 15%.

Lamp designation	No. of lamps	Initial lamp lumens	Magnetic ballast (W)	Electronic ballast (W)
T40T12RS	1	3,150	50	35
	2	6,300	86	69
	3	9,450	138	105
	4	12,600	-----	141
F32T8RS	1	2,900	37	39
	2	5,800	70	62
	3	8,700	----	92
	4	11,600	----	109

Table 1. *Total input wattages for 4-ft lamp/ballast combinations are shown for comparison.* The magnetic ballasts are all energy-saving type. Input wattages are from measurements made under ANSI guidelines, as explained in the text. Depending on the luminaire's thermal characteristics and other factors such as line voltage, ambient temperature, etc., initial lamp lumens and input wattages will generally be less than indicated.

Because of its higher-frequency operation, an EL ballast should not have the perceived lamp flicker that an EM ballast produces, which can be as high as 33%, depending on the type of lamp phosphors. An EL ballast can have a lamp flicker index of less than 2%. The percent flicker is a measure of the modulation of the light output and is defined as the difference between the maximum and minimum intensity divided by their sum.

Flicker can cause discomfort and reduce productivity. Typically, it affects only a small portion of the population. Some evidence shows that lamp flicker will affect more people who work at video display terminals (VDTs) because flicker may interact with the display refresh rate. (Refresh rate is the number of times a second the image on the screen is recreated by the retracing of a cathode ray beam.)

Other features include little or no ballast noise, less weight (because required impedances can be obtained with smaller capacitive and inductive components), and, in some cases, extended lamp life. In addition, the average rated life of an EL ballast can be considerably higher than an EM ballast; however, the life of any ballast is based on its operating ambient temperature.

Table 1 shows input wattage for popular T12 and T8 lamp/ballast combinations. Both EM and EL ballasts are represented. The T8 family, which is becoming very popular and may be the standard lamp of the future, has grown to include 2, 3, 4, 5, and 8 ft lengths, as well as U-shaped lamps. The T8 lamp fits the same medium bi-pin base as T12 rapid-start lamps, but the 4-ft T8 lamp operates at 265mA rather than 430mA. Except for specific electronic ballasts designed to operate both lamps, the T8 ballast is not interchangeable with a T12 ballast.

While the 4-ft T8 lamp has a lower lumen output than a 4-ft T12 lamp (2900 lumens vs 3150 lumens), it performs mere efficiently in a reflector system. The smaller diameter (1.0 in. vs 1.5 in.) blocks less reflected light within the fixture. Consequently, the lumen output of a T8 fixture usually matches that of a similar fixture with T12 lamps. Thus, T8 lamps are being used in shallow recessed luminaires, in shallow-depth suspended fixtures, in furniture-mounted luminaires and in architectural cove lighting applications.

The smaller diameter of the T8 also allows the economical use of better phosphors. While a conventional T12 lamp uses a single-coating of halophosphors, a T8 lamp receives one coating of halophosphors followed by a second thin coating of rare-earth phosphors. The rare-earth phosphors produce a mix of the three primary additive colors (red, green and blue) that offer improved color rendition.

Besides better color rendition, the rare-earth phosphors also improve lumen maintenance, since they maintain a higher percentage of initial lumen output for a longer period of time, compared with halophosphor lamps.

EL ballast performance characteristics

The three important performance characteristics to consider in selecting EL ballasts that relate to operating efficiency are as follows.

Power factor **(PF).** The power factor of a ballast is the measurement of how effectively the input current is converted into usable power delivered to the ballast; it is not an indication of ballast efficiency. A PF of 1.0 (optimum power utilization) means that the volt-amperes supplied are equal to the watts used. A value lower than 1.0 causes losses in the transmission/distribution system from the power plant to the load. Generally, a fluorescent lighting system with EM ballasts has a PF above 0.9. Most EL ballasts match this figure, while some EL ballasts can have a greater than 0.99 power factor.

ANSI defines a high power factor ballast as one with a PF greater than 0.90. A normal power factor ballast is 0.79 or less. A low power factor is 0.50 or less.

