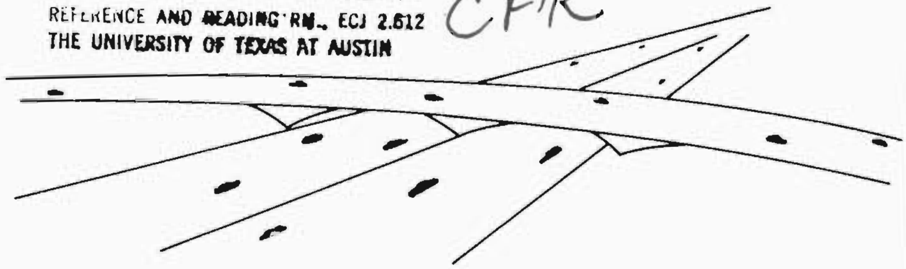


DEPARTMENTAL RESEARCH

Report Number SS 22.3

PROBLEMS ENCOUNTERED IN THREE HIGH-PRESSURE SODIUM HIGHWAY LIGHTING PROJECTS IN TEXAS

[redacted]

STATE DEPARTMENT OF HIGHWAYS
AND PUBLIC TRANSPORTATION

Problems Encountered in Three High-Pressure Sodium Highway Lighting Projects in Texas

Special Study Report No.

SS 22.3

by

H. Dexter Jones

Texas State Department of Highways and Public Transportation

November, 1980

PREFACE

This report is not intended to be a stilted, technically precise, chronological report. It is merely a collection of the problems encountered on three high pressure sodium high mast lighting projects in Texas, the efforts expended in trying to solve the problems, and the thoughts and opinions of the author. This report is not being offered as official opinion and policy of the Texas State Department of Highways and Public Transportation, but is offered as thoughts and opinions of the author alone.

It is realized that some of the participants' opinions do not agree with those of the author, as the author does not agree with some of the thoughts and opinions of other individuals expressed vocally and in correspondence included as attachments to the main body of this report. It is requested that anyone reading this report read the entire report including the attachments, as the attachments contain many problems and efforts too numerous to be repeated in the main body of the report. The attachments are the correspondence that the author thought was the most pertinent correspondence written during this most difficult period. The attachments were selected from a veritable mountain of paper work generated during the period.

This report is not intended to be offered in a derrogatory nature to any individuals or companies involved. The report may seem to single out General Electric Company. More is said about G.E. because actually G.E. responded more positively and did more than all of the other lamp companies to try to help solve the problems. Sylvania also made an endeavor but not to the extent of G.E.'s effort. I.T.T. gave S.D.H.P.T. excellent support in the investigation of the equipment problems.

Even though this was a trying period for all individuals and companies involved, it is felt that the lighting industry as a whole has gained from the things that were learned. This report was prepared and is offered in an effort to try to help other individuals in the field of lighting.

I wish to express my thanks to Mr. Thad Bynum of S.D.H.P.T., File D-8, Mr. Joe Raska and Mr. Dave Edwards of S.D.H.P.T., File D-9, and to the many other individuals and companies who were vitally active in this investigation.

On July 24, 1975, the contract for Project I-610-7(74)781, Control 271-15-11, was awarded to Delta Electric Company of San Antonio, Texas. The project extended on I.H. 610 for 6.5 miles from north of the I.H. 45 interchange to Gellhorn Drive in Houston, Texas. The project included the interchange of I.H. 610 with S.H. 225 and the interchange of I.H. 610 with I.H. 10. The project provided for the installation of signing, striping, guard rail, and a freeway illumination system. The Contractor furnished General Electric fixtures and Sylvania lamps. The wattages of the units ranged from 150 watt and 250 watt for underpass units to 400 watt for the 50' mounting height main lane units and 1000 watt for the high mast units. The freeway illumination system was based upon the use of high pressure sodium as the light source. Difficulty was experienced in passing the 14-day test due to lamp outages, starter board problems, and some minor ballast problems. The Sylvania Corporation was contacted on numerous occasions concerning the lamp problem. On several occasions, Sylvania, although they disclaimed any problem with the lamps, furnished lamps to the State for installation in the units to replace the failed lamps. The project finally passed its required 14-day test and was accepted by the State on June 10, 1977. Since acceptance, Houston Lighting & Power Company, who maintains the system through contractual agreement with the City of Houston, has experienced problems in maintaining the integrity of the system.

On January 26, 1977, Project I-610-7(172)787, Control 271-14-77, was awarded to Fosco Fabricators, Inc. of Dixon, Illinois. This signing project also included freeway illumination and extended for 7.2 miles from Gellhorn Drive through the U.S. 59 interchange to the interchange of I.H. 610 with I.H. 45 (North Freeway). The project did not include the lighting for the interchange of I.H. 610 and I.H. 45 as it was already illuminated with mercury vapor. Immediately after completion of the circuits, the system was turned on and problems appeared with starter boards, ballasts, and lamps. The Contractor had furnished I.T.T. American Electric fixtures and Sylvania lamps for the 50' mounting height units and the underpass units. The Contractor furnished a combination of I.T.T. fixtures for the symmetric and asymmetric high mast and Wide Lite fixtures for the "Z" pattern high mast in the approaches to the I.H. 610 and U.S. 59 interchange. Sylvania lamps were also furnished for the high mast units. Sylvania disclaimed any problems with the lamps but again supplied numerous lamps to the Contractor for replacement purposes. A letter from Sylvania to S.D.H.P.T. claimed that the 1000 watt lamp problems were basically due to mishandling by the Contractor. I.T.T. and Sylvania were requested to look into the problems to find out why the system would not burn. Part of the blame was laid to a rodent problem that was experienced in the northwest end of the project. The conduit system in that area was constructed on another project three years prior to installation of the lighting system. As this freeway is the major route of grain trucks to and from the Port of Houston, large amounts of grain are deposited in the median and rats had taken up residence in the conduit system and the elliptical steel median rail. This situation primarily existed in close proximity to the I.H. 45 interchange. The Harris County Rodent Control Department was contacted and rodent control measures were taken, although this cannot be reported to have been 100% successful.

On June 17, 1978, Project CGR 151-6-71, Control 151-6-71, was awarded to Mike Alder, Inc. of San Antonio, Texas. The project included freeway illumination on S.H. 183 from Loop 360 to I.H. 35 for 4.2 miles in Austin, Texas. The Contractor furnished I.T.T. high pressure sodium units as was done by Fosco on the second Houston project. The Contractor furnished General Electric lamps and the units were primarily 400 watt high pressure sodium cobra head units. Equipment failures were experienced in Austin that appeared to be the same as was experienced in Houston. Because of the problems, District 14 would not accept the project.

On October 24, 1979, a meeting was held in Houston between representatives of General Electric, I.T.T., Sylvania, Houston Lighting & Power, File D-8 (Highway Design Division), and the Houston Urban Project. During the meeting, pressure was brought to bear upon the manufacturers to investigate and determine the causes of the problems with the projects.

The City of Houston and Houston Lighting & Power were notified that the second (Fosco) project on I.H. 610 was being conditionally released to the City as it had been accepted on October 19, 1979.

However, the City was informed that the State Department of Highways and Public Transportation was endeavoring to determine the causes of the problems with the system and would endeavor to correct the deficiencies. Two fixtures, a bad fixture and a good fixture, were taken down from the S.H. 183 project in Austin and two fixtures, a good one and bad one, were taken down from the Fosco project in Houston. All four units were sent to General Electric's Edison Park labs in Twinsburg, Ohio. After testing there and some independent testing of production equipment by I.T.T. in their labs in Mississippi, on March 11, 1980, test equipment was brought to D-9's lab in Austin, Texas. A conference was held after sample testing was conducted in D-9's lab. It was attended by representatives of G.E., I.T.T., Alder Electric, File D-9, File D-8, Houston Urban, and District 14. G.E. confirmed, as had been previously pointed out to them by Departmental personnel, that there was indeed a vibration problem with their high pressure sodium lamp. They stated that they had redesigned their amalgam reservoir and the new amalgam reservoir would eliminate the vibration problem. They stated that vibration of the lamp caused the lamp to go out, but this new amalgam reservoir would eliminate the problem. I.T.T. stated that by additional testing they had discovered that there was a deficiency in their ballast and by adding additional shunts this problem had been eliminated. An agreement was reached whereby new lamps, ballasts, and starter boards, as required, would be furnished to Alder Electric for installation in the S.H. 183 project. It was agreed that G.E., I.T.T. and Alder Electric would share the cost of the replacement of the equipment.

As the Fosco project had been conditionally accepted, I.T.T. stated that they would send Mr. Bill Breining to Houston to test, unit by unit, the Houston Fosco installation. Houston Urban agreed to contact the City of Houston and Houston Lighting & Power for the acquisition of the necessary bucket truck, traffic control equipment and personnel. I.T.T. stated they were anxious to do the testing and get the system straightened out. I asked General Electric, during the meeting, if they had tested other manufacturers' lamps as had been requested. They said yes and that the other manufacturers had similar vibrational problems with their lamps. They were asked if they had contacted the other manufacturers. They stated that due to contractual laws their lawyers had told them that they could not contact the other manufacturers. G.E. was told that the other manufacturers would be contacted by S.D.H.P.T. and I.T.T. stated that they would also contact the other lamp companies because I.T.T. had no such legal limitation.

Upon returning to Houston, the leading personnel in the lamp division of the other manufacturers were contacted. I first contacted Mr. Jack Hoffman of Norelco in Hightstown, New Jersey. Mr. Hoffman was told that Norelco had a lamp vibration problem. He stated that Norelco knew that they had a vibration problem and had known it since the inception of high pressure sodium lighting. He was asked what caused the vibration problem.

Mr. Hoffman stated that all high pressure sodium lamps have an excess of amalgam. The excess of amalgam is placed in the lamp to increase the lumen output through the life of the lamp. This is probably done to place the high pressure system into a more favorable position against mercury vapor systems and low pressure sodium systems. Also he stated that theorectically the excess amalgam increased the lamp life. In actual practice this does not necessarily happen. It does increase the lumen output. However, some of the excess amalgam rests on the arc tube and when the lamp receives a vibrational shock the amalgam is vibrated off the arc tube. A large amount of the amalgam is then deposited on the electrodes. The electrodes heat the deposited amalgam and it vaporizes thus increasing the pressure in the envelope. S.D.H.P.T. tests indicate the increased pressure makes the lamp call for more voltage to drive the lamp, and the lamp voltage may increase as much as 30 to 35 volts. By ANSI standards, high pressure sodium lamps must operate within a certain trapezoid. It starts at approximately 85 volts and will drop out and ceases to burn at 160 volts. General Electric has tightened the trapezoid in their lamp design and their lamps normally start at 95 volts and then drop out at 160 volts. G.E. historically supplies high voltage lamps, with initial voltage at around 125 to 135 volts. With an additional 30 volt surge due to vibration and the lamp operating high in the trapezoid, the surge causes the lamp to exceed the 160 volts and it drops out. By design this causes the starter board to actuate trying to reenergize the lamp which will not energize because it is over voltage. In a 400 watt unit, the starter board strikes the lamp with a 2500 volt spike a minimum of 60 times a minute. This puts undue wear upon the starter board and ballast. After the lamp cools down, it restarts and continues to operate until it receives another vibrational shock sufficient to send it over the voltage curve, then the cycle starts over again.

The vibrational phenomena was accidently discovered by S.D.H.P.T. and Alder personnel. As the Contractor tried to get the Austin system operational, a lamp was replaced. It struck, burned in, and before the Contractor's workman could get to the ground from his bucket truck a large truck passed by. The truck caused a gusting effect vibrating the installation and the lamp went out. The Contractor's workman thought that he needed another lamp and proceeded to get one. The lamp came back on, burned in, and about that time another truck passed by and the lamp went out. The Contractor's workman picked up a piece of wooden 2 x 4, went up in the bucket truck alongside of the arm. By that time the lamp had restruck and it burned back in. He first checked to see if all of his electrical connections were tight. They were, and the lamp was burning. He struck the arm with the 2 x 4 and the lamp went out.

Mr. Hoffman was asked if the amalgam phenomena in the vibrational problem had been reported to the IES (Illumination Engineering Society). He said no, but that G.E. in their promotional literature had published that their new amalgam reservoir design eliminated vibrational "blink-out" problems, and this would not be experienced with G.E. equipment. Mr. Hoffman was asked to write a letter telling basically what he told me concerning the vibrational problem, and would he send me a copy of the G.E. promotional literature. A copy of Mr. Hoffman's letter and the G.E. promotional literature is Attachment A to this report. You will note that the G.E. literature is dated approximately one year prior to G.E.'s confirmation of the vibrational problem.

Mr. George Andreason of the Westinghouse Electric Corporation lamp division in Bloomfield, New Jersey was then called. Mr. Andreason stated that Westinghouse also knew of the vibrational problem. Westinghouse historically supplies low voltage lamps and as has been proven by the State of Texas experience and by other states and industry experience Westinghouse does not have the percentage of the vibrational problems as does G.E. and Sylvania. The lumen output of the Westinghouse lamp is generally lower than G.E. or Sylvania but in actuality longer life and better operational experience is gained with Westinghouse units. However, on one project, during a test, we experienced 100% failure in six 1000 watt Westinghouse lamps that were furnished. Mr. Andreason was asked if there was any way to eliminate the vibrational problem. He stated, as had Mr. Hoffman, by reducing the amount of amalgam, decreasing the lumen output, and theoretically decreasing the lamp life, the problem could be reduced but would not be eliminated. As Mr. Hoffman said, "It is the nature of the beast." Mr. Hoffman and Mr. Andreason both stated that they would run the problem back through their engineering design sections although, at the present time, they did not know any way to to eliminate the problem.

Mr. Besterman of the Sylvania lamp division in Danvers, Mass. was then called. Mr. Besterman was given a brief rundown of the problems with the systems both in Houston and Austin. He was also told of our contact with Mr. Steve Sirek of his company who is based in Dallas, Texas. Mr. Besterman was told that the 1000 watt Sylvania lamp problem had been attributed primarily to mishandling by the Contractor. Mr. Besterman stated, however, that Sylvania indeed knew that they had a vibrational problem. He said that they would also look into what could be done but also stated that they did not know an immediate solution to the problem. He said that S.D.H.P.T. would be contacted at a later date concerning their investigation.

I then met with Mr. Bill Earle, Director of Public Service, City of Houston. Mr. Earle was fully informed of the situation and arranged for the taking down of two of G.E.'s units from the Delta Electric job for shipment to G.E. for testing. These units were not sent to the Twinsburg Lamp Division but were sent to the Hendersonville Fixture Division as Hendersonville had been kept apprised of the situation through the entire problem period. Hendersonville people had been actively involved in trying to resolve the problems.

Mr. Earle later telephoned me and stated that he had been told by Houston Lighting & Power that although only three of the thirty circuits on the two jobs were working, the City of Houston was paying the bill for all units in both systems. This was because the units continued to use energy even though they were not burning. This was due to the starter boards and ballasts being actuated, trying to energize the lamps. Mr. Earle instructed Houston Lighting & Power to turn off the systems. He also stated that the City would like to replace the high pressure sodium units with either low pressure sodium or mercury vapor units. He was asked to refrain doing this until we could see if the problem could be corrected. He agreed to delay the action. Attachment B is a letter from Mr. Earle explaining his action.

