DETERMINING VIBRATIONAL FORCES EXPERIENCED BY HIGH PRESSURE SODIUM VAPOR LAMPS IN ROADWAY LUMINAIRES

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ABSTRACT

The Texas State Department of Highways and Public Transportation has experienced difficulty in maintaining highway lighting integrity. High pressure sodium vapor (HPS) lamp outages, and problems with starter boards and ballast systems occurred on a regular basis. Many of these lighting failures could not be traced to poor installation/ maintenance procedures or to lamp manufacturing defects.

Laboratory tests were conducted at the TTI Research Annex at Bryan, Texas, to determine if high pressure sodium vapor lamps (HPS) were subject to vibration. The tests showed that induced vibrational forces up to 2 g caused "blink-out" and structural damage to one half of the lamps tested. The results from the laboratory tests were utilized to set instrumentation parameters necessary to conduct field tests.

Based on the laboratory tests and visual observations in the field, it is postulated that: vibration causes dislodgement of amalgam which vaporizes and therefore requires more voltage to be supplied by the ballast to sustain the arc. If the vibration is severe enough, then sufficient amalgam is vaporized to require a greater voltage than the ballast is designed to supply, thus extinguishing the arc. This phenomenon is termed as "blink-out".

No "blink-outs" were experienced at five test sites on Houston freeways, but tests were relatively short in duration. The test sites encompassed various pole and freeway configurations. Acceleration levels in pulse excitation caused by close proximity traffic at speeds of 55 mph and more often exceeded 1 g. In some instances acceleration levels approached and possibly exceeded 10 g.

SUMMARY

Three Texas highway lighting projects have experienced difficulty in maintaining highway lighting integrity. High pressure sodium vapor (HPS) lamp outages and problems with starter boards and ballast systems occurred on a regular basis. Many of these lighting failures could not be traced to poor installation/maintenance procedures or to lamp manufacturing defects.

By laboratory testing, those HPS lamps used in the lighting projects were demonstrated to be sensitive to vibration. In addition, lamp "blink-out" was related to vibration levels. "Blink-out", a HPS lamp instability, is postulated to result from the vibrationally induced dislodging of amalgam which then vaporizes. Subsequently, the tube pressure increases to the point where the voltage required to sustain the arc is too high. The lamp then extinguishes itself and cools until the tube pressure falls to levels where the voltage pulse from the ignition (starter board) will again start the arc.

The Texas State Department of Highways and Public Transportation (SDHPT) contacted the Texas Transportation Institute (TTI), the Mechanical Engineering Department and the Electrical Power Institute of Texas A & M University to assist in the vibration and electrical system monitoring of high pressure sodium vapor (HPS) highway lighting systems. The monitoring equipment necessary to conduct the work was selected and installed in an insulated, air-conditioned thirty-four foot van.

The monitoring equipment was calibrated in instrumentation pre-test activities conducted at the T.T.I. Research Annex in Bryan, Texas. In these activities the "blink-out"

phenomenon was experienced and these test results were used to set the instrumentation parameters. Half of the lamps lab tested structurally failed at levels below 2g.

Six test sites were selected in the Houston freeway system. The tests involved sites using 40 foot mounting height (MH) and 50 foot MH steel poles with 5 foot rise trussed and "single pipe gull wing" poles. Some of the single arm poles were mounted on concrete drilled shaft foundations along the sides of ramps. Some of the single arm poles were mounted on brackets attached to ramp bridge structures. Twin arm poles were mounted in twenty foot wide flush freeway medians. Five of the six sites selected were tested. The sixth site was not used due to test equipment failure.

The test results showed that the vibrational environment experienced by luminaire structures is caused by moving vortices that trail rapidly moving semi-trucks, ambient wind environment, or by foundation excitation when the luminaire is mounted on a flexible structure such as a bridge.

It was found that severe pulse excitation of HPS by freeway traffic moving at 55 mph or greater in close proximity to the luminaire structure was greater than anticipated. Acceleration levels at these locations often exceed 1g and can approach, possibly exceed, 10g.

No lamp failure, breakage, or "blink-out" occurred at the five test sites. But since these tests were of relatively short duration, one must postulate that the lamp failure rate on Texas Freeways correlates with vibration levels.

Test reports were written and reviewed by SDHPT personnel. The reports were then sent to all major US based lamp and fixture manufacturers. Minimal response was received from the manufacturers.

Some of the lamp and fixture manufacturers have since made minor modifications to their equipment. These modifications have produced some slight improvement in the vibrationally induced problems. However, the problems such as ignitor failure, short lamp life, arc tube support apparatus weld failures and envelope breakage still persist. These problems are causing severe headaches for the maintaining agencies.

IMPLEMENTATION

To reduce the vibrationally induced problems with HPS lighting systems the authors suggest that the following recommendations be implemented:

1. Revise the specifications to require that fixtures supplied for usage on SDHPT projects be fitted with cushioned spring loaded supports for the outboard end of the lamps in all highway fixtures.

2. Investigate and/or devise a more substantial lamp socket and then specify for SDHPT projects.

3. Revise specifications to require the lamps that are furnished for use on SDHPT projects to be configured with a double longitudinal arc tube support.

4. Revise specifications to require lower voltage lamps.

5. Do not allow "gull wing" (single pipe) arms.

6. Investigate, devise and detail a more substantial arm to shaft connections.

7. Investigate and/or devise details and specify an effective, low cost dampening device for new and existing lighting standards.