Ballast factor **(BF).** BF is the ratio of light output (lamp lumens) produced by the lamps operating on a commercial ballast vs the light output of the lamps when operating on a standard laboratory reference, using an American National Standards Institute (ANSI) test setup. The initial lumen and mean-lumen ratings shown in a lamp catalog are based on the lamp being operated through such a reference ballast (called a standard reactor), which has very little or no internal power loss. In the test, both the lamps and the reference ballast are operated in open air.

The BF describes the relationship of the lamp's actual light output to the manufacturer's rated light output, and it is unique for every lamp-ballast combination. For example, an F40 ballast can operate 40W T12, 40W T10, or 34W T12 lamps, and with each lamp type the BF is different. It may also differ according to the number of lamps served by the ballast.

An EM ballast that meets the ANSI standard gives minimum light based on the lamp's rated output. For example, ballasts approved by the Certified Ballast Manufacturers Association (CBM) have a ballast factor of at least .925 (previously it was .95) ± 2½% of the manufacturer's rated output for a standard F40 rapid-start argon-filled lamp. The CBM uses an independent testing lab to certify ANSI performance standards. The CBM certification applies only to high efficiency, reduced-loss EM ballasts designed for, and operated with, 40W argon gas-filled lamps. When the same ballast operates energy-saving 34W krypton gas-filled lamps the BF is .87 and reduction in light output can be 8% or more. The reason is that the higher molecular weight of the krypton gas reduces the voltage drop across the lamp, thereby lowering power consumption.

An energy-saving fluorescent lamp, which also differs in construction from the argon gas-filled lamp in other ways, is not recommended for use with EL ballasts in certain applications because of the lamp's starting and operating characteristics.

***Ballast efficiency factor* (BEF).** BEF refers to a rating established by the National Appliance Energy Conservation Amendment of 1988. The BEF is a ratio of the BF to the input watts and it provides an easy way to make efficiency comparisons—but only between ballasts operating the same number of lamps.

Additional performance factors

Three other important ballast system performance parameters to consider in selecting EL ballasts are:

Line current harmonic distortion. The amount of harmonics created by an EL ballast is one of the most discussed concerns today. All EL ballasts used in arc discharge lighting systems (both fluorescent and HID) develop some harmonics, which are caused by resonance. Resonance is a function of the inductance and capacitance in a ballasting circuit.

The NEC first recognized harmonic currents in neutral conductors of 3-phase wye, 4-wire circuits serving arc discharge lighting with the 1968 edition of the NEC, and the presence of harmonics in these circuits continues to be an important Code topic. Specifically, the third harmonic and odd multiples of this harmonic called triplens (9, 15, 21, etc.) are created by the operation of arc discharge ballasts, add together in the neutral conductor of a three-phase power system.

The luminaire current total harmonic distortion (THD) for EM ballasted two-lamp systems typically range from 12 to over 20%. An EL ballast should keep THD at least below 25%. Some EL ballasts keep the THD below 10%, and there are ballast makers who claim to have products with a THD of 1 or 2%. Generally, a utility rebate program specifies the maximum THD that EL ballasts must have to qualify under the program. In any case, a lighting designer should carefully study the specifications, because the THD may differ for various ballast models from the same maker.

While there is no ANSI standard on the THD of EL ballasts, the ANSI Fluorescent Lamp and Ballast Committee has recommended a limit of 32%. The IEC has a proposed standard (555-2) limiting the third harmonic to 30% × PF and the THD to 33.8%. IEEE has a proposed Recommended Practice (519) on the subject.

Keep in mind that the harmonic currents created by EL ballasts on the neutral conductors of 120V lighting branch circuits could be added to the harmonic currents created by electronic office equipment, which may be on the same, or adjacent, branch circuits in a facility. Generally, both loads would be served by the same dry-type transformer.

Problems that are attributable to high harmonic content in neutral conductors include: overheating of panelboards, motors, transformers and capacitors; interference with the operation of other electrical equipment (both nearby and remote); and improper operation of power grid protective relays.