Mr. Tony Ball of the Federal Highway Administration division office was called and told the history of the problems and the progress made to that time. This was done on 3-31-80. Mr. Ball stated that he would contact Mr. Chuck McElroy of the regional office in Fort Worth. Mr. McElroy called and talked at length with me concerning the problem. I told him that I would like to talk to Mr. Chuck Craig in the Washington Office but wanted to go through channels informing each section of the FHWA of the problem. He stated that Mr. Chuck Craig and Mr. John Arens both were out of the Washington Office but that he would contact Mr. Bob Conners, Mr. Craig's superior. He immediately called Mr. Conners, apprised him of the situation and Mr. Conners called me. I explained the situation and Mr. Conners stated that he was quite surprised because the FHWA had not received any information concerning problems with H.P.S. lighting. He was informed that during the investigation we found out that other states had also been having similar problems. Mr. Conners requested that this report be prepared and sent through channels to Washington.

In all, S.D.H.P.T. personnel had three general meetings, one in Houston and two in Austin, with G.E. and I.T.T. personnel about the problems. After the second meeting in Austin, I met informally with Mr. Bill Breining, the trouble shooter for I.T.T. on lighting systems. Mr. Breining stated his experience with H.P.S. systems correlated with the problems experienced in Texas. He suggested calling several men in other states that were having problems with H.P.S. systems. He stated that several industrial installations were having similar problems. He also explained other problems with H.P.S. systems such as capacitor problems, heating of end seals, fragile arc tube supports that bend and break, and voltage fold over. He stated that when the lamp industry attempted to improve one problem they would create another problem.

Mr. Dick Stark, Illinois Department of Transportation, was contacted and he stated that they had experienced vibrational problems with H.P.S. and had worked with pole manufacturers to develop a dampening device. Attachment C is a handwritten note from Mr. Stark and a sketch from HAPCO of a dampening device. Mr. Stark also stated that he was working with Westinghouse to remotely locate the H.P.S. ballast in an effort to lessen vibration. Mr. Don Husby of Westinghouse confirmed their work in locating the ballast on the pole instead of in the fixture.

Mr. Howard Young with the Wisconsin Department of Transportation was also called and he stated that they had taken steps to lessen vibration and had therefore diminished their problems.

During this interval, G.E.'s Lamp Division was working on modifications to the lamp and devised a modified amalgam reservoir that was to eliminate the "blink-out" problem. This new lamp was brought to the second Austin meeting.

As previously agreed to on April 7, 1980, Mr. Breining, I.T.T. Field Service Manager, began testing the Austin S.H. 183 project, using the modified G.E. lamps, I.T.T. ballasts and starter boards. It was soon found that the new lamp still went out when subjected to shock or vibrational stresses and the test was terminated. A copy of Mr. Breining's field report is Attachment D to this report. The decision was later made by S.D.H.P.T.'s District 14 to continue the change out using the new G.E. lamp and at the time of this writing the system is reported to be operating satisfactorily. The project was accepted by the State in May, 1980.

On April 18, 1980, Mr. Breining began the inspection of the Houston Fosco project. Mr. Dave Edwards of S.D.H.P.T.'s File D-9, Materials and Tests Division, worked with Mr. Breining. Mr. Sirek of Sylvania was present during most of the test. Mr. Jim Johnson, the local I.T.T. representative, was also in attendance during most of the test. Mr. Breining's trip report is Attachment E. Mr. Edward's trip report is Attachment F. Mr. Sirek's trip report is Attachment G.

As stated in all three trip reports, the majority of the problems found in the Fosco job were either poor workmanship by the Contractor or by H.L.&P. maintenance crews. However, again the new G.E. lamp dropped out when subjected to shock or vibration tests.

Upon request, Mr. Breining tested the northern one mile section of the Delta Electric project. Mr. Breining stated in his report that the G.E. replacement lamps found on the job also reacted to vibration. It was pointed out by the H.L.&P. crew that on the Delta job some 24 to 30 fixtures had been replaced by G.E., yet no one in G.E. can be found that knows anything about the reported replacements. It was during this test that two G.E. fixtures were taken down and sent to Hendersonville. Mr. Breining furnished a copy of a Trouble Shooting Guide that he had previously prepared and the guide is Attachment H. Mr. Edwards made pole by pole daily logs of the Houston test. The daily logs are included in Attachment I.

At this point, it was back to the drawing board as far as the H.P.S. lamp was concerned. G.E.'s Hendersonville and Twinsburg Divisions worked diligently to solve the lamp "blink-out" problem by designing, making and testing numerous reservoir designs. G.E.'s Mr. James Stephenson, who is based in San Antonio, Texas, handled the liason work between S.D.H.P.T. and G.E.'s various offices.

At this time, it was learned that the Twinsburg "vibration" test consisted of dropping the lamp a predetermined distance into a box of sand. The length of the drop determined the G force. S.D.H.P.T. personnel did not consider this a valid test for it was actually a one time shock test. This type of test does not simulate the conditions experienced by a lamp in a fixture on a highway lighting pole.

Another meeting was held in Austin concerning vibration problems. The meeting was attended by S.D.H.P.T.'s Thad Bynum, Dave Edwards, Dexter Jones and G.E.'s Jim Havard and James Stephenson. G.E.'s Hendersonville fixture division was doing testing independently of Twinsburg. Hendersonville's vibration test was based on a 1968 paper entitled "Street Lighting Luminaire Vibration" by Harold A. Van Dusen, Jr. Attachment J is a letter that was hand carried to Texas by Mr. Jim Havard of G.E.'s Hendersonville fixture division. Attached to the letter is a copy of Mr. Van Dusen's paper.

Again, S.D.H.P.T.'s Dave Edwards of File D-9, Materials and Tests Division, Mr. Thad Bynum of File D-8, Highway Design Division, and the author did not agree with the test method. First of all, the lamp was out of the fixture, and it was in an upright position, contrary to normal position in a fixture. The G forces were increased by increasing the frequency of travel and again this in no way simulated actual field conditions. This was discussed at length between the five in attenance. Mr. Havard stated that he would return to Hendersonville, change the test method and report back the results.

The G force loading as given in Mr. Van Dusen's report was probably valid for the thirty foot mounting height poles used in 1968. However, most highway lighting poles are much higher today. In fact, the poles involved in all three Texas projects were fifty foot mounting height poles. Mr. Havard agreed to revising the test.

To date no one knows what G forces are actually encountered by the lamp as installed in the highway lighting systems. Therefore, the S.D.H.P.T.'s Raska, Bynum and Jones are now proposing a research project to determine what G forces are encountered.

Just prior to Mr. Havard's trip to Texas, I received a call from Mr. Tony Lorio of the Louisiana Department of Transportation. Mr. Lorio said that he had heard that Texas was having problems with H.P.S. and wanted to know what we had learned as he was having problems with H.P.S. on high mast poles. He was told that we were having problems with low and high mast H.P.S. The problem does not just exist only on low mounting height poles.

On August 8, 1980, I received a call from Mr. Havard. He stated that the latest lamp (later than the lamps installed in Austin) which had tested okay by their previous testing (prior to trip to Austin) had failed under the new test method. The lamp failed at One G. He stated that G.E. had to face the fact that they were going to have to produce an industrial lamp for the static type of mountings such as buildings and a highway lamp in the base down configuration because of the dynamic loading experienced in highway installations. He stated that tests were continuining.

As a result of our investigation, I personally feel that the entire high pressure sodium system has been pushed to the limit to acquire peak lumen output. This has been done to place it in more favorable position against other lighting systems. By pushing the lamp to its limit, the lamp is unstable. The instability of the lamp creates operational problems with the ballasts and starter boards thus making the total system not dependable.

The existing H.P.S. system may be suitable for installation in an industrial or office environment where maintenance personnel are readily available and the systems are constantly monitored. However, maintenance personnel are not as available on highway installations with the thousands of units on miles of freeways. The highway units cannot be watched as closely as in industrial installations. It is a fact that some of the manufacturers place a label on their units stating that if the lamp goes out it must be replaced within 30 days or it may cause starter board and ballast failure. The 30 day replacement requirement possibly is practical within an installation in an industrial or commercial environment but it is not practical on a freeway installation.

It is felt that if the system was redesigned to a lower output performance, where all the pressures and voltages, etc. were not so critical, the system would become more dependable. Admittedly, some lumen output would be lost but the system would probably gain overall performance. Also, if the cool spot or amalgam reservior were to be placed on the low operating end of the lamp, better operating characteristics would be achieved. I certainly agree with Mr. Havard that if the maximum lumen performance is to be maintained, two lamp types are imperative.

APPENDIX

Attachment A	Mr. Jack Hoffman's Letter and G.E. Literature
Attachment B	Mr. Bill Earle's Letter
Attachment C	Mr. Dick Stark's Letter and HAPCO Sketch
Attachment D	Mr. Bill Breining's Austin Trip Report
Attachment E	Mr. Bill Breining's Houston Trip Report
Attachment F	Mr. Dave Edwards' Trip Report
Attachment G	Mr. Steve Sirek's Trip Report
Attachment H	Mr. Bill Breining's Trouble Shooting Guide
Attachment I	Mr. Dave Edwards' Daily Logs
Attachment J	Mr. Jim Havard's Letter and Mr. Van Dusen's Report

ATTACHMENT A

NORTH AMERICAN PHILIPS LIGHTING CORPORATION
HIGHTSTOWN, NEW JERSEY 08520 (609) 448-4000 TELEX: 843350

March 14, 1980

Mr. Dexter Jones
Texas Department of Highways and Public Transportation
PO Box 187
Houston Urban Project
Houston, TX 77001

Dear Mr. Jones:

It was a genuine pleasure to review our acquaintance by our telephone conversation of yesterday. I'd like to confirm to you the aspects of high pressure sodium lamp performance under vibration conditions.

All high pressure sodium lamps contain an excess of amalgam - the solution of sodium dissolved in mercury. The excess is necessary in order to insure that sufficient amounts of the amalgam are present in the arc stream to have a fully stabilized and efficient operation. Furthermore, as an arc tube ages, it tends to leak small amounts of sodium through the arc tube wall and seals. Sufficient excess amalgam must be present to replace any amalgam leakage plus any amalgam which may be used up during arc tube clean-up ("gettering") which can occur in the first few hours of lamp operation.

The amalgam collects in an area behind the electrodes. Because this area is the coolest part of the arc tube during lamp operation, the excess amalgam will stay there. See figure #1. It is important to note that while the tube wall behind the electrode area is the coolest portion of the arc tube, the electrode itself is one of the hottest parts of the tube.

Suppose that the lamp is subjected to shock or vibration severe enough to dislodge some of the amalgam from the tube wall. The amalgam will land on the electrode or its support, which is hot due to heat conducted from the electrode. The high temperature of these parts will cause the amalgam to vaporize, increasing the pressure in the arc tube. The higher the arc tube pressure, the higher is the voltage necessary to sustain the arc. Should the increased pressure be such that the voltage supplied by the ballast is insufficient to maintain the arc, the lamp would extinguish. The lamp will then cool down, the amalgam condensing behind the electrodes, until the pressure in the arc tube falls to a point to where the voltage pulse from the ignitor will again strike the arc. The lamp will then warm-up until stabilized operation results. Additional severe shock or vibration could again cause this "blink-out" phenomenon.

The above sequence of events is probably what has occured in your installation near Austin and Houston.

Lamps that employ an "amalgam reservoir" are also prone to blink-out. This happens because one end of the tube does not have a reservoir, and even in the end that does have the reservoir not all of the amalgam condenses in it; much remains in the arc tube proper behind the electrode, just as in arc tubes without the reservoir. Particularly when the HPS lamp is operated on or near the horizontal position, the operation of the tube with the amalgam reservoir is not significantly different than arc tubes without the reservoir. Thus, under vibration or shock, all HPS lamps may extinguish due to excess amalgam vaporization.

Dexter, as we have discussed on the phone, G.E. admits to blink-out. On page 3 of their publication #205-9307 (R1) of 8/79 entitled,"GE Lucalox lamp have the Edge", GE claims that "this effect is significantly reduced" with their lamp. As your experience proves, and the above explains, their lamp is as subject to blink-out as lamps that do not employ an amalgam reservoir. A xerox copy of this sheet is attached, as is a copy of the Engineering Bulletin "High Pressure Sodium Lamps", which details the operation of an HPS lamp over its lifetime.

Low pressure sodium lamps are not as liable to blink-out as are HPS lamps. This is because there is no surplus sodium in the area of the electrodes. In Norelco LPS lamps, the sodium is contained in dimples (reservoirs, if you will) spaced along the arc tube so that the sodium stays away from the electrodes. Should the excess sodium be displaced from the dimple, it will land on the opposite wall of the arc tube, which is at nearly the same temperature as the dimple. Thus, little additional sodium vaporization will occur. Because the arc tube volume is large, the pressure increase due to the additional vaporization will be very small, and only a very small and momentary arc volt use may occur. The rise will be short lived because the arc tube in a SOX lamp is temperature stabilized by the indium oxide coating on the outer jacket. The small amount of additional vaporized sodium will quickly condense in one of the dimples to restore the equilibrium, and the arc volts will return to normal.

I hope that the above explanations answer the questions that you had on operation of HPS and LPS under vibrations and shock. Thank you for the opportunity to serve you.

Best Regards,
NORTH AMERICAN PHILIPS
LIGHTING CORPORATION

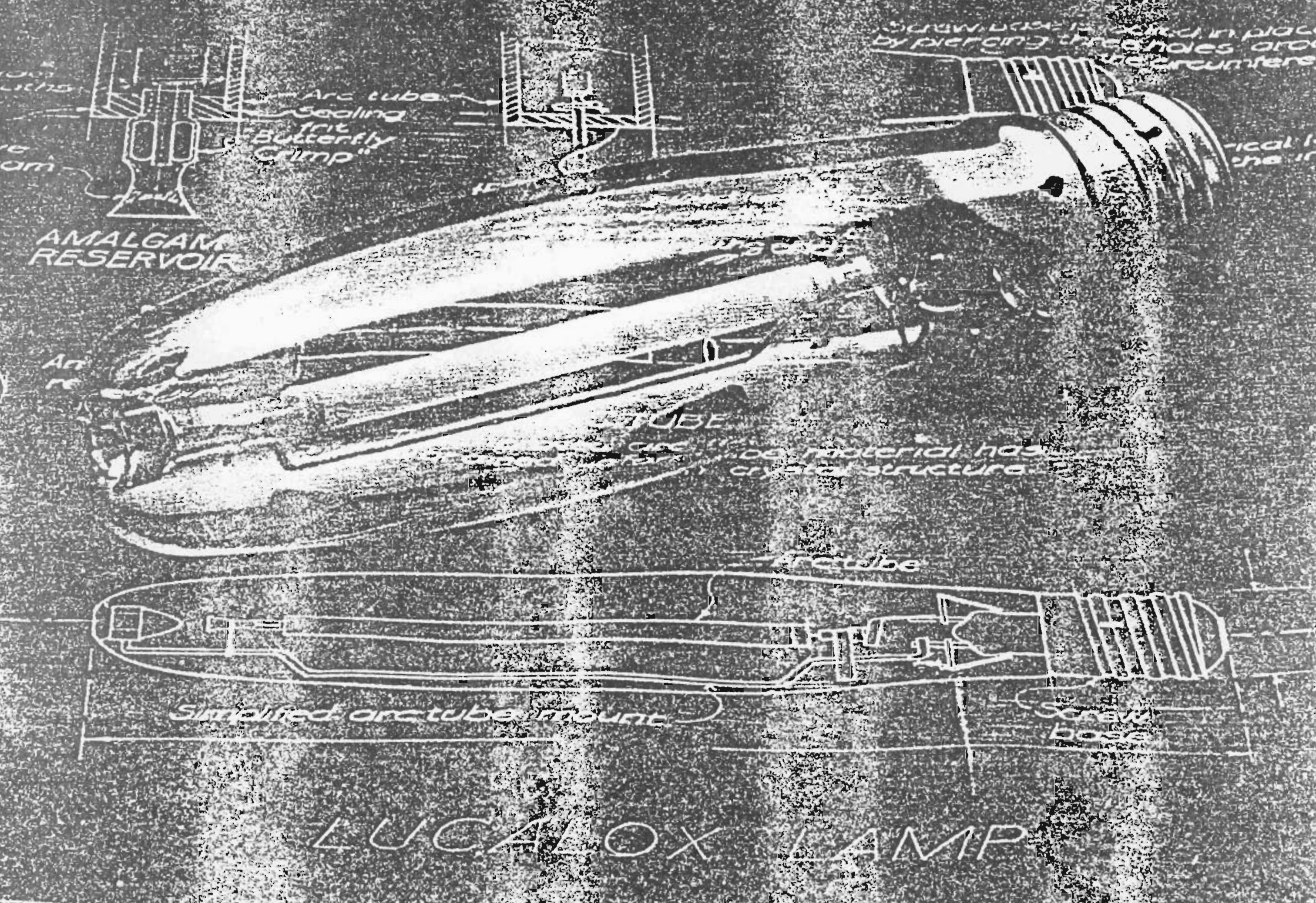
Jack Hofmann
Marketing Engineer

JAH/bk
Attachments
cc: J. York

High-Pressure Sodium

GE LUCALOX® LAMPS

Have the EDGE



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You buy high pressure sodium lamps for one principal reason...

