



A NEMA Lighting Systems Division Document

34 Watt Fluorescent Lamps And High Frequency Electronic Ballasts

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Introduction

This NEMA white paper discusses the operation of tin-coated energy-saving fluorescent lamps on *high frequency* ballasts. Information is presented that explains the technical basis for potential starting difficulties that may occur as the result of interactions between the inside tin-coated energy-saving lamps and some high frequency ballasts.

The initial objective of this report is to act as a vehicle to facilitate future joint discussions between NEMA Lamp and Ballast Section and Technical Committee members with regard to the subject.

Background

Prior to the energy crisis of 1974, the fluorescent lamp-ballast interaction was relatively simple. Four-foot argon filled T-12 rapid-start lamps operated on rapid start electromagnetic ballasts. This “system” represented the vast majority of mainstream indoor commercial lighting installations.

Ballast designs utilizing American National Standards had matured since the industry adopted rapid start as the preferred operating approach. As a result, electromagnetic ballast designs tended to exhibit only minor differences among manufacturers, at least in terms of their electrical circuit and component equivalencies. Ballasts started and operated lamps in essentially the same manner, and as a class electromagnetic ballasts exhibited similar variations in manufacturing parameters and operating frequency was identical for all ballasts (the AC mains frequency of 60 Hz), the equivalent leakage paths for such systems were also essentially the same.

Four-foot lamps were of simple construction compared to energy-saving lamps. Argon was the fill gas of choice, at about 2.4 torr. Tin coatings had not yet been

introduced, and phosphor coatings consisted of simple halophosphate single-coat materials. Starting problems, when they occurred, were most likely the result of poor lamp processing or ballasts that did not meet ANSI standards.

High frequency operation of lamps was pioneered on a very limited scale, but the costs of high voltage semi-conductors as well as line operated control circuitry resulted in such systems being prohibitively costly. Energy rates were relatively low in the 1950s and 1960s, so there was little incentive to consider such systems.

1974--The Energy Crisis

The first “energy crisis” occurred in 1974. As a result users, looking for quick ways to reduce their energy operating costs, experimented with a variety of approaches aimed at installed lighting fixtures. Many users soon began removing two of the four lamps from the then very common four-lamp-two-ballast luminaires of the day. It was soon recognized that this practice had some major deficiencies:

- Removal of two of the four lamps resulted in drastic light level decrease.
- The resulting appearance of the fixture was very unattractive.
- The unlamped ballast continued to dissipate significant energy even though it was de-lamped.

Thus, de-lamping was not considered acceptable for the long term. Lamp manufacturers began considering ways to design a lamp that could be retrofitted into the same fixture or luminaire, but that would operate at significantly reduced wattage on existing electromagnetic (60 Hz) ballasts.

Energy-saving Fluorescent Lamp

The answer became the first generation “energy-saving” fluorescent lamps. All fluorescent lamps are energy-saving when compared to many other alternatives, but the misnomer stuck. Energy-saving fluorescent lamps became the generic term used to describe a new class of lamps that were designed to consume fewer watts when operated on existing, installed electromagnetic ballasts.

By changing the lamp buffer gas to predominantly krypton, the lamp operating voltage was reduced approximately 15 percent. Since the electromagnetic ballasts tended to operate lamps in a constant current mode, this resulted in a comparable system wattage reduction. These new lamp designs operated at a nominal 34 watts when contrasted to the nominal 40 watt reference condition of argon filled lamps.

The energy-saving design would permit most users to discontinue de-lamping and still save significant energy costs. A moderate light loss was acceptable, and the aesthetics of the ceiling and luminaire were restored.

Unfortunately, changing the gas fill to krypton required significantly greater starting voltages to reliably initiate the discharge, or “start” the lamp. The starting voltage requirements were found to be beyond the capability of the existing electromagnetic ballasts.

As a result of many experiments and innovations, lamp manufacturers discovered that the deposition of a thin conductive coating on the inside of the lamp wall was roughly equivalent to moving the fixture ground plane closer to the lamp. This internal lamp starting aid permitted the available starting voltage from existing electromagnetic ballasts to initiate reliable starting of the new energy-saving lamps.

From this point the “tin-coated” lamp became a permanent addition to the fluorescent lamp family.

Following this, the ballast industry developed new energy-saving electromagnetic ballast designs, which were basically the same ballast circuit with lower loss steel for magnetic laminations and copper, instead of aluminum wire.

High Frequency

It had long been known that frequencies in excess of ten kilohertz (kHz) reduced the end losses associated with fluorescent lamp cathodes. The energy crises of 1974 resulted in many small and large manufacturers re-looking at “electronic” and “high frequency” ballasts, where the objective was to operate the lamp at frequencies above the audible range to achieve the increased efficacies that had been observed. The 20 to 30

kHz range was commonly used, but with each manufacturer choosing a frequency optimized for their design or approach.

The advent of the first successful generation of electronic ballasts did not occur until the mid-1980s. Even then, volumes were small compared to electromagnetic designs. Hence, the optimization of tin-coated energy-saving lamps was driven by the electromagnetic (60 Hz) applications.

Description of the Issue

The remainder of this paper focuses on the tin and high frequency interaction between energy-saving four-foot fluorescent lamps and high frequency electronic ballasts.