I. <u>SUBJECT</u>

Determining Vibrational Forces Experienced by High Pressure Sodium Vapor Lamps in Roadway Luminaires.

II. <u>PURPOSE</u>

A. Study Problem Statement:

Early failures of high pressure vapor (HPS) lamps have occurred on a number of roadway lighting installations, both in the State and elsewhere. Preliminary investigation has determined that HPS lamps are susceptible to vibration, causing very early lamp failure. The lamp failure also causes premature failure of other system components. This research study will gather data to determine amplitude, frequency and source of lamp vibration. Results of the study will actually assist in the determination of a solution to the problem.

B. Background and Significance of Work:

The HPS lamp is being used nationwide to replace the mercury vapor lamp for roadway lighting. The HPS lamp, unlike the mercury lamp, is a dynamic lamp with a lamp voltage that increases during the life of the lamp. At end of normal lamp life, the lamp has reached a level at which the ballast cannot sustain the lamp. It has been determined that vibrational stresses will greatly accelerate the lamp voltage rise and cause early failure of the lamp. Two manufacturers have conducted laboratory tests to investigate the problem. However, no criteria has been established to determine the vibrational parameters to which the lamp should be subjected. This study is designed to gather sufficient data for further investigation for a solution to the vibrational problem.

C. Objectives of the Study:

1. Install vibration-measuring instruments on selected existing roadway lighting to measure amplitude and frequency of lamp vibration.

2. Analyze data to determine amplitude, frequency and source of vibration.

3. Make recommendations for solutions to HPS vibrational problems; revise existing lighting specifications as necessary; coordinate with equipment manufacturers where necessary to ensure proper lamps and luminaires are available.

III. MATERIALS

The high pressure sodium vapor (HPS) lamps tested were manufactured by the General Electric Company, Sylvania and the North American Phillips Lighting Corporation. The lamps were installed in aluminum housing roadway (cobra head) luminaires by the General Electric Company. The luminaires were mounted on five (5 foot rise trussed arm and "gull wing" (single pipe) arms attached to 35 foot and 45 foot steel poles. This arrangement produced 40 foot and 50 foot mounting heights. (MH).

Forty foot MH poles and fifty foot MH poles were either single arm for mounting alongside the roadway on concrete drilled shaft foundations, and on steel or concrete roadway bridge brackets. Twin arm 50 foot MH poles were mounted in 20 foot wide freeway medians on concrete drilled shaft foundations. The twin arm poles had 8 foot long arms. The single arm side mounted poles had 8 foot and 10 foot long arms.

IV. EQUIPMENT:

The test equipment was housed in a Fruehauf thirty-four foot long air-conditioned van. The air-conditioning was necessary to protect the temperature sensitive instrumentation.

Data were recorded using an AMPEX PR 220016 channel tape recorder. A tape speed of 15/16 ips and ampex 766 intermediate band tapes, 5600 feet long, enabled continuous monitoring for twelve hour periods before tape change.

Pearson Model 411 wideband (35MHz) precision current transformers were used to obtain the pre and post ballast currents. Tektronics P6007x100 voltage probes were used to monitor the voltage.

Accelerometers having a sensitivity of 100 mV/g and a frequency range of 1-3000 Hz. Two PCB312A high-temperature accelerometers were used to monitor the vertical (Z) accelerations on the tube surface and at the lamp base. Because the PCB 321A accelerometers lack internal amplifiers, in-line charge amplifiers mounted on the lamp chassis were used to amplify the PCB 321A signals to 100mV/g sensitivity.

V. PROCEDURE FOR DATA

Six test sites were selected. The sites were on the freeway system in Houston, Texas. The sites were selected to obtain data from single arm poles located on ramps in master interchanges, both on the ground and on bridges. Some sites were selected to obtain data from double arm poles located in the median of the freeway main lanes. Table 1 lists the five test sites used and the test durations and dates.

Table 1 - Field Test Sites

Site No.	Site Description	Test Duration (days)	Test Dates
1	Bridge mounted, single arm pole, south approach to Ship Channel Bridge, site on prestressed unit approximately 30' from a bent	7	3-11-82 to 3-19-82
2	Ground mounted, twin arm pole north of Ship Channel Bridge at Clinton Drive exit	2	3-28-83 to 3-30-83
3	Side mounted, ground mounted, single arm pole on off-ramp from I-10 EB to I-610 EB	3	4-25-83 to 4-28-83
4	Side mounted, bridge mounted, single arm pole on ramp from I-10 EB to I-610 SB, pole located at midspan	3	5-31-83 to 6-03-83
5	Median mounted twin arm pole on I-610 North Loop at T.C. Jester exit	2.5	7-05-83 to 7-07-83

At site 1, data was recorded for seven continuous days with the HPS being permitted to function normally (photocell on/off). The lamps at sites 2 through 5 were operated continuously even during daylight hours.

Figure 1 identifies the accelerometer locations and instrumentation used to acquire the accelerometer time histories. The instrumentation van, fondly named the "yellow-elephant" was insulated and air-conditioned to protect the temperature sensitive instrumentation. At each test site the van was placed to be the least visual and disruptive to traffic.

Wires carrying the ballast and lamp voltage and currents were segregated from the accelerometer wires on opposite sides of the mast/arm to minimize cross-field electrical excitation. Pre and post ballast currents were monitored.