LOWEST COST-OF-LIGHT!

In these pages, you'll see examples of the EDGE* in Lucalox® lamps that has continually lowered the cost-of-light for their users.

*Extraordinary Design from General Electric.

Milestones along General Electric's path of leadership with Lucalox:

1958 — 1962 GE developed transLUCent ALuminum OXide (LUCALOX®) the arc tube material.

1965 — First Lucalox lamp introduced — 400 watts, 105 lumens/watt — a major breakthrough in reducing cost-of-light.

1969 — 250-watt Lucalox announced — for greater flexibility in applications.

1971 — 1000-watt Lucalox announced — reduced cost-of-light for high-bay and area lighting.

1974 — The millionth Lucalox shipped — users saved at least $100 million in electrical energy costs, compared to mercury lamps.

1975 — Line included 70, 100, 150, 250, 400 and 1000 watts — for complete flexibility in applications.

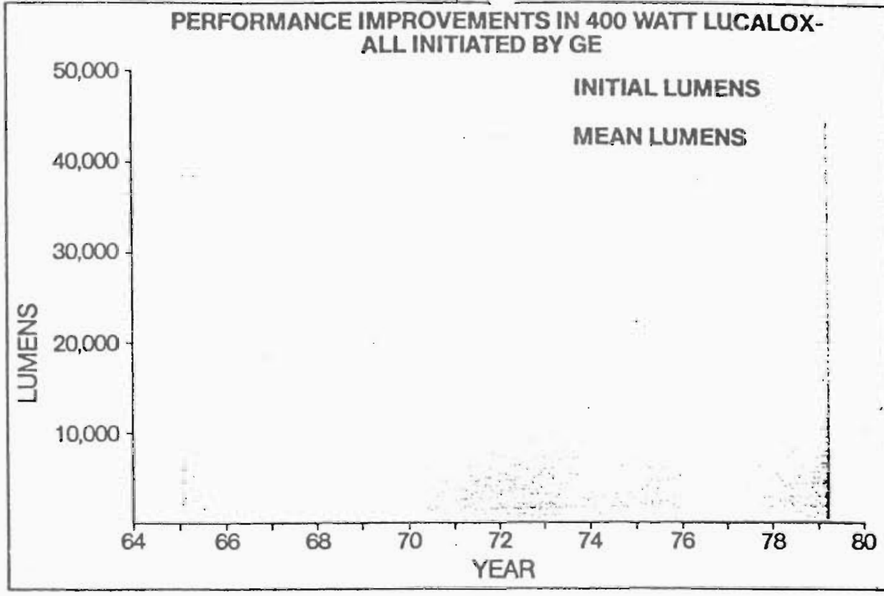
1975 — Diffuse-coated Lucalox introduced — to give "softer" lighting from open fixtures.

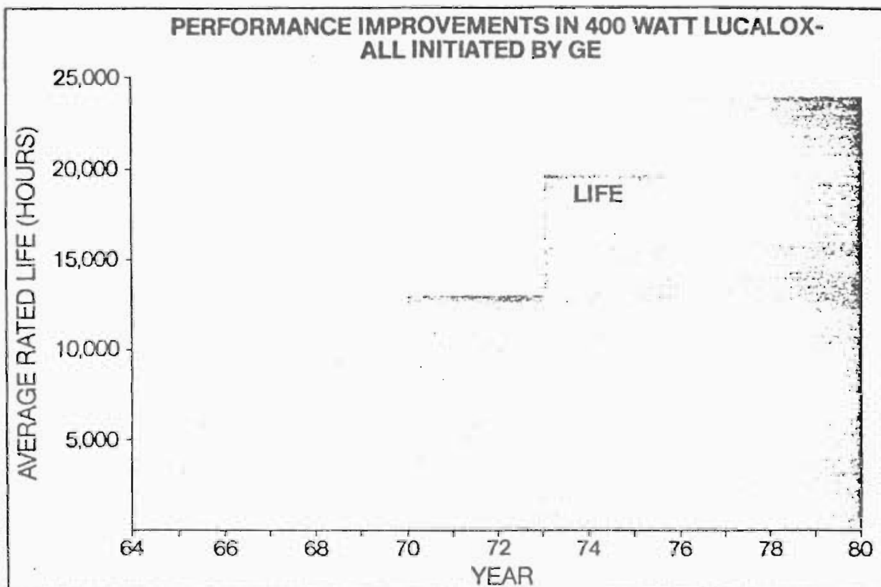
1976 — Lucalox lamp life extended to 24,000 hours — a further reduction in lamp cost per hour.

1977 — First universal-burning-position lamp with performance features of external amalgam reservoir — one lamp type does the job of two — simplified stocking — no chance of improper burning positions.

1978 — 50-watt Lucalox introduced.

1979 — Five millionth Lucalox shipped — representing savings in energy costs to users of over $800 million, compared to mercury lamps.





As you see, virtually all major new products and performance improvements in high-pressure sodium lamps have been initiated by General Electric. And users of GE Lucalox lamps have benefitted from the results. Competitors of GE have played "follow the leader," to each GE improvement.

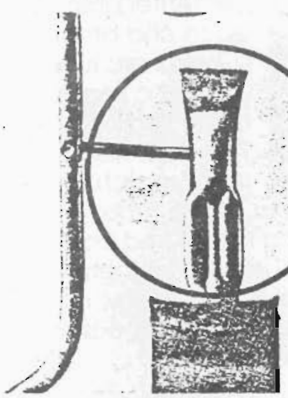
At GE, we've never stopped inventing the Lucalox lamp!

For general lighting, to get the lowest cost-of-light TODAY... and TOMORROW...you need lamps with a balanced combination of Efficiency (lumens per watt), Life, and Reliability. And, today, Lucalox gives you the ultimate combination of these factors. Providing you the **EDGE** in lamp performance based on these extraordinary design features now built into GE Lucalox lamps.

External Amalgam Reservoir

This GE construction feature provides a method of controlling the amount of sodium/mercury amalgam in the arc stream during lamp operation. It provides these benefits in GE lamp performance:

1. **Extended lamp life** — by limiting the rate of arc voltage rise during operation.
2. **Optimized light output of each lamp** — by permitting fine-tuning of amalgam temperature.

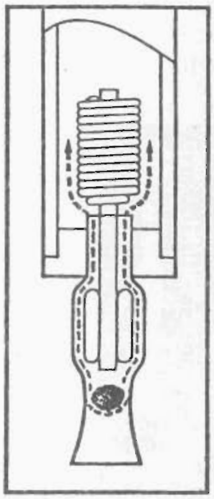


3. **Avoids "blink-out" due to vibration or shock, such as "wind-slap" of pole-mounted lamps** — by preventing excess amalgam from splashing into the arc stream.

Effect of Amalgam Control on Lamp Life

High-pressure sodium (HPS) lamps must contain more sodium/mercury amalgam (the light generating ingredient) than is needed for stable arc operation. The excess amalgam is needed to replace that which is lost or used up during life. Lamp operating voltage, as a result of sodium loss, increases during life. It finally reaches a value at which the available ballast voltage will not sustain the arc and the end of life has been reached. Thus, HPS lamp life depends on how rapidly the voltage rises. If the excess amalgam is within the arc tube, it could vaporize into the arc prematurely, thus raising the arc voltage more rapidly and bringing an earlier end to life.

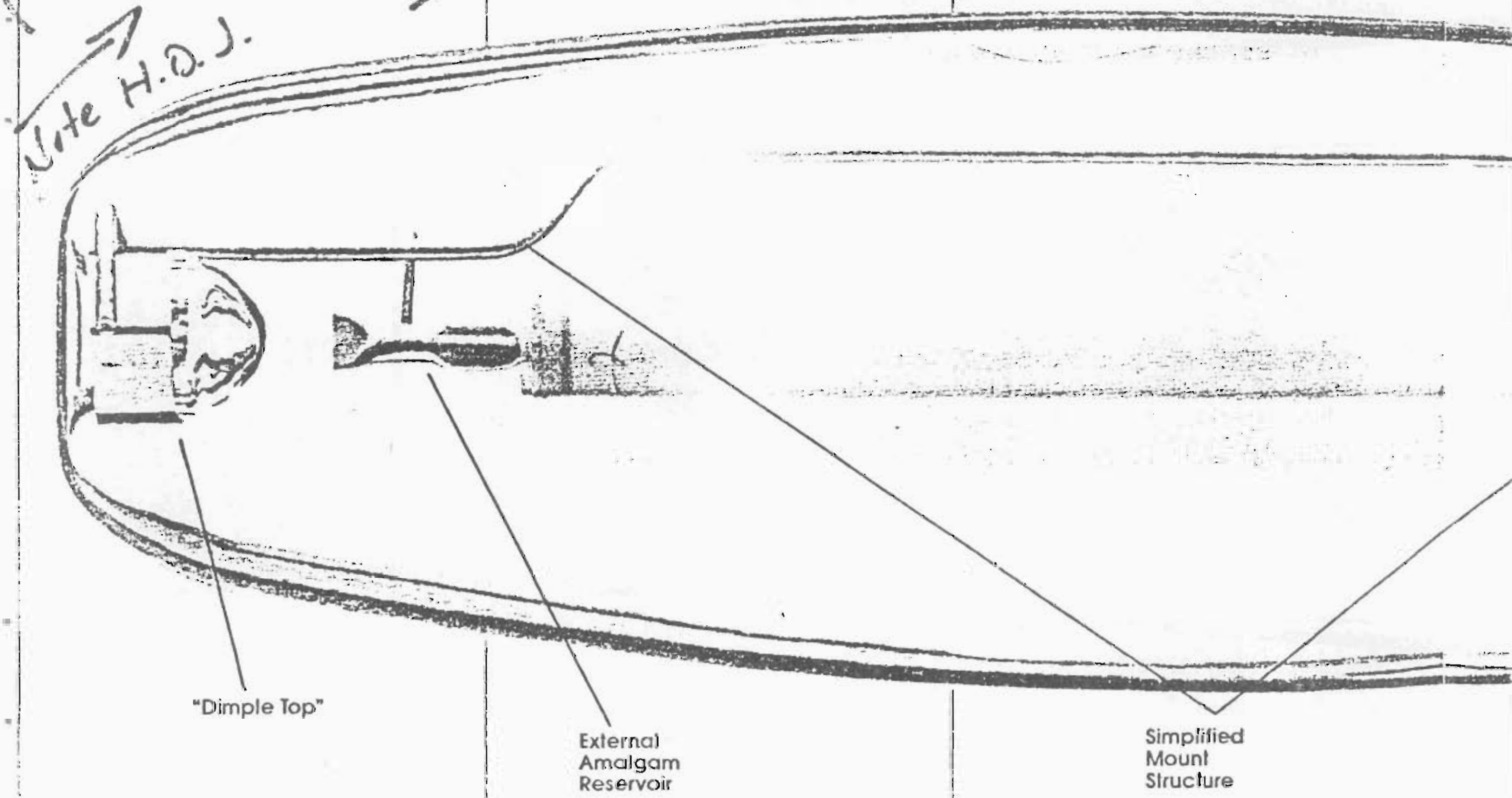
The GE external amalgam reservoir retains the excess sodium/mercury mixture outside the arc chamber, where temperatures are lower and more constant during lamp life. Small vents permit the necessary amount of vapor to enter the arc stream at a controlled rate throughout life, thereby increasing the life expectancy of the lamp.



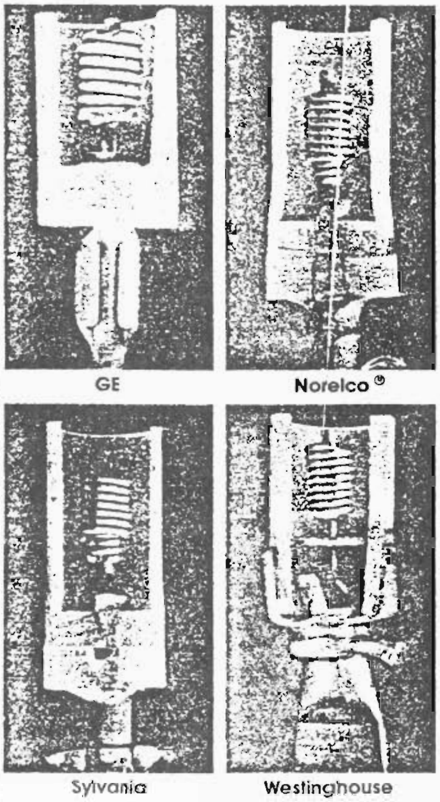
Detail of GE amalgam reservoir construction. Patented* "Butterfly Crimp" supports the electrode structure and permits exhausting and gas dosing of the tube through hollow "wings".

*Patent No. 4,065,091

When the amalgam reserve is freely available within the arc tube, as in lamps without the external reservoir, it can be dislodged by mechanical shock or vibration (example: "wind-slap" of pole-mounted lamps) and shaken into the arc stream. This may temporarily increase the arc voltage, causing the lamp to "blink out" and re-ignite a minute or so thereafter. Such repeated blink-outs can substantially shorten lamp life. But this effect is significantly reduced with GE's external amalgam reservoir.



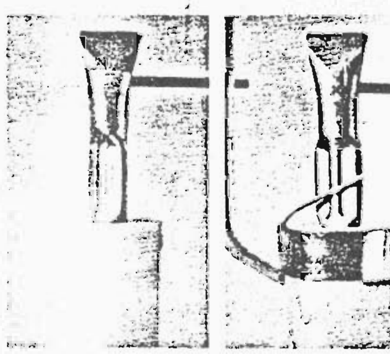
Competitive lamps with ceramic seals recently obtained in the market do not have an external amalgam reservoir. Westinghouse still uses metal-end cap seals.



Cutaway end sections of HPS arc tubes. Only GE has external amalgam reservoir and ceramic seals.