Lamp current crest factor. The lamp current crest factor (CCF) is a numerical value relating to the input current wave shape to a fluorescent lamp and has a direct effect on lamp life. In a sinusoidal current waveform, the crest factor is the ratio of the peak value to the root mean square (rms) value. In a pure sinusoidal waveform, the crest factor is 1.41, as shown in **Fig. 2A**. But **Fig. 2B** shows a distorted waveform where the ratio of peak value to rms value is higher than 1.41, and the current waveform is nonsinusoidal.

Lumen maintenance curves from lamp manufacturers are based on operating with the lamp current sine wave having a crest factor of about 1.41. ANSI specifications recommend that a ballast have a CCF of 1.7, or less. A higher than 1.41

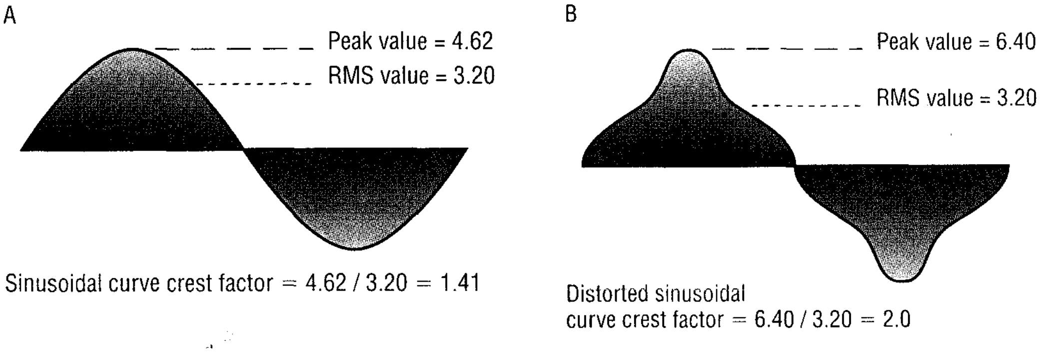


Fig. 2. Lamp current crest factor is an important ballast operating parameter because of its direct effect on the life of a rapid-start lamp. The sinusoidal current wave form (a) has a crest factor of 1.41. The non-sinusoidal current waveform (b) having a crest factor of 2.0, will erode the emission material from a rapid-start lamp at a faster rate.

value causes the barium oxide coating on the cathodes to be depleted at a faster rate than normal at each peak of the waveform. Since the emission coating has a finite thickness, the increased rate of loss reduces lumen output and thus the useful life of the lamp. So, the lower the CCF, the better the lamp life.

Some ballast manufacturers list the CCF of their products. If a catalog does not show the CCF, a specifier should request such information.

Voltage regulation. An EL ballast should maintain rated light output under the same ±10% variation in the supply voltage that is required for an EM ballast. However, some EL ballasts allow a constant light output to be maintained over a wider variation in supply voltage. In a facility that consistently suffers from reduced utility supply voltage levels, this operating characteristic can be an asset.

Other standards and requirements

EL ballasts are subject to Federal and other regulatory agency requirements because the recreated current waveform (which is between 10 kHz and 60 kHz as mentioned earlier) can generate radio frequency interference (RFI) or electromagnetic interference (EMI), which may in turn interfere with the operation of nearby data-processing and communications equipment. For that reason, the EL ballast is subject to FCC regulations (CRF 47 part 18) regarding the amount of radiated energy.

The grounded metal case of the EL ballast prevents RFI radiation from its interior. However, fluorescent lamps can radiate RFI; but (depending on lamp wattage), by keeping the fixture from 4 to 10 ft away from sensitive equipment, interference should not be experienced. A filtering circuit in the ballast usually prevents EMI from being conducted along the branch circuit power line.

In addition, the input power supply sections of the EL ballast should be able to sustain power-line transients and surges without damage. These requirements are found in ANSI C62.41, Category A, formerly IEEE Publication 587.

Underwriters' Laboratories, Inc. requires that all ballasts for indoor fixtures have a Class P thermal protector. The thermal protector disconnects the ballast from the branch circuit power supply before a temperature of 110°C is reached. This temperature is not likely to be attained in an EL ballast, but it is a requirement nevertheless.