Of the ten accelerometers, channels 1-8 used accelerometers having sensitivity of 100mV/g and a frequency range of 1-3000Hz. Two high temperature accelerometers, channels 9 and 10, were used to monitor the vertical (Z) accelerations on the tube surface and at the lamp base.

Comparing the PCB312A mass, including mounting components (approximately 50 grams), to the mass of the HPS tube (approximately 165 grams), it was considered permissible to mount one accelerometer on the lamp surface. The accelerometer was mounted on the tube surface near the lamp socket. The tube surface temperature here falls within the PCB 312 limitation of 400°F. Also, this location enabled the researchers to discern the vibration transmissibility across the lamp socket. Since the lamp tube is protected from direct wind loading by a glass shield, the socket provides the only means of tube excitation.

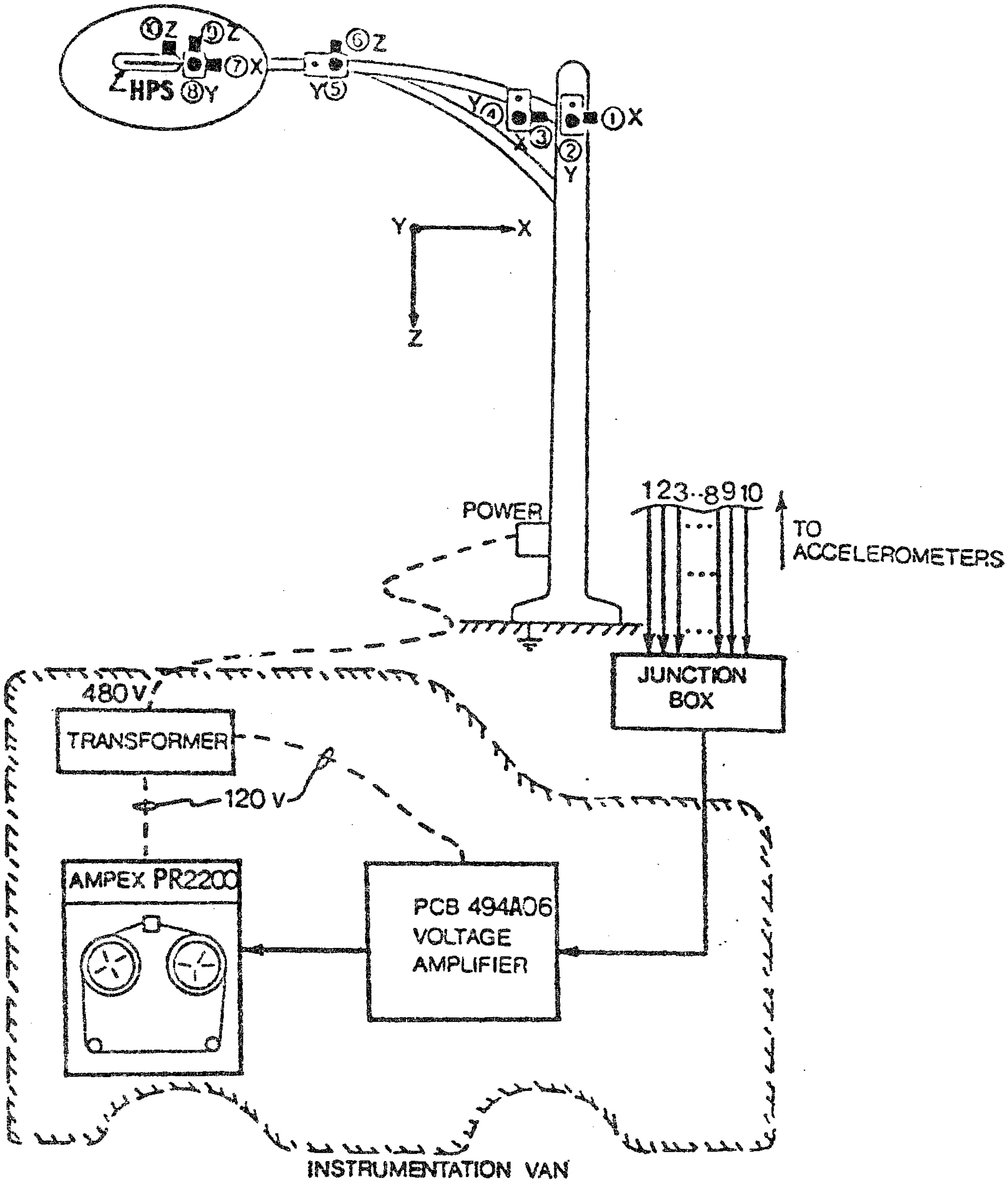


Figure 1 - Instrumentation

Instrumentation Pre-Test

Luminaire inaccessibility at most test sites made close proximity of the instrumentation van to the luminaire base impossible. Concerns relative to signal loss in wiring runs approaching 250 ft., proper amplifier settings, and the interactions that may occur during "blink-out" all necessitated an instrumented pre-test. In this pre-test the tip of a partially instrumented luminaire arm was forcefully excited by test personnel elevated from a bucket truck. Periodic impulses were applied in all directions to excite the dominant modes of vibration and to raise vibration levels through resonant amplification. The test results were used to set the instrumentation parameters.