Fine-Tuned Amalgam Temperature

Each GE Lucalox arc tube is operated for up to 1/2 hour during lamp manufacture to find its electrical characteristics. Final adjustments are made before the tube is sealed into the lamp:
(1) The amalgam reservoir may be etched by grit blasting, so as to radiate more heat and operate cooler. This reduces the amount of amalgam vaporized into the arc and lowers the lamp voltage, thus increasing life expectancy.
Or (2) a heat-reflecting metal band may be added to one or both ends of the tube to increase

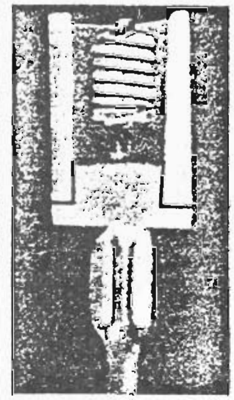


arc temperature and voltage. This minimizes the possibility of low-voltage lamps that would give low light output on commercial ballasts.

®Norelco is a registered trademark of North American Phillips Corp.

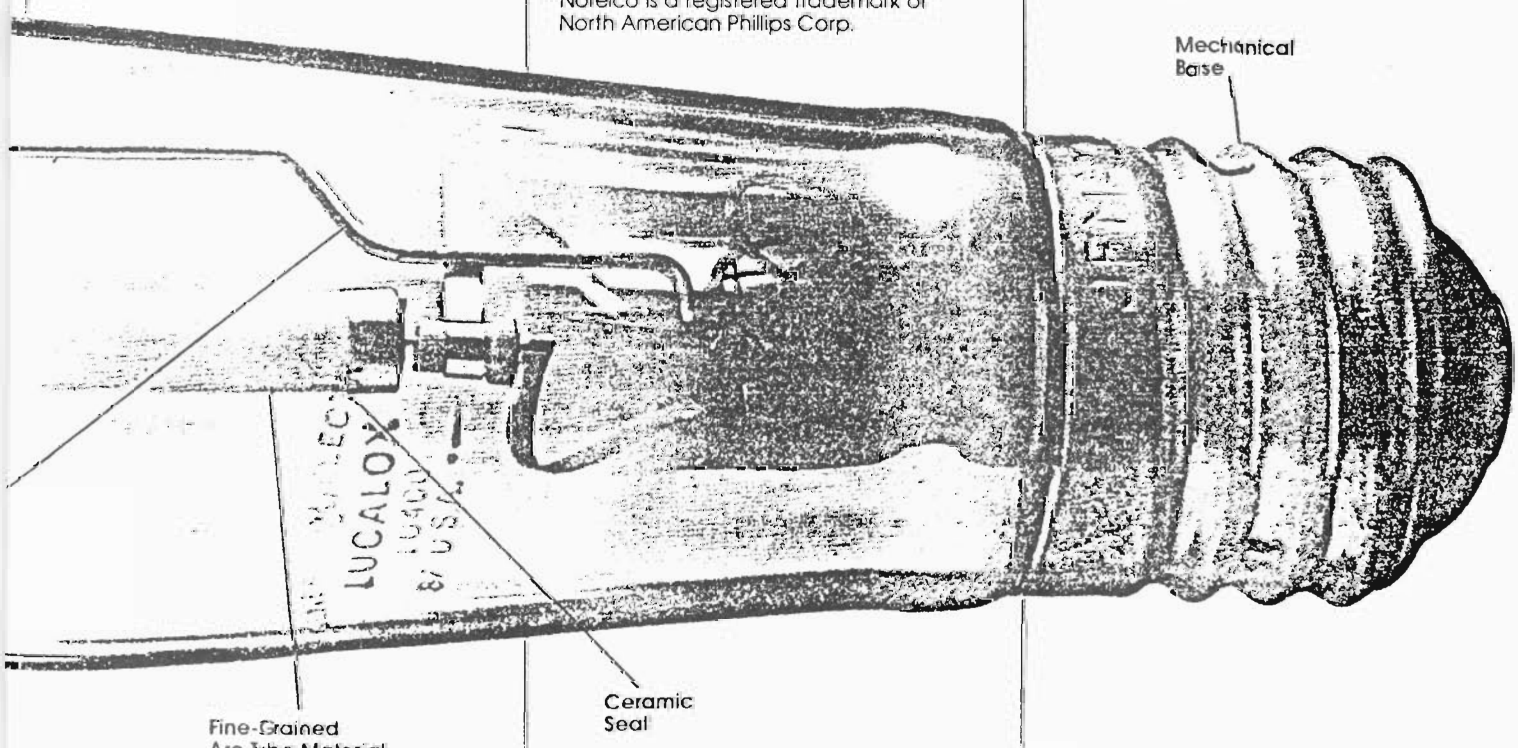
This unique fine-tuning procedure — possible only with the external amalgam reservoir — gives GE HPS lamps consistent light output from lamp to lamp, plus the highest possible initial light output without reducing average rated life.

Ceramic Seals



These replace the metal end caps used on early Lucalox lamps. A ceramic "plug" is cemented into each end of the Lucalox arc tube, utilizing a proprietary "sealing frit." The ceramic plugs match the thermal expansion of the tube much better than metal end caps, minimizing the possibility of thermal cracks. Even more importantly, the entire seal area is 100% inspected by microscope to minimize potential leakers.

Thorough microscopic visual inspection of the integrity of opaque metal end cap seals (such as are used on Westinghouse HPS lamps) is not feasible.




Thin wire through end plug.

A unique, patented* construction feature of the GE ceramic-seal arc tubes is the "thermal loop" support for the electrode opposite the amalgam reservoir end. The added length of the loop reduces the temperature gradient along the wire as it passes through the end plug. This minimizes the possibility of thermal cracks during life.

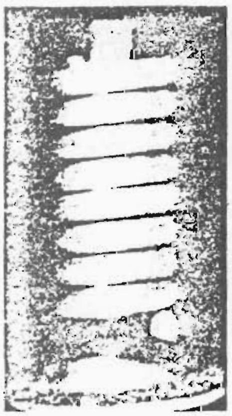
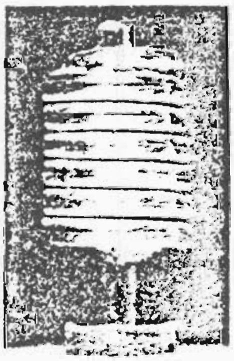
The use of a thin wire to carry current through the ceramic end plug is unique to GE. Such construction requires a minimum area of metal-to-ceramic sealing — thus further reducing the possibility of leaking seals.

Other lamps with ceramic end plugs that we have seen use a metal tube of greater diameter through the end plugs — a much greater sealing area. (See cutaway photos of Norelco and Sylvania lamps earlier.)

These GE design features, plus 100% inspection of seals, are major reasons for the extremely low, early failure rate of GE Lucalox lamps.

*Patent Nos. 4,032,252, and 3,992,642

Improved GE Electrode Emission Mix



Left. GE 400-Watt Lucalox electrode from a lamp operated over 24,000 hours. Note clean, unpitted appearance. Traces of emission mix remain beneath c
Right. New unburned GE electrode of current construction, impregnated with emission mix.

Patented* chemical mixture, dip-coated on the coil-wrapped electrodes, produces more electrons for a longer period of time than earlier emission mixes used in Lucalox lamps, thus delaying voltage rise and extending lamp life.

*Patent No. 3,708,710

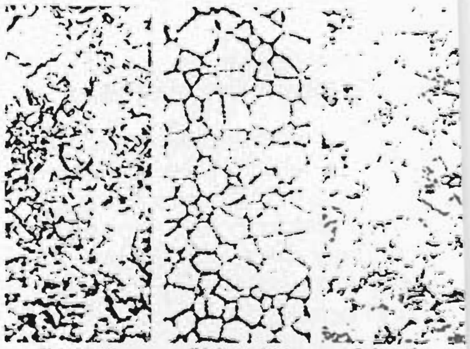
"Back-Wound" Coil On Electrodes

GE Lucalox lamps employ a "back-wound" coil over the electrodes. The coil is first wound toward the arc, then reversed without interruption and back-wound away from the arc. This provides a double-layer wrap (to hold more emission mix) without any sharp coil ends toward the arc, where they could cause "sputtering" and hasten end-darkening of the tube, with consequent reduced light output and possible shorter life.


GE 400-Watt Lucalox lamp electrode showing back-wound construction.

making such tubes more susceptible to fracture and short life.

The improved arc tube material* in GE Lucalox lamps has a fine-grained, uniform crystal structure, which provides (1) greater resistance to thermal stress and



Photomicrographs (100x) of poly-crystalline aluminum oxide arc material from 400-watt HPS lamps obtained in the market, 1979.

(2) reduced possibility of sodium loss due to migration through the arc tube wall. Both of these factors contribute to General Electric's leadership in extending the rated average life of HPS lamps.

*Patent No. 4,033,743

Simplified Arc Tube Mount Structure

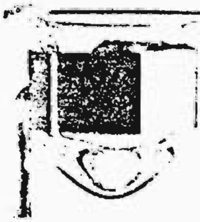
Strength, rigidity and accurate arc tube alignment are achieved in GE Lucalox lamps, along with simplified internal construction employing a minimum number of welds. Lucalox lamps of 50–400 watts have only 11–14 welds, varying by wattage.

Fine-Grained Poly-Crystalline Arc Tube Material

Conventional aluminum oxide ceramic tubing used in some other HPS lamps has irregular crystalline shapes and considerable variation in sizes. These crystals have different rates of thermal expansion lengthwise than crosswise,

Fewer welds means fewer points of possible mechanical failure due to repeated thermal stressing, which could shorten lamp life.

The "dimple-top" of the GE outer bulb automatically centers the mount structure, without use of the "bumpers" used in competing lamps. Mount bumpers can cause rattle, and/or poor appearance because of rub-off of the internal white coating of diffuse-coated lamps.

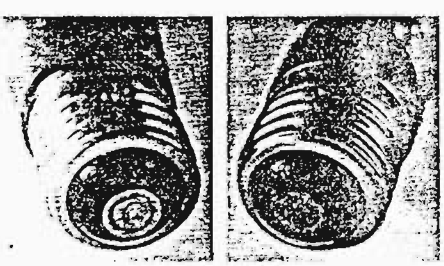


Mechanical Base, All-Welded Connections

Unlike incandescent lamps, most of which have cemented-on bases, GE Lucalox lamps have "mechanical bases" that remain securely attached throughout the long lamp life. This insures that lamp and base will be intact upon removal from the socket.

A metal, inner base shell is closely fitted to dimpled contours molded into the bottom part of the bulb. The outer base shell is then screwed onto the inner one, and is mechanically locked in place by piercing three holes around the circumference.

In GE Lucalox lamps, both electrical leads are welded — one to the inner shell, the other to the center contact at the bottom of the base — permanent, positive connections at both points.



Mechanical bases-Left, GE Lucalox with welded center contact, Right, typical soldered center contact.

In 1000-Watt Lucalox, A Special High-Dielectric-Strength Base Insert

The base of a 1000-watt lamp is subjected to higher starting voltages than lower-wattage HPS lamps. GE developed a special base design for 1000-watt Lucalox lamps, with a white, glazed ceramic insert supporting the center contact instead of the dark-colored glass used in the bases of other wattages. The result — superior resistance to high-voltage breakdown, which can cause arc-over of the high-voltage ignition pulse and premature lamp failure.

Minimal Early Failures with GE Lucalox

GE lamp design, quality control and thorough in-process inspection procedures have established an enviable record of lamp reliability. Our published data on lamp mortality assure you that 98% of the GE lamps you use will still be operating after 4000 hours of service (more than a year, in many installations). Further, 95% of your GE lamps will still be going strong after 8000 hours. Actual operating experience reported by users confirms that these figures are not only accurate, but often quite conservative.

A low, early failure rates saves lamp-changing labor costs in new installations.

GE Lucalox High-Pressure **Sodium Lamps were invented by GE, continuously improved by GE, and followed by others**...each of whom now uses some GE design/construction features.

But only GE has them all and puts them all together in innovative, yet conservative HPS lamp designs to create the Lucalox EDGE.

Extraordinary
Design by
**General
Electric**

CERTIFIED PERFORMANCE

General Electric certifies that GE Lucalox lamps will meet or exceed GE published values for average life, lumens, lumen maintenance, and early mortality. If any individual lamp fails within 4000 hours (when operated 10 hours or more per start), in approved systems, a new lamp will be furnished at no charge.

Statements herein are based on information available to GE as of July 1, 1979.

GENERAL ELECTRIC

205-9307 (R1) 8/79

PRINTED IN U.S.A.

Norelco

NORTH AMERICAN PHILIPS LIGHTING CORPORATION

High Pressure Sodium Lamps (SON)

High pressure sodium (SON) lamps are highly efficient electric discharge lamps that produce a golden amber light. Although the first uses of high pressure sodium lamps were for outdoor applications (roads, parking lots, interchanges, etc.) the lamp is now also being used successfully in many indoor applications, such as warehouses, factories and even in some office environments.

I. Parts on the lamp:

High pressure sodium lamps consist of a base, bulb, and arc tube and an internal structure designed to support the arc tube, called the mount. See figure 1.

The base is a metal shell with screw threads stamped in it to enable the user to screw the lamp into a socket. The base has two electrical contacts: one is at the end of the base (or eyelet), the other is the shell itself. Wires are connected to these two contacts and lead inside the lamp to provide electricity to the arc tube. The base does not form a part of the airtight seal of the lamp; it merely serves to provide a means of mounting the lamp in the socket and getting electricity into the lamp.

The bulb is made of borosilicate glass to withstand the high temperatures inherent in the operation of a high pressure sodium lamp. The purpose of the bulb is to provide an airtight environment around the arc tube. The inside of the bulb is under an extremely high vacuum to minimize the heat loss from the arc tube through conduction. It is important that the arc tube be maintained at the proper temperature for the lamp to operate efficiently.

At the base end of the lamp a thin film of barium is applied to the inside of the bulb wall. The barium appears as a black spot. Barium readily forms a powder when it combines with certain gasses. In this way, the barium maintains the high vacuum inside the tube as various lamp parts outgas over the life of the lamp.

The mount consists of lead wires which are used to bring electricity from outside the lamp inside the lamp to the arc tube. Lead wires are made in three sections. The outer lead is soldered to the lamp base and is welded to the middle section of the lead wire. The middle lead is normally made of tungsten and is used to form an airtight seal with the bulb glass. The inner lead wire connects to the arc tube. The top end of the long inner lead is either formed into a hoop to mate with a dimple in the bulb glass, or has spring clips welded onto it. The purpose of the hoop or clips is to provide support for the mount structure.

The arc tube is the element of the lamp that produces the light. In it are two electrodes made of tungsten, niobium (columbium) tubes to bring electricity into the electrode (and form part of the air tight seal of the arc tube), xenon gas and a drop of mercury-sodium amalgam. The tube itself is made of polycrystaline alumina, a ceramic substance that is translucent, air tight and resists the extreme corrosiveness of sodium. Figure 2 illustrates an arc tube.

II. Operation of a High Pressure Sodium Lamp:

All of the light is generated in the arc tube of the lamp. Refer to figure 2.

For the tube to operate, an arc must be started between the two electrodes. An arc is merely the flow of electrons (electricity) through a gas. The initiation of an arc across the electrodes requires a lot of electrical force which is measured in volts. To help start the arc, a paste, called emitter, which readily emits electrons, is placed on electrodes. As the lamp ages this paste boils off the electrodes and forms a black area on the arc tube wall. This darkening is a major determinant of lamp performance during lamp life. Additionally, xenon gas, which is readily ionized to conduct electricity, is placed in the tube as an ignition aid. An additional feature of xenon gas is that it retards the boiling off of the emitter from electrodes.