Another important parameter is protection against transient voltages on the AC power line. Most transients with high peak voltages are of such short duration that they have very little energy and can be handled by a variety of solid state transient suppressors. These suppressors are specialized zener diodes, silicon control rectifiers (SCRs), or combinations of the two that will limit the voltage across the line. As a rule, however, they have limited power handling capacity and will burn out if the transient exists long enough to contain significant energy. Metal oxide varistors (MOVs) contain more mass than the previously mentioned devices, and, as a result, can absorb more energy. Unfortunately, the effectiveness of an MOV deteriorates slightly with each transient pulse it suppresses. Most EL ballasts are designed to meet the surge limits specified in IEEE 587, Category A.

EL construction/design differences

Since a wide variety of ballast types are available today, in addition to the voltage, a specification should consider the following.

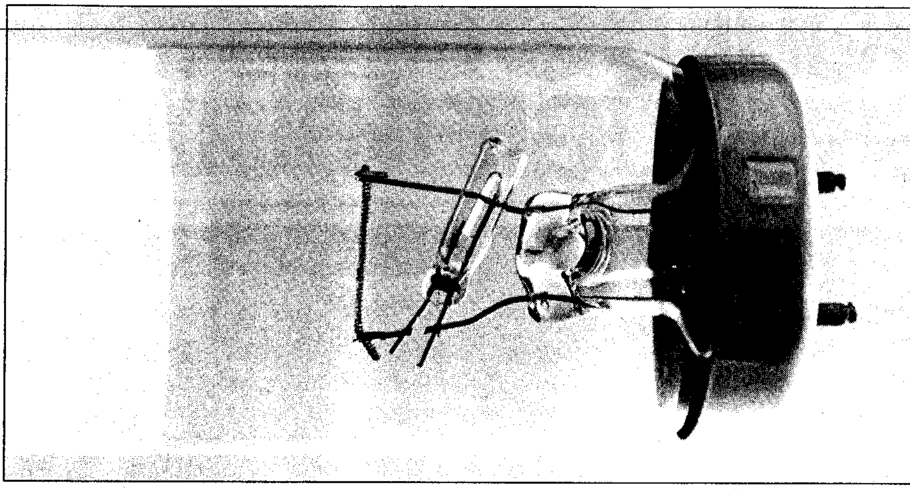
- Lamp starting/operating modes.
- Wiring configuration to the lamps
- Number of lamps served by a ballast.
- Ballast control system.

The starting voltage, the lamp filament voltage, and the current crest factor (mentioned previously) are three parameters determining the proper starting and operation of fluorescent lamps. When these factors are kept within limits, the lamps should achieve their rated life, since the end of life for most lamps occurs when the barium oxide coating (emission coating) on the tungsten filament of the lamp is depleted.

Lamp starting/operating modes. The EL ballast is available in three lamp starting/operating modes: rapid-start, modified rapid-start (MRS), and instant-start. Each mode, or type, has specific performance characteristics.

The rapid-start circuit heats the lamp cathodes (electrodes) for a second or more before voltage is applied across the two cathodes and lamp arc conduction begins. The time delay assures that the emission mix on the electrode structure is properly heated to a high enough temperature so that minimum sputtering of the emission coating occurs as the lamps reach full rated current.

The modified rapid-start circuit lowers lamp cathode heating voltage after lamp conduction begins. This action reduces power consumption by the cathode heating circuit; however, the deterioration or evaporation of the emission coating may occur at a faster rate, compared with a rapid-start circuit that retains the lamp cathode voltage. For example, complete filament cutout saves about 1.5W per lamp, but it may lower the average rated life of a 20,000-hr lamp



A cathode heater bimetal cutout switch inside a T12 lamp is a second method of reducing the lamp's wattage.