VI. Discussion

Introduction

Three Texas highway lighting projects have experienced difficulty in maintaining highway lighting integrity. HPS lamp outages and problems with starter boards and ballast systems occurred on a regular basis, see Figures 2A and 2B. Many of these lighting failures could not be traced to poor installation/maintenance procedures or to lamp manufacturing defects.

By laboratory testing, those HPS lamps used in the lighting projects were demonstrated to be sensitive to vibration. In addition, lamp "blink-out" was related to vibration levels. "Blink-out", an HPS lamp instability, is postulated to result from the vibrationally induced dislodging of amalgam which then vaporizes. Subsequently, the tube pressure increases to the point where the voltage required to sustain the arc is too high. The lamp then extinguishes itself and cools until the tube pressure falls to levels where the voltage pulse from the ignitor will again strike the arc.

To assess the nature and severity of the field vibration environments by actual luminaire structures, the Texas State Department of Highways and Public Transportation (SDHPT) contracted the Texas Transportation (T.T.I.) to monitor and record vibration environments of six Houston area sites. Piezoelectric accelerometers were placed at ten positions on the luminaire mast, arm and lamp chassis to monitor vibrational histories over specific testing periods. Because the recorded correlation of the ballast control reaction to vibrational levels and frequencies during the blink-out was an important test objective, the primary voltage/current to the ballast and the secondary voltage/current to the lamp were also instrumental.

Test Results

The pulse frequencies of occurrence as distributed over specific g bands at the five test sites were compiled, see Appendix A of the Supplement to this report. As would be expected, Sites 1, 3 and 5 proved most active for pulse loading whereas Sites 2 and 4 were at locations where due to roadway geometry, vehicle speeds would generally be reduced. Although the luminaire at Site 3 was located on an off-ramp, significant pulses still occurred. This resulted from entrance location of the luminaire where vehicle speeds are still high.

A direct correlation between pulse severity, measured in terms of g level, and site location (vehicle speed) is evident. Dynamically active sites may be subject to over 100 pulses per week which exceed 1g in magnitude. One site experienced 14 pulses over 4g and one which may have exceeded 10g had not instrument saturation occurred. In contrast two sites were not subject to pulses having magnitudes which exceed 1g, obviously because the ramp configuration reduced the nominal vehicle speeds.

These results seem to indicate that vortex-induced pulses are insignificant until vehicle speeds exceed 50 mph. It was also postulated that severe pulse levels do not occur until vehicle speeds approach or exceed 60 mph, although the direct correlation of "measured" speed to acceleration level was not made.

Discussion of the Results

The vibration environment experienced by luminaire structures results from:

1. Short duration pulses which are caused by vortices that trail rapidly moving semi-trucks. Vibrational forces experienced in the field were normally 1 to 2 g.

2. Periodic, "modal" vibration of the luminaire structure at g levels less than those caused by short duration pulses. Modal vibration can be excited by short duration pulses, by a fluctuating ambient wind environment, or by foundation excitation when the luminaire is mounted on a flexible structure such as a bridge.

3. Vibration of the luminaire structure at or near the frequency of a vibrating foundation, such as a bridge vibration.

Much of the pulse energy appears to be distributed over frequencies below 5Hz. This distribution makes shock isolation of the HPS bulb difficult because of its low mass. No lamp failure, breakage, or "blink-out" occurred at the five test sites. But, since these tests were of relatively short duration, one must postulate that the lamp failure rate on Texas freeways correlates with vibration levels experienced during pretest activities. We note that half of the lamps tested structurally failed at levels below 2g.

In an earlier research paper, Van Dusen predicted that 5% of luminaires will see g levels that exceed 1g. This paper failed to recognize the severe pulse excitation of HPS by freeway traffic moving at 55 mph or greater in close proximity to luminaire structures. Acceleration levels at these locations often exceed 1g and can approach, possibly exceed, 10g.

Post Test Activities

SDHPT personnel involved in the project reviewed the data and reports written by Texas A&M project personnel. After the review and completion of minor revisions, the reports were sent to all major U.S. based lamp and fixture manufacturers.

After an extended period of time only three manufacturers returned brief comments. The authors did not consider the comments to be significant.

However, it must be noted that General Electric did make further minor modifications to their lamps. After these modifications were made it was considered mandatory to monitor the field service results of these modifications.

The City of Houston Electrical Division performs the maintenance on roadway illumination in Houston and they report the modifications made by General Electric showed minor improvement in overall service life of the lamp.

Some manufacturers redesigned their ignitors. Very little change was noted in the "blink-out" problem. However, it was noted that the survival rate of the ignitor improved. Some manufacturers still produce high voltage lamps that yield a higher lumen output. High voltage lamps are more susceptible to vibrational "blink-out" than lower voltage lamps.

In addition to "blink-out" problems, arc tube support failure and envelope failure at the base are quite common. Some fixture manufacturers are providing a support at the outboard end of the lamp, either spring loaded or semi-rigid metal supports. All indications are that "blink-out", arc tube support and envelope to base failure problems are reduced. However, it appears that the semi-rigid metal support may be causing an envelope breakage at the support.

A foreign manufacturer now produces a lamp equipped with a double longitudinal arc tube support. The double longitudinal arc tube support seems to minimize the support weld failure.