Even with the emitter and the xenon gas, an electric force of over 2000 volts is needed to start the arc. This force is supplied by an ignition device external to the lamp.

Once the arc has been started, white light, characteristic of a discharge in xenon gas, is emitted from the tube. The discharge heats the xenon gas which, in turn, heats the mercury-sodium amalgam. When the amalgam reaches the right temperature the mercury begins to boil into a vapor state. At this point in time, both xenon and mercury gases are present in the arc stream, and the light from the tube shifts to a blueish color, characteristic of a discharge through mercury vapor.

As the temperature of the arc tube continues to rise the sodium begins to boil into a vapor state. This discharge is now through xenon, mercury vapor and sodium vapor. The light output from the tube changes to the yellow color characteristic of a low pressure sodium discharge.

As the temperature of the tube finally reaches a stabilized temperature, the sodium vapor pressure inside the tube increases, and then stabilizes, which stops the sodium from boiling. Under these high pressure conditions, the yellow light from the sodium discharge broadens and a golden amber light is emitted from the tube.

III. Lamp Operation over life

Like all discharge lamps, a ballast is required to operate a high pressure sodium lamp. A ballast is an external device that limits the current through a discharge lamp. Without a ballast, the current density inside the arc tube would increase to the point at which the tube would overheat and fail. Another important function of a ballast is to supply enough voltage to sustain the arc. While individual ballast characteristics may vary from manufacturer to manufacturer, the following narrative is representative of the operation of a typical HPS lamp on a typical HPS ballast.

As the high pressure sodium lamp ages, the voltage necessary to sustain the arc (arc voltage) increases. There are two reasons for this. First, emitter boils off the electrodes, leaving less emitter to emit electrons into the arc. Consequently, additional voltage must be applied across the two electrodes to have them supply enough electrons to sustain the arc.

The second reason the arc voltage increases over lamp life is additional vaporization of the amalgam. Some of it remains behind the electrodes in the liquid state. It is necessary to have this excess amalgam present in order to insure that sufficient pressure is built up inside the arc tube. However, as the emitter sputters off of the electrodes, it collects on the arc tube wall making the area around the electrodes dark. This darkening traps heat, raising the temperature of the area. Because the amalgam has collected there, it is also raised in temperature and additional quantities of it are vaporized. This additional vaporization raises the pressure in the tube. As the pressure increases, more voltage is required to sustain the arc; hence arc voltage increases.

The consequence of this arc voltage rise is that a high pressure sodium lamp does not consume the same amount of power as it ages. A ballast must supply a nearly constant electrical current to the arc tube in order to generate a relatively constant light output. Most HPS ballasts can do this over a wide range of arc voltage; but as the arc voltage gets to a fairly high value, the current that the ballast can supply starts to fall off.

Electric power is defined as the product of voltage times current. When the lamp is new, the current remains constant, but arc voltage increases. Thus the power that the lamp consumes increases as the lamp ages. During the middle period of the lamp's life, it's arc voltage continues to increase, but the ballast can no longer supply a constant current. During this period, the increase in arc voltage is nearly offset by the decrease in current that the ballast can supply. Thus, at this point, the power consumed by the lamp is constant; however, it is at a value of 15% over the nominal watts of the lamp. As the lamp approaches the end of life, the arc voltage increases very rapidly, but the ability of the ballast to supply current decreases even more quickly, and the power consumed by the lamp falls off quickly to a value close to the nominal lamp power or slightly below it. See figure 3.

At some point, between the time when the lamp's consumed power starts to taper off and when the lamp has fallen close to its nominal power, the arc voltage has reached such a very high value that the ballast can no longer supply enough voltage to sustain the arc. At such time, the lamp will extinguish, having reached the end of life. A typical lamp will cool down, reignite, then warm up until the pressure inside the arc tube has increased the arc voltage to a point where the ballast can again no longer supply sufficient voltage for lamp operation, and then the lamp will again extinquish, and the cycle starts again. This cycling process occurs at the end of the lamp life (usually many thousands of hours); a typical cycle will last 10 to 30 minutes. To avoid damage to the lamp's ignition device, however, the lamp should be replaced at the beginning of such a cycling process.

IV. Retrofit High Pressure Sodium Lamps (SON-H)

Standard SON lamps are intended for use only on ballasts and ignitors specifically designed for high pressure sodium lamps. However, there are countless instances where a user having a mercury vapor system, needs to reduce his consumed power and/or increase his light level, and does not want to invest in new ballasts and ignitors. For this application a series of "retrofit" high pressure sodium (SON-H) (Penning) lamps have been designed.

SON-H lamps consume less power and emit more light than the mercury lamps they replace. However, this type of SON lamp has a rated life of one half to two thirds of the original mercury lamp. Moreover, SON-H lamps are designed to be used only on lag type ballasts. The reason for this has to do with the lamp current waveshape, and is beyond the scope of this Bulletin.

Mercury vapor ballasts do not have ignitors, so the SON-H lamp must be able to start at the voltage supplied by the mercury ballast. To accomplish this end, the discharge tube of a standard type of lamp is modified.

The first modification is the change of the fill gas from xenon to neon. Neon gas ionizes more easily than xenon, so that an arc can be struck at a lower voltage. However, neon does not retard the boiling of the emissive paste as well as xenon, one reason for the shorter lamp life of retrofit high pressure sodium lamps.

The second modification is the ignition coil that surrounds the arc tube near one electrode. See figure 4. This coil is connected to the opposite electrode by a bi-metallic switch. When the lamp is cold, the coil is connected to the far electrode, creating a strong electric field inside the arc tube in the area of the near electrode. This electric field pulls electrons off the electrode to start the discharge. When the lamp warms up slightly, the switch opens and disconnects the coil from the far electrode, stopping the electric field caused ty the coil. However, by this time, the arc has been initiated and voltage from the ballast will sustain it.

The operation of a SON-H type lamp is identical to a standard high pressure sodium lamp once the arc has been started.

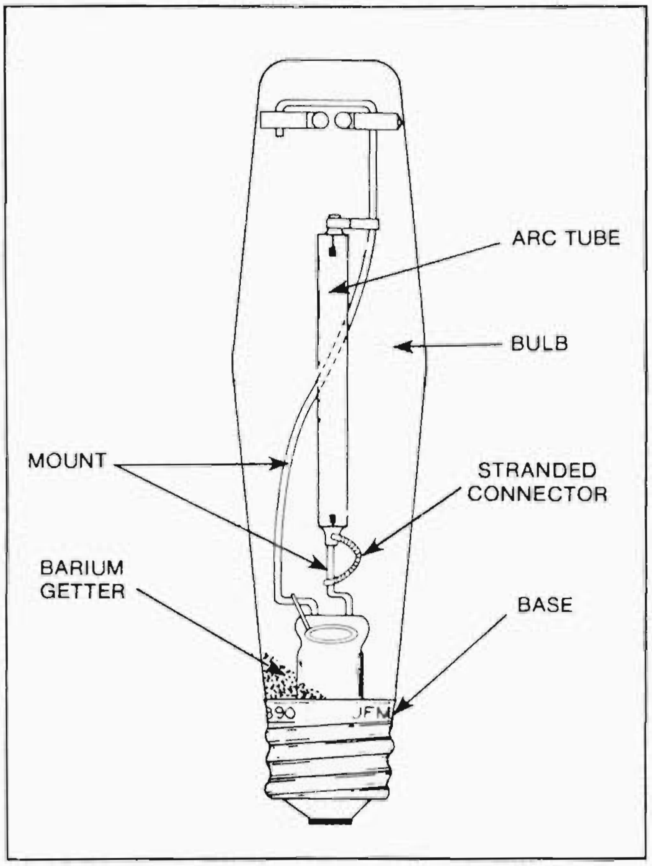


FIGURE 1. PARTS OF A HIGH PRESSURE SODIUM LAMP (SON)

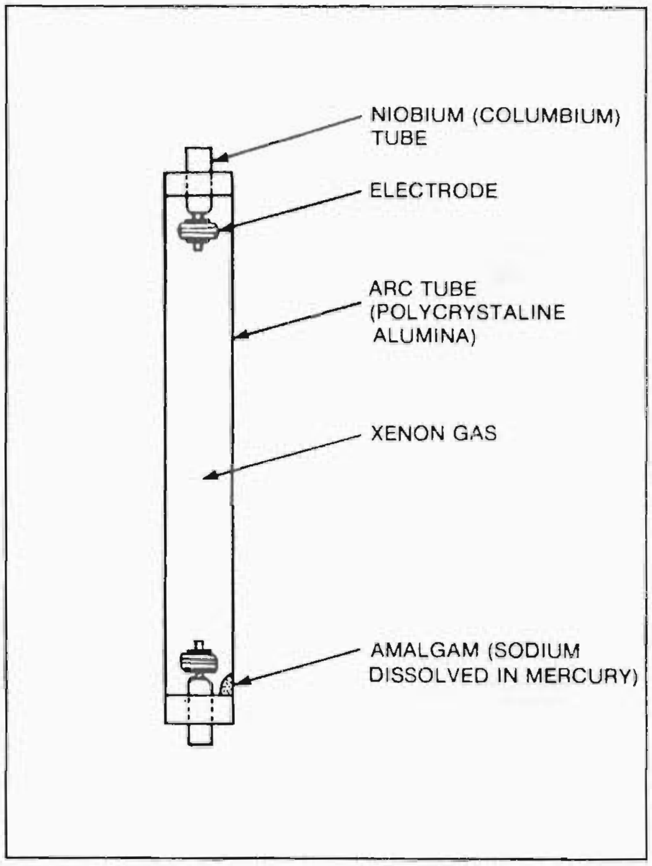


FIGURE 2. PARTS OF A SON ARC TUBE

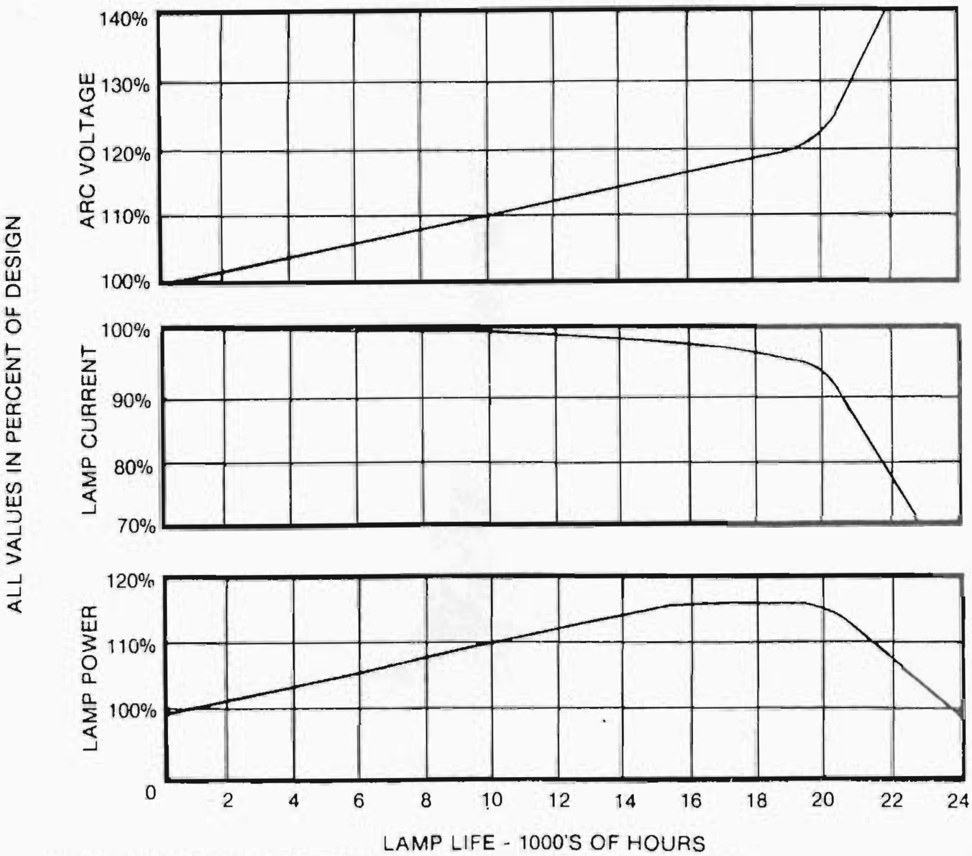


FIGURE 3. TYPICAL ELECTRICAL PERFORMANCE OF A HIGH PRESSURE SODIUM LAMP OVER LIFE.

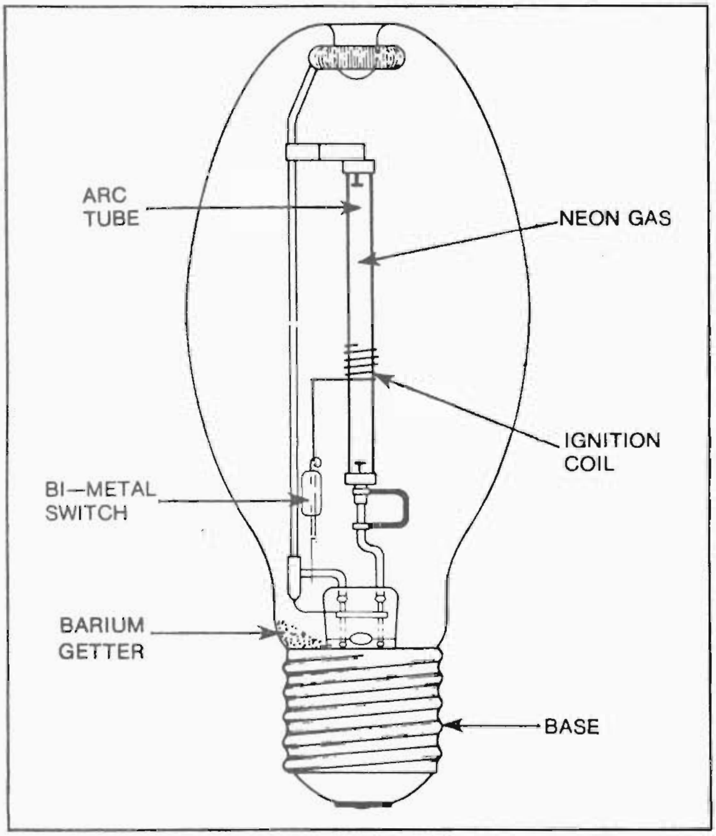


FIGURE 4. A SON—H LAMP

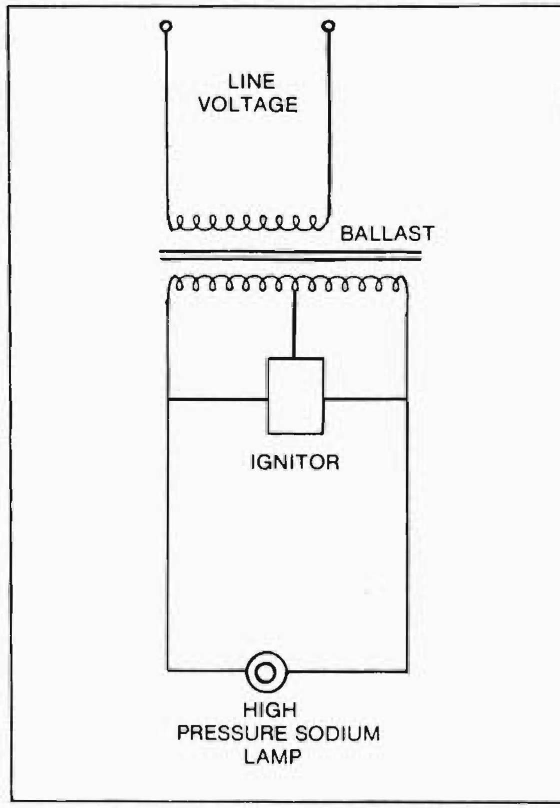


FIGURE 5. THE CIRCUITRY NECESSARY TO OPERATE A HIGH PRESSURE SODIUM LAMP. THE IGNITOR STARTS THE LAMP WHILE THE BALLAST CONTROLS THE LAMP CURRENT AND SUPPLIES ENOUGH VOLTAGE TO MAINTAIN LAMP OPERATION.