The same tin coating that ensures reliable starting of energy-saving lamps and electromagnetic ballasts works to reduce the reliability or margin for starting for high frequency systems. Fundamentally, the cylindrical capacitor created by the addition of an internal tin coating to an F40T12 lamp acts to provide a capacitive leakage path to ground that is more significant than the leakage current path at 60 Hz. The formula

$$X = 1 / 2\pi fC$$

shows that, for a given physical capacitance, C , created by the tin coating the leakage impedance will be significantly lower as frequency increases from 60 Hz to approximately 30 kHz. The leakage impedance is greatly reduced, on the order of 500 to 600 times, when compared to traditional 60 Hz operation. This increased ability of a high frequency leakage path to more readily couple high frequency current to the tin coating can result in a tendency to prevent the necessary starting avalanche effect that propagates the initiation of the discharge down the length of the lamp. If the propagation is prevented from traveling down the length of the lamp, the lamp is prevented from starting. This condition is often described in the vernacular as the lamp “hanging up” and is considered a “no start” by the customer or end user.

In very severe situations, a tin-coated lamp may not start on some high frequency ballasts “right out of the box,” or at “zero hours” in lamp terminology. In such cases, it is normally easy to discern that the cause of the starting problem is an interaction of the tin

coating (equivalent capacitor and leakage path) with the high frequency ballast and equivalent circuitry.

However, the problem may develop as the lamp operates, or “burns,” and may become more severe later as the lamp ages. Failure to start may also result from lower line voltages.

The “zero hour” problem is generally considered to occur much less today than in the past. There are two likely reasons for this. First, the lamp manufacturers have learned to stress the process control associated with maintaining the low end of the tin coating resistance range across a four-foot lamp to no less than approximately 8 k Ω . Second, ballast manufacturers have generally increased the capability of their series ballast designs to provide greater open circuit voltage and an attendant greater capability to source or sustain high frequency leakage or glow current during the starting phase. Increasing the capacitance of the so-called “starting capacitor” in series type electronic ballasts increases the glow current, which in turn mitigates the no-start condition.

Increasing the glow current capability to improve the starting reliability for tin-coated lamps results in an excess glow current situation for non tin-coated lamps. This too high glow current for argon filled lamps can result in instant-starting and an attendant premature end discoloration and short lamp life. So, while zero hour starting compatibility has improved, only half the issue has been addressed.

Conclusive tests show that tin-coated lamps that start reliably on a given electronic ballast at zero hours can become non-starting lamps later in life. Normal end discoloration near the cathode region can increase the ability of the high frequency leakage current to couple to the tin near the cathodes as materials associated with the end discoloration deposit onto the inside of the bulb wall. This has the same effect as once again greatly increasing the high frequency coupling to the point that avalanche starting of the discharge is prevented.

Unfortunately, it is not possible to predict at what point this condition can occur. In some cases it has been observed as early as approximately 3,000 hours into the life of the lamp. In other cases, it occurs closer to 10,000 hours. In one instance approximately 20 to 30 percent of tin-coated lamps were found to exhibit starting problems when aged to

approximately 10,000 hours in the field. In many situations these cases are not diagnosed as tin and high frequency interactions. The more likely diagnosis is that such a situation is the result of premature lamp failures or short life. However, experience indicates that, if such lamps are removed and installed in fixtures operating with 60 Hz ballasts, the lamps will start and operate normally. Additional experiments where the ends of such lamps are heated have revealed that materials deposited near the ends can be re-distributed, again resulting in lamps that will start once this has occurred.

Two implications must be considered from the above discussion:

- First, focusing on lamp or ballast changes that only address zero hour starting will not ultimately improve compatibility.
- Second, the incident level of unreliable starting of tin-coated lamps with high frequency electronic ballasts is likely understated as a result of the developmental aspect.

Today's ability of most electronic ballasts and tin-coated lamps to start at zero hours is biased towards a marginally acceptable compromise condition. As lamps age and normal end discoloration occurs, this marginally acceptable situation can become significantly worse. The rate and probability of this deterioration of starting margin is dependent upon many factors that are much more complicated than the historical 60 Hz set of variables. Any lamp operating situation that can accelerate or worsen end discoloration can make the situation worse (lamp processing, ballast starting scenario, poor electrical socket conductivity, electrode heating, etc.)

High Frequency Sensitivity

Many variables contribute to making it difficult to find one easy solution to this problem.

The tin coating effectively magnifies any high frequency parameters that can contribute to poorer starting. This effect becomes worse at higher frequency and becomes magnified for the industry to the degree that there is not a standard fundamental operating frequency for ballasts.

Variation in the finished lamp tin coating is another factor. The NEMA manufacturers each control the range of their finished lamp tin coating resistance, R , to state-of-the-art levels. The aggregate range runs from a low of about 8 k Ω to a high of about 55 k Ω . To tighten this range is not feasible given the variables that can affect the final resistance as the lamp is processed. Tin coating and tin lehr temperature control is one set of variables that occurs early in the process. Phosphor coating and phosphor lehr temperature control adds another set of variables that widen the ultimate finished lamp tin resistance. At the exhaust step still more variables result in a final widening of the total practical process window.

$$\begin{array}{ccc}
 \textit{Tin Lehr} & \textit{Phosphor Lehr} & \textit{Finished Lamp} \\
 R1 \pm V1 & \mathcal{P} R2 \pm V2 & \mathcal{P} R3 \pm V3
 \end{array}$$

Where: Process variables $V1 < V2 < V3$.

Variation in ballast circuitry and leakage current paths is very significant in determining which ballasts are more susceptible to this issue. As opposed to the 60 Hz scenario, where these parameters are relatively similar, the world of high frequency electronic ballasts is extremely diverse, with technology and circuit engineers developing new concepts almost daily. If anything, complexity may make this more of an issue in the future, not less.