In addition, a search was made for dampening devices that could possibly be used to effectively dampen the vibrational shock to the luminaire and lamps. No devices were found that appeared to effectively lessen the shock. Most of the devices were very expensive either to buy and/or install. Other agencies have also been researching this dampening problem with little success.

Copies of the supplement to this report which contain the reports and data as produced by project personnel from Texas A&M University are available from Planning and Research Division of the Texas State Department of Highways and Public Transportation, Austin, Texas, 78701-2483.

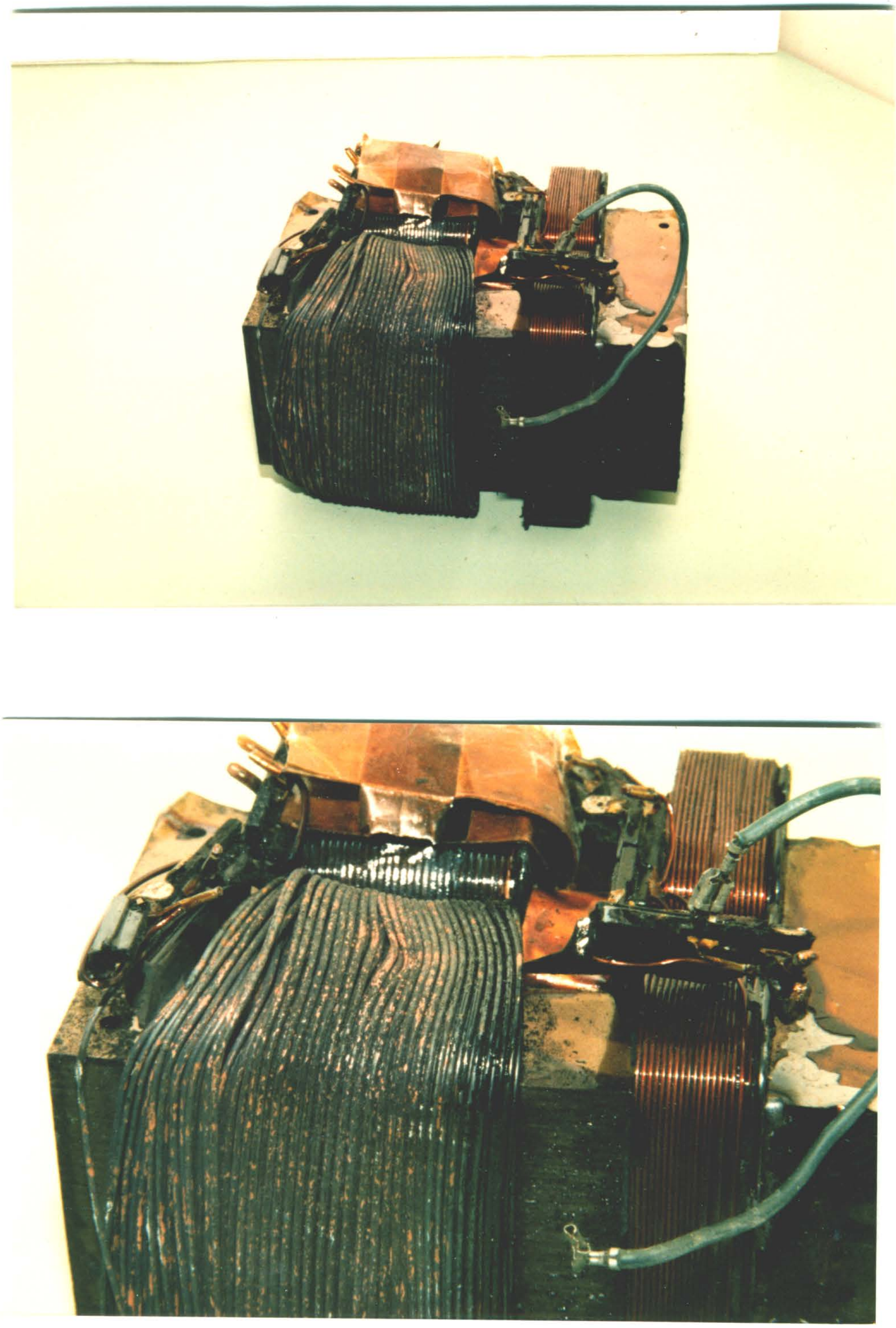


Figure 2A

Typical Ballast Failure

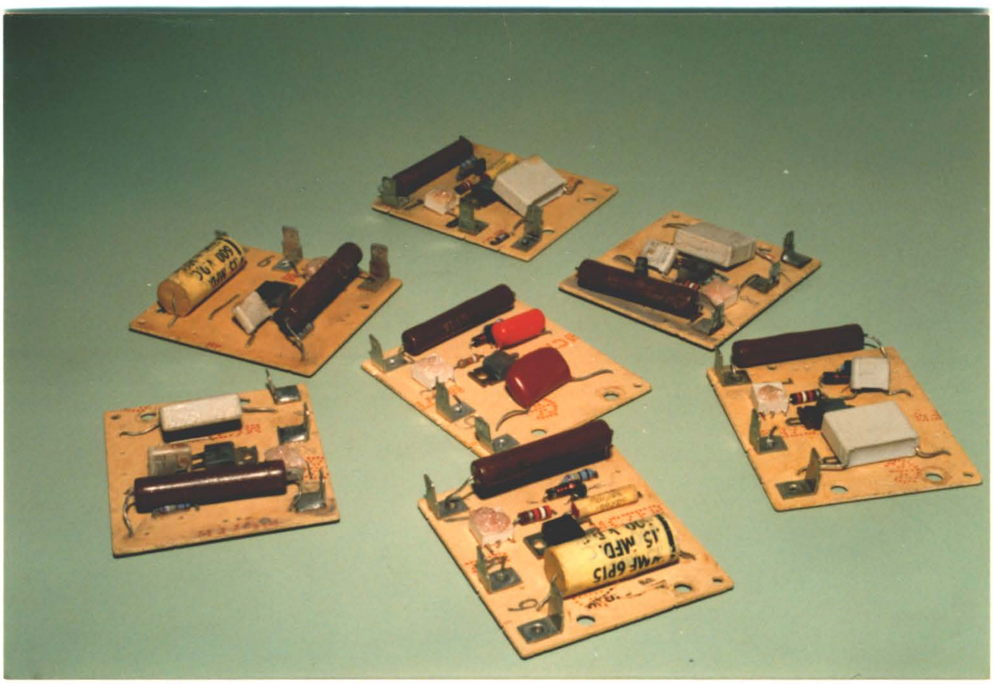


Figure 2B

An Array Of Burned Out Ignitors

(Starter Boards)

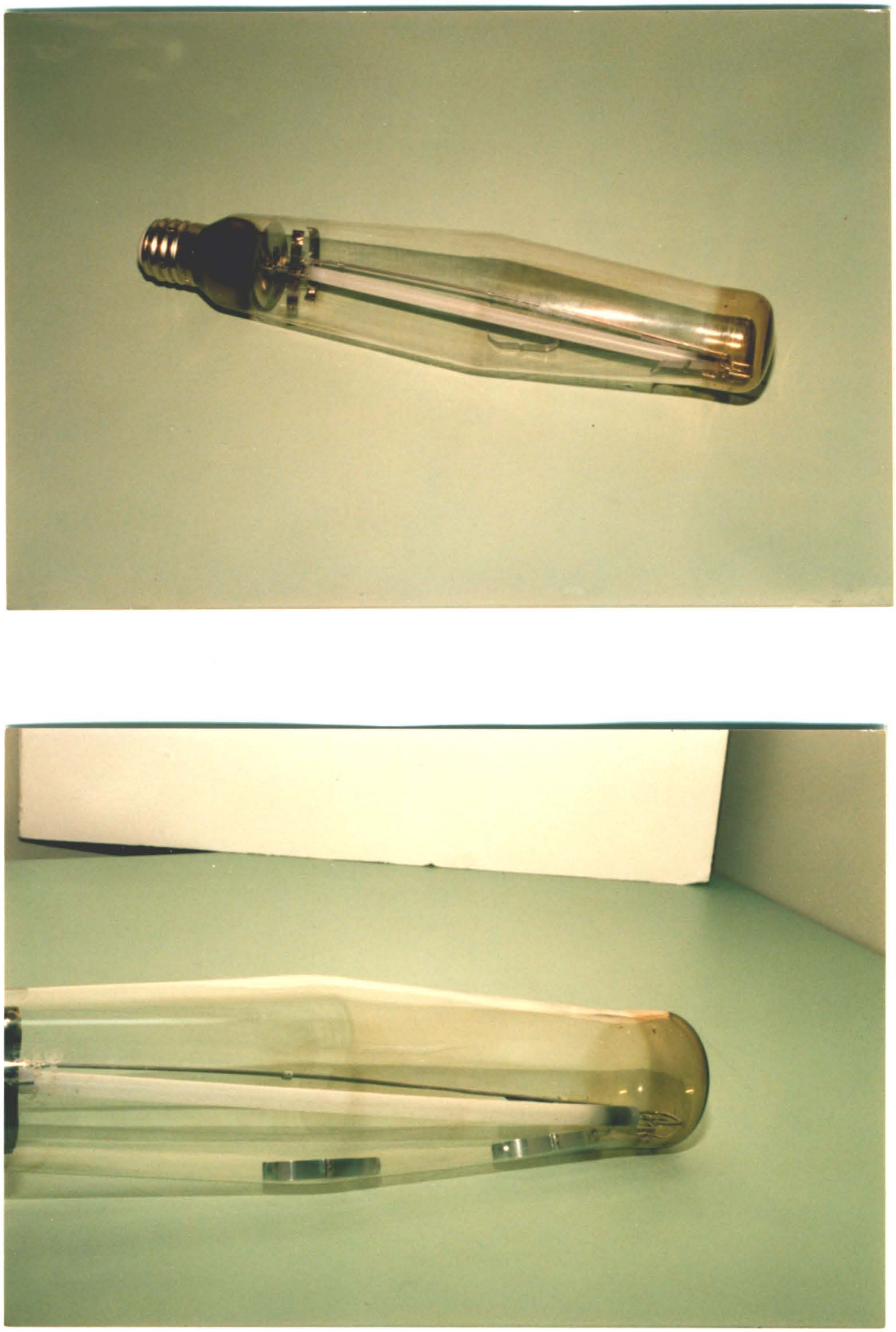


Figure 3A

Lamp Failure At Outboard End

(Single Arc Tube Support)