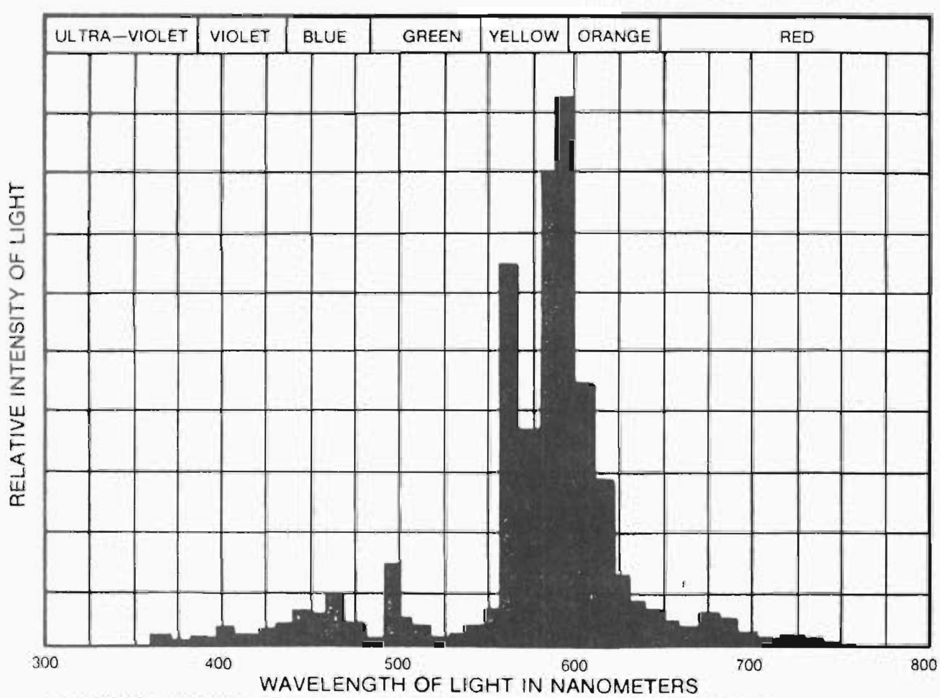


FIGURE 6. THE SPECTRAL OUTPUT OF A 400W SON HIGH PRESSURE SODIUM LAMP.

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NORTH AMERICAN PHILIPS LIGHTING CORPORATION
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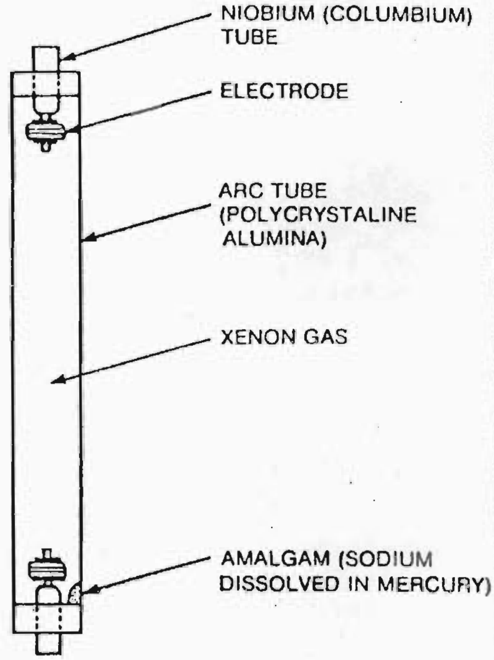

NIOBIUM (COLUMBIUM) TUBE
ELECTRODE
ARC TUBE (POLYCRYSTALINE ALUMINA)
XENON GAS
AMALGAM (SODIUM DISSOLVED IN MERCURY)

figure 1

ATTACHMENT B

City of
HOUSTON

JIM McCONN, MAYOR

HOUSTON, TEXAS 77001

J. WILLIAM EARLE
Director
Department of Public Service

April 1, 1980

Mr. Dexter Jones
State Department of Highways
and Public Transportation
P. O. Box 187
Houston, Texas 77001

Re: High Pressure Sodium Lights
on the 610 Loop

Dear Dexter:

As per our conversation, I have personally inspected the freeway lights on the 610 Loop between Highway I-45 South proceeding north to Highway I-45 North ("subject Area"). The inspection was in conjunction with an inspection of the entire 610 Loop.

The lighting from the Subject Area is engineered to be high pressure sodium lights. The installed system is totally unacceptable at this time. Only a few circuits in the Subject Area are actually burning. Pole after pole and mile after mile of high pressure sodium "lighting" is dark.

At this time, I have instructed HL&P to turn off all of the circuits north of Highway 225 to I-45 North which are high pressure sodium lights. This is to save energy costs when the lights are not actually burning.

At this time, it is my opinion that the City should not authorize any further use of high pressure sodium street or freeway lights until such time as the reliability is established. If the matter is not solved promptly, I will recommend that the City seek to relight the area with a more dependable lighting system at someone other than the City's expense.

Should you have any questions regarding this matter, please contact me at your earliest convenience.

Yours very truly,

J. William Earle, Director
Public Service Department

JWE/lm
cc: Mayor Jim McConn

ATTACHMENT C

Illinois Department of Transportation

Richard E. Stark
District Electrical Engineer

4-9-80

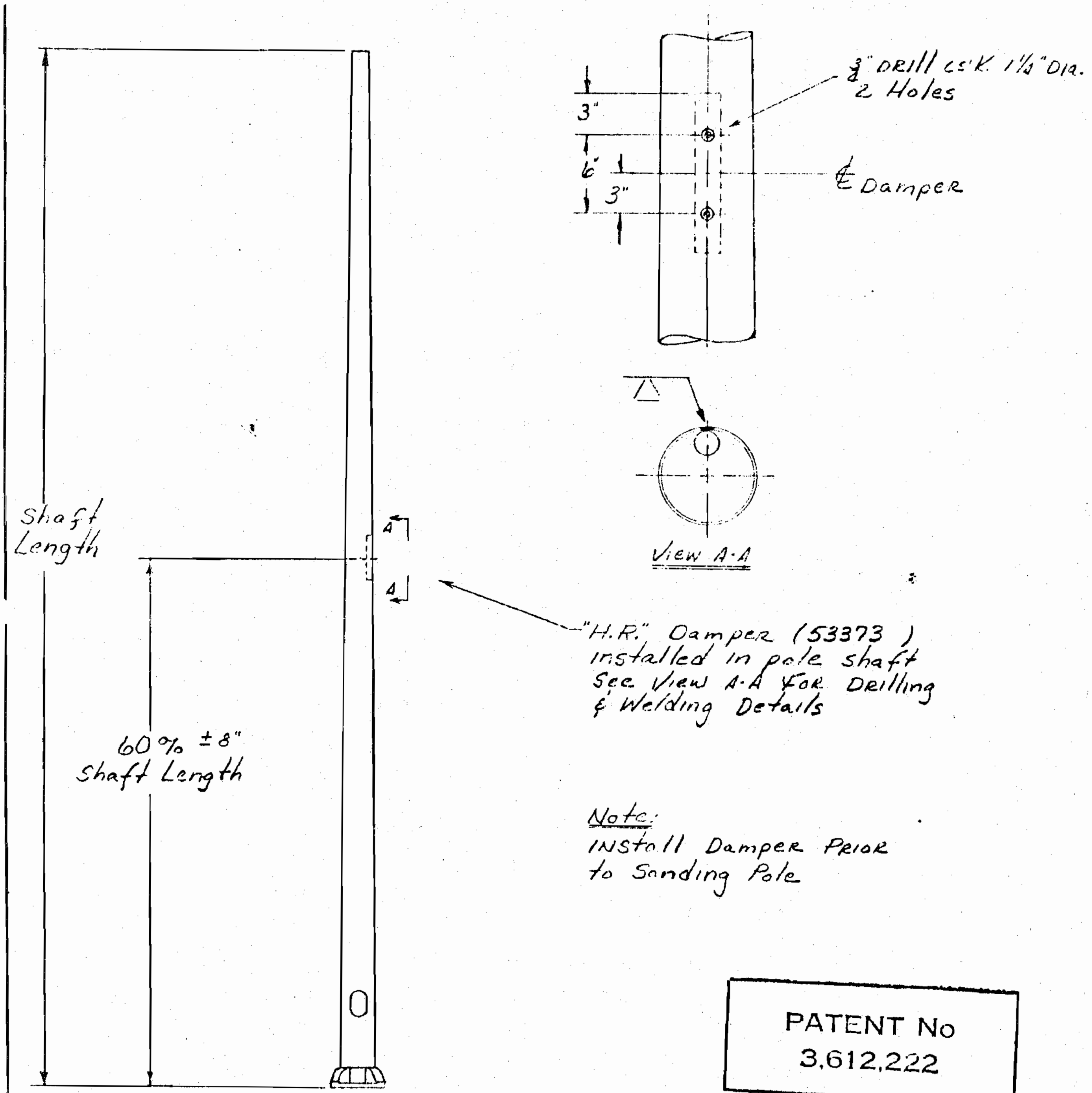
Dexter Jones

This is (enclosed) the damper we spoke about. So far we have had not premature failure of H.P.S. on the poles where it was used.

I hope you get a quick solution. Let me know how you make out.

Sincerely

R. E. Stark



PATENT No
3,612,222

STANDARD DRAWING SYSTEMS
BOOKS: ....

NO.	REVISIONS	DATE

hapco
COMPANY
DIVISION OF KEARNEY-NATIONAL, INC.
P. O. BOX 547 ABINGDON, VA. 24210

TITLE Method for Installing "H. R."	
~~CUSTOMER~~ Damper in Pole Shaft	
SCALE N.T.S.	DATE 9-4-69
BY YB	DWG. NO. A53374
CHK'D	

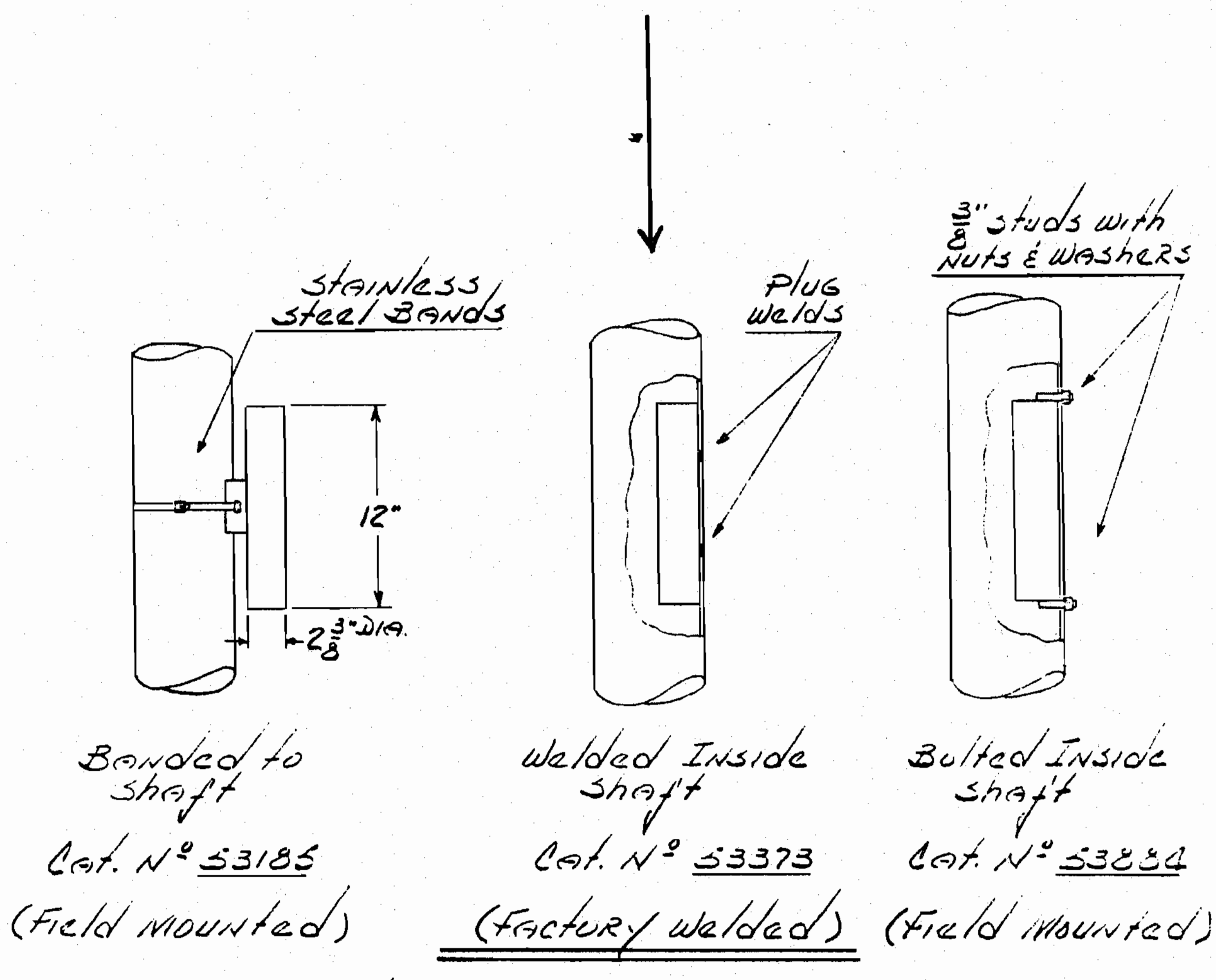
DAMPERS FOR WIND INDUCED VIBRATION

Lighting poles as well as other structures exposed to wind may be subject to periodic forces associated with Karman vortices. Karman vortices may cause vibrations in a plane perpendicular to the wind velocity, due to shedding of wind around the surface. The frequency of periodic forces caused by vortex shedding varies with the wind velocity and size of the object around which the wind must flow. At certain wind velocities, the frequency of these periodic forces may coincide with a natural frequency of a given pole-luminaire combination. Damaging vibration may result if the wind velocity holds steady at this resonant condition unless there is sufficient natural dampening in the luminaire, pole and foundation combination.

It has been found that steady 10-20 mph winds sometimes induce second or higher mode of vibration in lighting poles. Second mode vibration is characterized by the maximum periodic motion occurring at approximately the mid height of the pole. This type of vibration can result in failure of the pole and/or luminaire. No method has yet been found for predicting destructive lighting pole vibration. HAPCO engineers have learned from experience, however, that poles supporting certain types post top mounted floodlight fixtures are more susceptible to second mode vibration. The rectangular or "shoebox" shaped luminaires, for example, seem to encourage vibration.

HAPCO has developed and patented (patent No. 3612222) a vibration damper which very effectively quells second mode vibration of lighting poles. This damper is attached to the pole at approximately the midpoint and can be factory welded inside the pole, or installed on the inside or outside of an existing pole as shown on the following page.