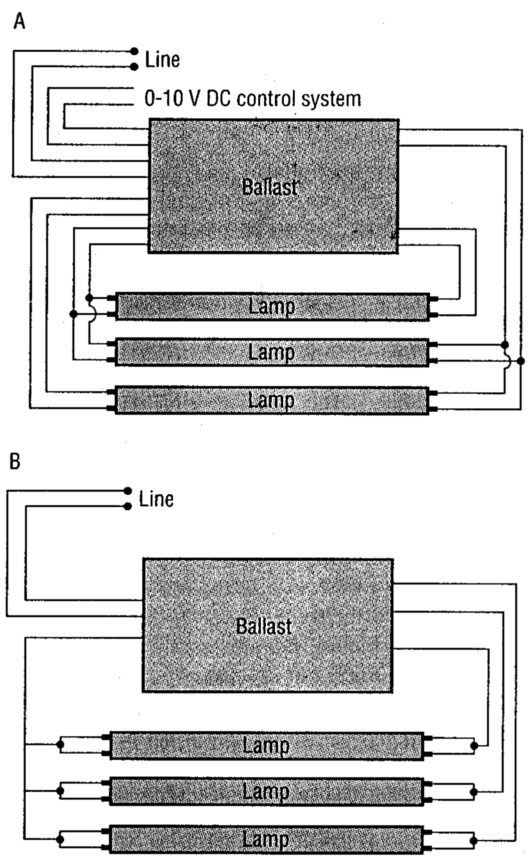


Fig. 3. Two EL ballast circuit types are shown for comparison. (A) is a 3-lamp (series) rapid-start circuit with two additional conductors that allow for external control; the lamps have continuous cathode heating. (B) is a 3-lamp (parallel) rapid-start circuit. An instant-starting procedure (a high voltage pulse) begins lamp conduction and the lamps are not continuously heated.

to about 15,000 hrs.

Operating rapid-start lamps without continuous cathode heater current may result in early end blackening or discoloration, as the emission coating that is lost from the cathode is deposited on the nearby bulb wall. The end blackening may be objectionable if it is visible, for example, in an open-cell parabolic fixture.

The instant-start circuit uses a high voltage pulse to begin lamp arc conduction and the cathodes are not heated. (This is the starting method for slimline lamps mentioned earlier). Using the instant start method on rapid-start lamps may also cause a more rapid deterioration of the emission coating, resulting in a reduction of lamp life. However, at operating cycles longer than the standard three hrs per start, the difference in lamp life for instant-start operation compared to rapid-start operation can become negligible.

Series/parallel wiring. An EL ballast for rapid-start lamps serve from one to four lamps, and the lamps can be wired from the ballast case to the lamp sockets in either series or in parallel. For example, a 3-lamp fluorescent fixture can be fitted with a single EL ballast rather than with a 2-lamp and a single-lamp EM ballast. Or, a four-lamp EL ballast can be used to serve a pair of 2-lamp fixtures, and the wiring to the lamp sockets of both fixtures can be done in a master/slave arrangement.

In **Fig. 3**, two EL ballast' circuit types are shown for comparison. **Fig. 3A** is a rapid-start circuit serving three T12 lamps (in series) which have continuous cathode heating; **Fig. 3B** is a rapid-start circuit serving three T8 lamps (in parallel), having continuous cathode heating. An instant-start procedure (a high voltage pulse) begins lamp conduction.

Ballast dimming controllers. A number of controllable (dimming/ON-OFF) ballast systems are available that add a control circuit to the EL ballast, allowing external signals to be delivered to the EL ballast through a low voltage DC circuit. Fig. 3A shows two additional conductors to accept an external signal.

The external signal can be from a manual continuous dimming control, an occupancy sensor, a photocell, a central building control system, or other similar device. With one such system, up to 50 ballasts (that do not necessarily have to be on the same branch circuit) can be connected via the control circuit, thereby adding a high degree of flexibility or versatility to a lighting layout.

Another EL ballast design allows the user to change between full and 50% light output simply by using a standard wall-mounted snap-switch to control the ballast. Circuitry within the ballast senses the momentary interruption of power on the branch circuit and initiates the control sequence. Since the switching system is an integral part of the ballast circuitry, no additional wiring or external control equipment is needed.

Still another system, using a two-gang, wall box-mounted control unit to serve in the place of a wall switch on the branch circuit, allows a stepped dimming sequence. The faceplate of the control unit has six vertical bars, each with different lengths to represent a particular light level. An occupant simply touches one of the bars, which initiates a coded control signal. Circuitry within the ballast senses the coded signal on the branch circuit and sets the selected light dimming level. ■