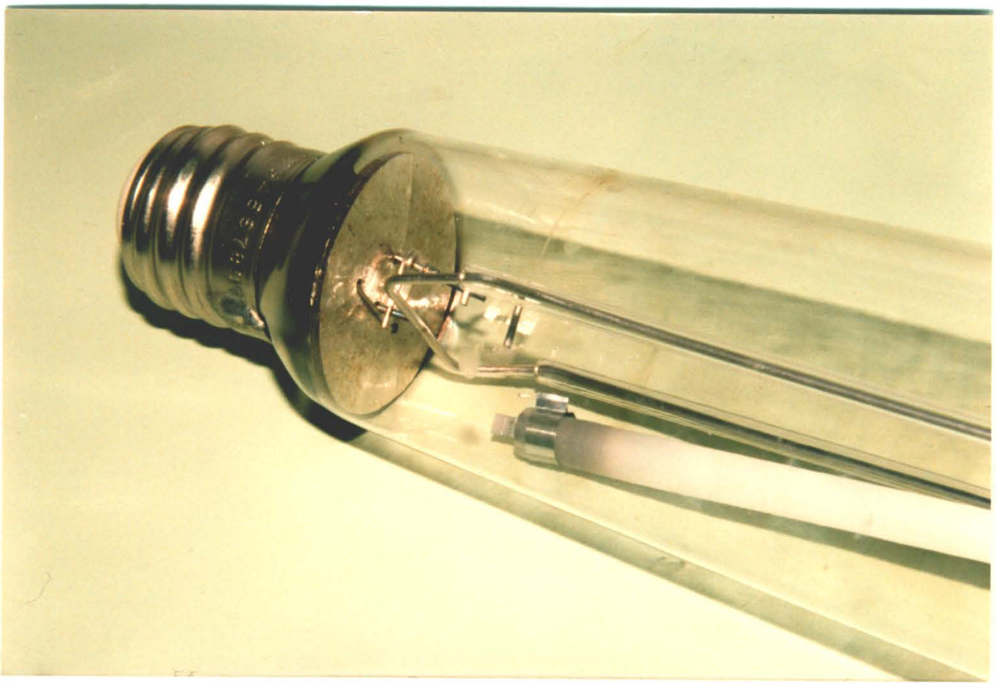


Figure 3B

Lamp Arc Tube Support

Failure At Base End

(Double Arc Tube Support)

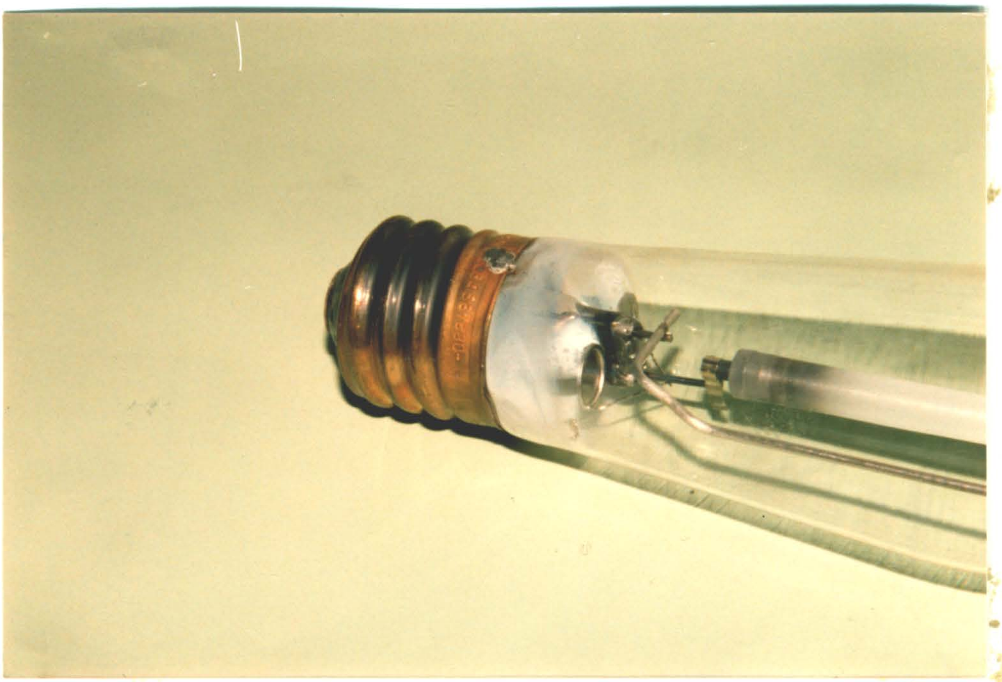
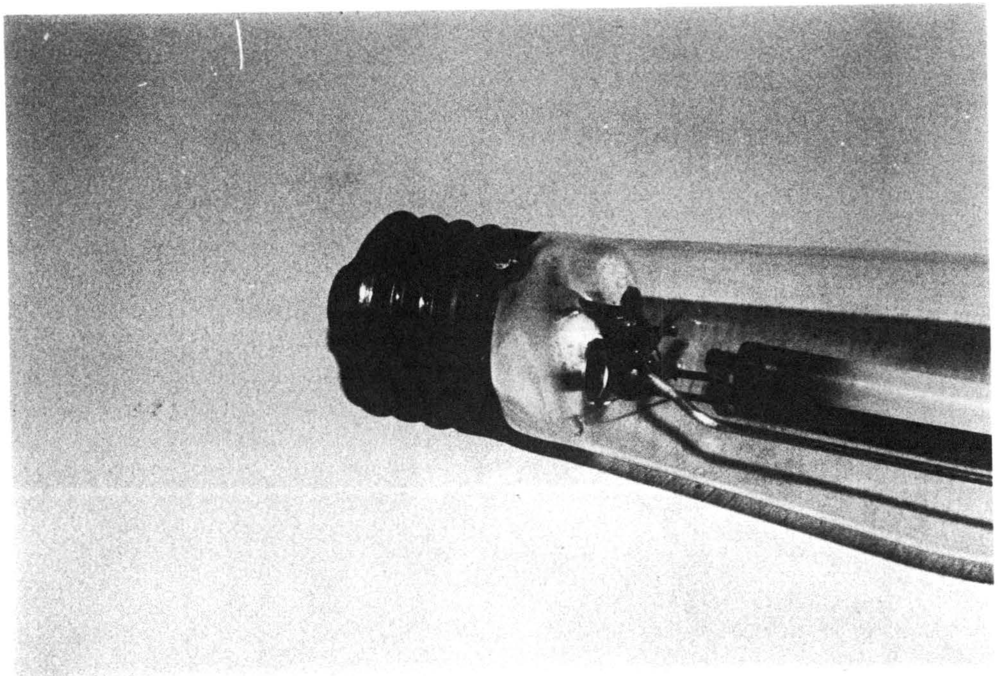