Based on past experience, some HAPCO poles included factory installed vibration dampers as a standard component. If you think you have or could have a wind induced vibration problem, contact HAPCO for more information on vibration dampers.



Vibration Damper Installation

3-10-79

ATTACHMENT D

MEMO

#21

TO: JOE LANGER

CC: ART THOELE
JAY BROWN
STAN HAUN
J. D. MCINGVALE
MAURY AYRER
BILLY SHELBY
JAYNA SPARKS
ROGER OLSEN
RON JAMES
NORMA BURNHAM
ALEX POPE
ROBERT REEVES
FRANK REAL
DON ATKINS
JIM JOHNSON, JAMES M. JOHNSON CO.

FROM: BILL BREINING *Bill*

DATE: APRIL 7, 1980

SUBJECT: BALLAST AND LAMP CHANGEOUT ON THE 400 WATT HPS HORIZONTAL LUMINAIRES ON TEXAS HIGHWAY JOB ON 183 IN AUSTIN, TEXAS

Thursday, April 3, the changeout was begun on the subject job. These fixtures were mounted two on the pole in the center median of the roadway. At the completion of the changeout on the 14th fixture, we looked back at the completed fixtures and noticed that one was cycling. The fixtures had been energized approximately one hour earlier. At this point, 12 of the 14 fixtures were energized. The first two were on a different circuit and were not energized.

We then went back to the cycling fixture and inspected the fixture for the cause of the cycling problem. A voltage check across the lamp was 100 volts. When the lamp was tapped the voltage increased at the rate of 5 volts each time the lamp was struck. The voltage continued to rise during the tapping to a point where the lamp reached 150 volts. At this point, the lamp arc extinguished.

After cool down, the lamp restruck. I then bumped the side of the luminaire to see what effect this had on the lamp voltage. The lamp was not up to full brilliance at this time and the voltage change was not as fast as before. However, the adjacent fixture on this pole extinguished at this time. The lamp was then replaced in the first fixture. After approximately ten minutes, the lamp voltage appeared to stabilize at 100 volts. When this lamp was tapped the voltage increased to 125 volts but would increase no further and cycling did not occur on this new lamp. I then moved over to the adjacent fixture and checked it. The lamp voltage was at 100 volts. Tapping of this lamp caused the voltage to increase to 180 volts where the lamp arc extinguished.

A Westinghouse lamp was installed at this time. After fifteen minutes, the lamp voltage stabilized at 100 volts. The voltage would not increase on this lamp when it was subjected to the tapping that was done on the G. E. lamps. A new G. E. lamp was then installed in this fixture. Again, the lamp voltage stabilized at 100 volts after ten minutes of operation, but would rise to 125 volts when tapped. This was as high as it would go at this point and no cycling would occur.

Due to this lamp problem, Jay Brown was notified and the changeout was terminated as it was apparent this changeout was not solving the problem as intended.

After notifying Jay Brown, we returned to the job site and struck the lower part of the five remaining poles with the repaired luminaires that were energized. Three more fixtures on three different poles went off. A 3 foot piece of 2 x 4 lumber was used in this test.

The Texas Highway Dept. Engineering Inspector, Mr. Forest Crow, was driving to the job site at this time and saw the fixtures extinguished. After explaining to him what had occurred he agreed that the changeout should be terminated as the cycling condition would not improve with this fix. Mr. Crow took the two cycling lamps that were removed from the fixtures. The lamp removed from the second cycling fixture checked had a broken weld at the arc tube support at the base end of the lamp. There was no apparent damage noticed on the other lamp.

Mr. Mike Alder, the contractor for this job, was notified on the problem and the decision to terminate the changeout. He was in agreement with this decision.

Friday morning, our agent, Jim Johnson, was called and made aware of the events to date.

Wednesday, April 2 at Jay Brown and Jim Johnson's request, I met with Mr. Dexter Jones with the Texas Dept. of Highways and discussed HPS problems. This discussion lasted four hours. His concern was that HPS was not as successful as it was presented to be. He indicated that every HPS job in the State was experiencing a high percentage of problems. He said that this condition coupled with untruths told to him by some of the manufacturers of HPS equipment had him very upset. He further said that the Federal Government had requested him to give them a report on the Highway Department's experience with HPS as related to reliability and performance. He said that his report was now in a rough draft form, but would not be finalized until after my visit to Houston on April 14. At this time, we would analyze and put the HPS problems in perspective,particularly, the Fosco Cummins Job.

By copy of this report, I am asking Jay Brown to notify the people involved in the Austin, TX Highway #183 job as to the action he is taking as soon as possible as I have only notified the people mentioned in this report.

WAB/ss

ATTACHMENT E
II 21

FIELD TRIP REPORT

TO: JOE LANGER

CC: ART THOELE
JAY BROWN
STAN HAUN
J. D. MCINGVALE
MAURY AYRER
BILLY SHELBY
JAYNA SPARKS
ROGER OLSEN
RON JAMES
NORMA BURNHAM
ALEX POPE
ROBERT REEVES
FRANK REAL
DON ATKINS
JIM JOHNSTON

FROM: BILL BREINING *Bill*

DATE: APRIL 18, 1980

SUBJECT: INVESTIGATE AND REPAIR TEXAS HIGHWAY DEPT. JOB I-610 IN HOUSTON, TX

Tuesday, April 15, agent-Jim Johnson and I met with Mr. Dexter Jones and Mr. Dave Edwards with the Texas Highway Dept. and Mr. Steve Sirek, the Sylvania Lamp Representative and began our inspection and repair of the subject job with the help of the Houston Power & Light Company expressway lighting maintenance crew.

The major problem found with this job was due to power supply problems. These problems included blown fuses, poor electrical connections at the base of the poles, overloaded and defective circuit breakers at several of the circuit power supply points. Breaks in the circuits due to missing conductors, pole knock downs where the conductors were not spliced through to complete circuits. Other discrepancies were found that did not necessarily result in luminaire failure, but did not comply with the job specifications. As per Mr. Dexter Jones, the power supplied to the luminaires was to be phase to phase 480 volts. Two circuits were found that were phase to ground circuits. The remaining circuits checked were found to be phase to phase circuits but had pole base fuses in one phase only. These poles were wired with black and white wires. This color code designates a phase to ground circuit. This condition constitutes a safety hazard. These wiring discrepancies were pointed out to Mr. Dexter Jones.

The other fixture outages found were due to various causes. Eight starting circuits and two ballasts were found in failure. It is felt that a quantity of these failures were due to the previously discussed power supply problems. Several lamps were also found in failure. One was a 250 watt lamp installed in a 400 watt fixture. Some of these lamp failures could have also contributed to the ballast or starting circuit failures as this job was not serviced on a timely basis when outages occurred.

During this investigation, Mr. Jones requested that we install other brands of lamps in the fixtures other than the brand originally installed and test them for vibration and lamp voltage stability. The 400 watt Sylvania HPS lamp supplied as original equipment in this installation. These lamps appear to be performing very satisfactorily in this installation. After a year in service, the majority of these lamps inspected tested at approximately 90 to 100 volt range. The new Sylvania and Westinghouse lamps installed tested at between 80 to 100 volts. The stabilized voltage did not vary when the lamps were tapped to check for lamp voltage stability. The G. E. Universal burning lamp was the other brand of lamp tested in this installation. These lamps when installed stabilized at between 125 and 135 volts and increased to more than 150 volts and extinguished when tapped. These lamps continued to cycle until replaced with another brand of lamps. One of the new 400 watt HPS G. E. lamps with the flattened amalgum reservoir that was sent to us by G. E. to test the ballasts that were used in the Austin, Texas Highway 183 job was also installed and tested for stability on this job. The lamp stabilized at approximately 95 volts. This is the same voltage that was measured on this lamp after it had been aged in on a standard reactor in our lab prior to testing the Austin ballast. When this lamp was tapped, it increased in voltage to 150 volts and extinguished, similar to all other Universal burning G. E. lamps. Again, this condition did not occur on the Sylvania and Westinghouse lamps installed on this job.

The adjoining job to the subject job was an installation of approximately 100 of the 400 watt HPS G. E. Luminaires. Due to the high failure rate experienced on this job, Mr. Jones requested that I inspect several of these luminaires in an effort to determine the failure cause. Our inspection revealed that a large quantity had been replaced with a model other than specified. One of the Houston Power & Light maintenance crew said that they had changed out eight to ten of these luminaires on three different occasions. When asked where these fixtures were, the crewmen said that the fixture manufacturer had return them to their plant for failure evaluation. Mr. Jones said he was not aware of this action, but would find out what the failure was.

Houston Power & Light has the maintenance contract on these luminaires and installed the different model when the original fixtures failed. The Highway Dept. specifies a non-power door model and Houston Power & Light uses the power door model.

The inspection did not reveal any apparent deficiencies in the G. E. luminaires. The Sylvania lamp was also the original equipment lamp furnished with these luminaires. The Sylvania Lamp Representative verified that these lamps dated back to the original installation date three years ago. These lamps checked at between 90 and 100 volts after three years of service.

A defective starting circuit and a defective ballast was found. The starting circuit failure was probably due to a partially installed lamp. The lamp base center contact and the lamp socket center contact was etched. This appeared to be due to a poor contact between the lamp and socket contact. The lamp was difficult to remove and also to install. The lamp socket threads did not appear to be fully formed. The ballast failure was apparently due to handling damage prior to installation. This was on a replacement power door fixture. The ballast has been dropped on the terminal side of the ballast damaging the bobbins and terminals mounted to them.

Once the power supply system problems are corrected, only a small quantity of the fixtures will have to be repaired.

It was first felt that a majority of the wiring was defective because of rodent damage. Only one circuit was found with this type damage.

Mr. Jones and Mr. Edwards thanked us for this equipment evaluation.

WAB/ss

ATTACHMENT F

Form 433-B

INTEROFFICE MEMORANDUM

TO: Mr. Joe Raska

Date April 29, 1980

FROM: Dave Edwards

Responsible

SUBJECT: Assist Houston Urban with Lighting Problems
5-02-80-502

Desk D-9-B

Troubleshooting of the Houston I-610 illumination system began on Tuesday morning, 4-15-80. Steve Sivek represented Sylvania lamps, Jim Johnson and Bill Breining for ITT, and Dexter Jones and Dave Edwards for SDHPT. Bill Breining worked with Houston Lighting and Power personnel in checking the fixtures on the poles. HL&P provided spare fixtures.

Work on the I-610-7(172)787 portion of the loop was started at Gelhorn and proceeded toward I-45. There was a multitude of problems but no major problems that would cause confusion or could not be corrected. Thirteen lighting units with ITT fixtures required repair. Six starting boards, one capacitor and two ballasts were found bad. The contractor probably was responsible for two of these failures. A 250-watt lamp in one 400-watt fixture could have caused premature failure of a starting aid. Ballast and capacitor failure in one unit could have been caused by only one side of a phase-to-phase circuit being fused. One lamp was actually cycling but it turned out to be a G.E. lamp. The Sylvania lamps that failed mainly had problems with the glass envelope. Some others showed distortion of the support rod for the arc tube, but this apparently hadn't caused any problems.

There were several areas where a whole string of luminaires would be out. HL&P had to replace a defective transformer that was too small for the load on the first section. One pole was removed after a truck had hit it and the units from there to the end of the line were out. HL&P was asked to replace the pole at that time but it was never done. A couple of lines would not operate because the wrong size breaker was used when HL&P rewired the service poles. One line had a short in it but we didn't take the time to trace the problem. On the last section, we found where there had been a rat problem, but the lines had never been repaired. The contractor had however pulled one strand of wire for a hot line about two units down from the last working pole. The wire was rated at 600 volts, but it was not the correct gauge or color.

About half of the poles were missing the access covers. Wires were just left hanging out of some of them and some of those had wires pulled out of the connectors like they had never been crimped. On several poles the power had been disconnected, and on one the power had never been hooked up. All that was needed on these was just to plug in a single-prong connector. On one other unit, a 10-inch length of copper was gone from the wire.

Form 433-B

INTEROFFICE MEMORANDUM

TO: Date

FROM: Responsible

SUBJECT: Page 2 Desk

We never got to look at any high mast units because HL&P couldn't seem to locate their drive assembly to lower the ring.

The majority of the problems encountered on this section should not have been. A certain amount of component failure is to be expected. Although the starting board failure rate is higher than it should have been, it only accounted for a small amount of the actual outages. The quality of work exhibited by the contractor is very poor and not what should be expected of a professional, and should not have been accepted. Measures should be taken to avoid similar occurrences in the future. The work done by HL&P hadn't been much better. The crew we worked with told us that they had not done anything on this section, but the evidence shows that someone for HL&P had. They had reworked the service poles for metering and probably in doing so mixed the breaker sizes. Two mercury fixtures like the power company has were installed in the HPS areas. Many things were left undone; two fixtures knocked off the pole were never replaced; the pole that was never replaced and several refractors and reflectors were missing on others.

The I-610-7(227)782 section between I-10 and Galena Park had G.E. fixtures and Sylvania lamps. The HL&P crew told us that they had replaced units three different times with 8 to 10 units each time. Most of this section was operational with the exception of the last service pole. HL&P told us that there was a bad line in that circuit. We did replace one fixture because of a bad starting aid. The lamp couldn't screw all the way into the socket and caused arcing between the base of the lamp and the contract. This caused heating and damage to the lamp base and failure of the starting board.

DLE:cc

cc: Dexter Jones, Houston Urban ✓
Thad Bynum, D-18T
Research Section

GTE SYLVANIA INCORPORATED

Lighting Products Group
Lamp Division
P.O. Box 30234
13555 Inwood Road
Dallas, Texas 75230
214 239-8171

REPORT ON 610 LOOP TROUBLESHOOTING
APRIL 15-17, 1980 HOUSTON, TX

Complaint;

The general complaint was that the high pressure sodium system installed as highway lighting on the 610 loop around Houston, Texas (particularly the section from Highway 45 around to Highway 10 - approximately a nine mile section) was not satisfactory. Many of the lights were out, some lamps were cycling and generally, the stretch of highway was not well lit.

Action taken;

A task force comprised of Bill Breining, Field Service Manager- ITT Lighting Fixture Division, Dave Edwards, State Department of Highways and Transportation - Test and Measurement Division, and myself were to troubleshoot the section of Highway. Houston Light and Power provided a highway maintenance crew and the equipment. The total project was organized and supervised by Dexter Jones, State Department of Highways and Transportation - Houston Urban Project. Three days were allocated to the task. Dave Edwards used the prints to identify each finding with the pole involved.

Findings;

The following is a list of the problems encountered as we progressed along the strip of highway.

April 15, 1980

A delay in energizing the first circuits starting at the I-10 end of the stretch was due to faulty or wrong sized breakers on the line.

The first stop was to close a lens on a fixture that had apparently popped open due to vibration or not being properly closed. The lamp voltage of each lamp on this pole was measured as a reference at 118 volts. One lamp dropped to 105 volts (lamp operating voltage) after the fixture was open for a while. Both lamps (Sylvania) were stable with respect to vibration induced by tapping on the bulb wall of the lamp.

Replacing a small missing portion of wire energized five poles that were out initially. All lamps came on and operated normally.

Two missing heads were replaced. One was lamped with a Westinghouse lamp and the other with a G.E. Lamp.