Figure 3C

Lamp Envelope Failure



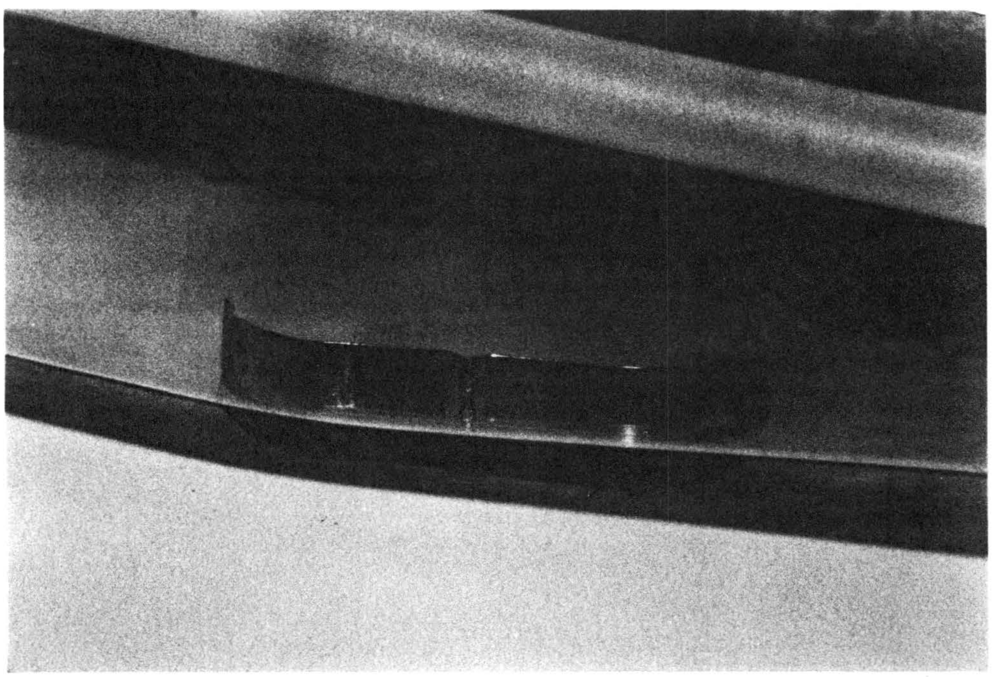


Figure 3C

Lamp Envelope Failure

VII. CONCLUSIONS AND RECOMMENDATIONS

General

"Blink-out" was experienced in the laboratory tests but not in the field tests. However, since vibrational forces measured in the field in some cases exceeded those that caused "blink-out" in laboratory tests, one must postulate that the field environment is conducive to producing "blink-out. It appears that all lamps used in the field tests were low voltage lamps and, therefore, not necessarily subject to "blink-out" caused by vibration.

A direct correlation between pulse severity, measured in terms of g level and site location (vehicle speed) is evident. Dynamic sites may be subject to over 100 pulses per week which exceed 1g in magnitude. One site experienced 14 pulses over 4g; one site experienced in excess of 10g.

With such a small site sampling of 5 sites out of 6,000 in Houston alone, it is easy to see the magnitude of the vibration induced problems. Even with the modifications made in lamp and luminaires made by some manufacturers, the vibration induced problems still persist. This problem not only exists in Houston, it exists statewide. In fact the problem is experienced nationwide.

A complete solution to the HPS lighting vibrational problems is not known. However, the following recommended specification changes should minimize the problems in new projects:

1. Luminaires be fitted with spring loaded supports for the outboard end of the lamp.

2. Specify a more rigid metal socket and possibly attach to porcelain shell in three places instead of two.

3. Require double longitudinal arc tube support.

4. Use a more rigid trussed arm (no single pipe, "gull wing") with stiffer arm to shaft connections. Widening the attachment points of the truss to the shaft may eliminate any vibrational harmonics.

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