The first lamp that was out due to a problem at the fixture was due to a bad starter board (ITT) which was replaced. The lamp was removed to give a representative sample of lamps for factory analysis. A new G.E. Universal burn design lamp was placed in the fixture. The lamp was not stable with respect to vibration. Tapping the side of the lamp resulted in progressively higher lamp operating voltages and the lamp cycled out. The lamp was replaced with a new Sylvania lamp which had a lamp operating voltage of 75 Volts and was stable with respect to the same vibration test. The lamp was then changed out to G.E. Universal design 400 watt lamp. The second fixture on this pole was then also lamped with a G.E. Universal design lamp. The initial lamp operating voltage of each lamp was 125 volts. As an additional test of vibration the base of this pole was hit four times with a two by four and both lamps cycled out. The lamps were both replaced with Westinghouse lamps per directions from Dexter Jones.

The next pole was changed out to two Westinghouse lamps. The lamp operating voltages were 108 and 125 volts. The ballast with the 125 volt reading was thought to be high since the Sylvania lamp removed had also read about 125 volts. The Westinghouse lamps were stable with respect to the vibration test. One of the Sylvania lamps had a voltage rise from 125 to 135 volts under vibration but would not cycle out. Note that the Sylvania lamps in this test had been in the fixture for about one year while the Westinghouse lamps were new.

General Electric had furnished an improved design that they claimed would not vibrate out for a similar problem in Austin. A test of this "improved " lamp showed that the lamp could still be vibrated to the point of cycling out. The only difference between this lamp the the standard Universal burn G.E. lamp is that the external reservoir in the new lamp has been crimped.

April 16, 1980

A fixture was replaced because the optical assembly and lamp were missing from the old fixture.

Just beyond a section with six poles not operating a lamp was noticed cycling after we had passed the point. The Houston Light and Power crew was working to restore power to the six poles not operating at the time. The Sylvania lamp in this fixture was found to have a lamp operating voltage of 135 volts, but it was not vibration sensitive. The work of the Houston Light and Power crew may have caused some voltage fluctuation in the line causing the lamp to cycle. The lamp had a distorted side rod and was removed for analysis.

A starter board (ITT) was replaced to restore the next fixture.

A capacitor was bad in the next fixture tested.

The next fixture tested produced the first definately defective Sylvania lamp. This was an outer jacket leaker, date code 75, retained by Dexter Jones for demonstration purposes.

The next outage was a mercury fixture.

A 250 watt lamp in a 400 watt fixture was the cause of the next failure.

The next unlit fixture was due to a bad starter board (ITT) The lamp was replaced because of a distorted side rod although it is assumed to be a good lamp.

The next pole had no power. When the power was restored one lamp came on normally. The other side was found to have a bad ballast.

April 17, 1980

The first pole had a bad ballast. (I had another appointment and had to leave for a while) No additional lamp problems were found during my absense.

The General Electric Fixture section south of I 10 was examined. Most of the lights in the first circuit were on. The problems encountered here are listed below.

The first pole examined had a bad G.E. ballast, probably a starter board. The other side of the pole had a G.E. lamp of the base down design with an operating voltage of 145 Volts, but it was not vibration sensitive. The two fixtures were replaced.

One Sylvania lamp was replaced due to a broken weld, date code 58, and a burned contact due to the lamp not being completely in the socket.

Conclusions;

Most of the problems were no power to the poles for a variety of reasons. The system apparently was either poorly installed or only marginally maintained or both. Neither ITT not Sylvania showed any excessive problems. ITT had three bad starter boards, two bad ballasts, and one bad capacitor by my count. Sylvania had one outer jacket leaker, one broken weld, and one lamp that cycled perhaps due to line voltage variations and not the lamp. General Electric lamps tested during these three days have a definite problem with the lamp operating voltage of the Universal burn design lamp climing due to vibration.

GTE Products Corporation
(Sylvania)

Steven W. Sirek
Illumination Specialist

A SIMPLIFIED TROUBLESHOOTING CHECK GUIDE FOR HIGH PRESSURE SODIUM LIGHTING SYSTEMS

By Bill Breining
Field Service Manager
ITT Lighting Fixture Division

Due to the increased demands on energy conservation, more and more people are turning to High Pressure Sodium lighting (HPS) as an energy efficient light source.

Not only are we seeing more usage in outdoor applications such as roadway and area lighting, but increased interest is seen in indoor lighting as well. The use of HPS lighting for manufacturing, warehousing, and ambient lighting in offices can provide tremendous energy savings and aid in meeting Federal Energy Guidelines.

Though this is not a new light source, it is new to the installer or maintainer who has not previously been introduced to it. For this reason, we will briefly describe some of the unique characteristics of HPS.

Starting Aid

Your first inspection of the components in an HPS luminaire will reveal an additional component not noticed before in high intensity discharge lighting fixtures, such as mercury vapor or metal halide luminaires. This is the starting aid. It serves as an ignition device to start the HPS lamp. This is done by bridging the gap between the operating electrodes located in each end of the lamp arc tube with an impulse voltage that must be from 2,500 to 5,000 volts.

This device is used only during lamp start (first few seconds) and not during operation. The starting board may be found as a printed electronic circuit board in some luminaires. However, it may be packaged in a small can or encapsulated in a small paper cyclinder in other luminaires. Regardless of how they are packaged, they all perform the same function. However, they should never be mixed as there are slight differences among the various manufacturers and mixing could result in unreliable starts. There are also differences in the various wattage match-ups provided by the fixture manufacturers. Therefore, it is not recommended to mix various wattage ballasts with various starting circuits as this could also result in unreliable lamp starting.

Failure Mode

The failure mode not normally seen in other high intensity discharge lighting, but common to HPS end of life failure, is lamp cycling. Cycling occurs when the lamp goes off for no apparent reason, only to come back on after being off for approximately one minute. The on-time will vary due to operating conditions such as supply voltage stability, ballast design and lamp stability. This cycling continues until the lamp is replaced or another fixture component fails. Other conditions that can cause cycling would be: loose electrical connection, faulty internal electrical connection to the lamp, high ambient light level causing fixture photocontrol to cycle (outdoor), or severe fixture vibration causing lamp voltage to rise above operating limits (outdoor). It should be pointed out that these conditions are common to any high intensity discharge luminaire.

Fixture and Lamp Evaluation

Unlike other light sources, the HPS lamp can be evaluated as to the approximate remaining lamp life. This is due to the continuing voltage rise through its operating life cycle. The new lamp voltage, as well as the end of life maximum voltage, appears in Table I. Once you have found a good lamp with a voltage between the new and end of life voltages, it can be used to evaluate other fixture components such as the ballast and capacitor for proper operating voltage.

Troubleshooting

Normally the only aids necessary in troubleshooting HPS are a voltmeter, mercury vapor* and HPS lamps in the wattage of the fixture being checked. To check a no-burn fixture, replace the lamp. If the lamp still doesn't come on, install a mercury vapor of a similar wattage. If the mercury vapor lamp burns, it indicates the starting aid is inoperable. This could be due to a defective starting aid or a lead disconnected at the ballast or starting aid. If the mercury vapor lamp fails to operate, it is an indication that there are problems other than the lamp or starting circuit. Troubleshoot this fixture in the same manner as you would a mercury vapor fixture. Inspect fixture for burned or physical damage, such as burned ballast or a swollen capacitor. Also check for disconnected fixture component leads. Check for proper fixture supply voltage. Check photocontrol (outdoor) for proper type and operating when using fixture wiring diagram for proper wiring.

*When testing the 150 watt 55 volt lamp, 100 watt, 70 watt and 50 watt lamps, use a 100 watt 120 volt incandescent lamp with a medium to mogul base adapter. This is necessary due to the low socket voltages on these lamps. A mercury vapor lamp will not start reliably at these low lamp voltages.

When troubleshooting a fixture that will not start an HPS, mercury vapor lamp, or an incandescent, as in the case of the low wattage sizes, leave the lamp in the fixture until you are able to determine the problem. This way, if there should be a defective starting aid along with another defective component, you will be able to see when you have corrected the problems as you correct them. (The lamp will burn.) Do not leave the mercury or incandescent lamp in the fixture for an extended period of time as the HPS system was not designed to operate with these other lamps and failure or limited ballast life could occur.

Troubleshooting Check Guide

Problem	Solution
1. Fixture will not come on.	A. Check for burned or damaged fixture components and for loose or disconnected electrical connections.
	B. Check for inoperable lamp. Replace lamp.
	C. Check supply voltage. Is it the same as fixture is rated for?
	D. Check for correct and functional photoelectrical control (outdoor).

Troubleshooting Check Guide

Problem	Solution
2. Fixture cycles.	A. Replace lamp.
	B. High wattage - wrong ballast, defective ballast or capacitor: replace ballast or capacitor.
	C. Incorrect capacitor or capacitor wired incorrectly: replace capacitor.
	D. Intermittent wiring connections: secure wiring.
	E. Internal lamp failure, intermittent internal electrical connection: replace lamp.
	F. Wrong size lamp used in fixture: Install correct lamp. (NOTE: 150 watt available in 100 volt and 55 volt lamp systems.)
	G. High vibration: stabilize lamp movement. Check lamp voltage during vibration to make sure lamp voltage does not exceed end of lamp voltage during vibration.
	H. Change photoelectric control to sensitive.
	J. Photocell turning luminaire off because of luminaire output: shield photoelectric control,ambient light level too high.

Troubleshooting Check Guide

Problem	Solution
3. Fixture burns night and day outdoor fixtures.	A. Replace photocontrol. Common photocontrol failure mode.
4. Fixture output too low.	A. Supply voltage too low: check supply voltage and ballast voltage label.
	B. Multi-tap ballast connected to wrong voltage tap: correct wiring.
	C. Incorrect regulating capacitor: replace with correct capacitor.
	D. Regulating capacitors wired incorrectly check wiring diagram.
	E. Capacitor lead disconnected: reconnect lead.
	F. 55 volt HPS lamp used in 100 volt fixture: check lamp and fixture labels. Change lamp.
5. Lamp burns out shortly after being energized.	A. Fixture mis-wired: check fixture wiring diagram for correct wiring.
	B. Capacitor too high: contact manufacturer for correct size capacitor.
	C. Incorrect ballast: check ballast and fixture labeling for correct combination.

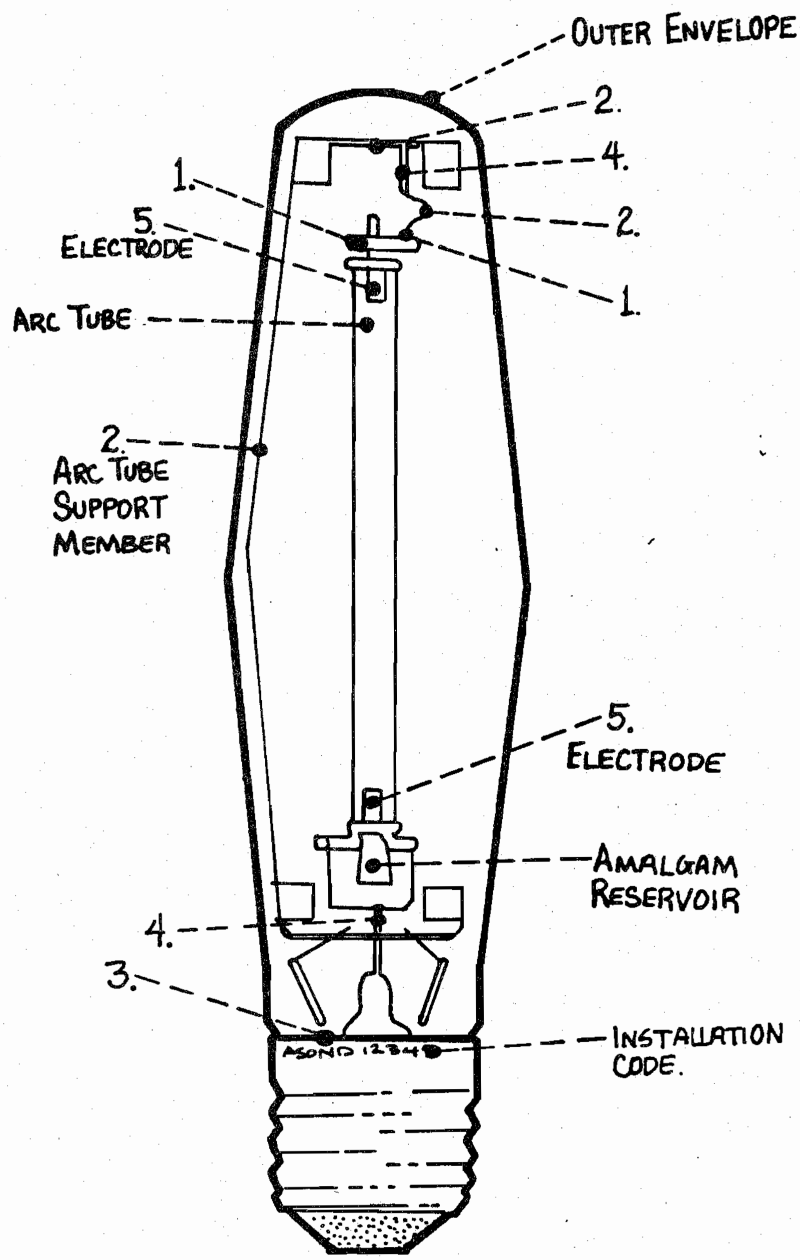
TABLE I

Lamp Data

Lamp Watts	Rated Lamp Life*	Rated Voltage	Minimum Open Circuit Voltage	New Lamp Check Lamp Voltage Range (At 100 Hrs.	Nominal Lamp Amps	End of Life Max. Lamp Voltage	Average Volts Increase Per 1,000 Hrs. Life
50	24,000 Hrs.	52	110	44-62	1.2	84	1.5
70	24,000 Hrs.	52	110	44-62	1.6	84	1.5
100	24,000 Hrs.	55	110	45-62	2.1	84	1.5
150 (55 volts)	24,000 Hrs.	55	110	48-62	3.2	88	1.5
150 (100 volts)	24,000 Hrs.	100	195	84-115	1.8	160	1.5
200	24,000 Hrs.	100	195	90-115	2.3	160	1.5
250	24,000 Hrs.	100	195	85-115	3.0	160	1.5
310	24,000 Hrs.	100	195	90-115	3.6	160	1.5
400	24,000 Hrs.	100	195	90-115	4.7	140	1.5
1000	24,000 Hrs.	250	418-456	210-275	4.7	350	1.5

* Rated lamp life is based on 50% survival.

"CAUTION" - Disconnect starting aid lead not common to the lamp to eliminate the starting voltage when checking the minimum open circuit voltage. The high starting voltage may damage your volt meter.



MECHANICAL INSPECTION CHECK LIST

1. Broken welds
2. Bent arc tube support member, allowing arc tube miss-alignment more than 3^{o}
3. Loose screw base
4. Broken arc tube mounting
5. Broken electrodes (not connected to end cap)

technical papers

SUBJECT Electrical Data

PAPER NUMBER 1

DATE April '79

THIS PAPER IS PRESENTED IN THE FOLLOWING OUTLINE

I. **Electrical** *(page 1 of 8)*

A. Basic Definitions

1. Voltage
2. Current
3. Electron
4. Conductor
5. Wattage
6. Frequency
7. Power Factor
8. Open Circuit
9. Short Circuit
10. Resistance
11. Watts Loss

B. HID Lamps

1. Physical Characteristics
2. Operating Characteristics
3. Chart of Lamp Characteristics

C. Ballasts

1. Need for Ballasting
2. Ballast Types
3. General Operating Principles
4. Table of Ballast Characteristics

ITT OUTDOOR LIGHTING

I. Electrical *(page 2 of 8)*

A. Basic Terminology Definitions

In developing a working understanding of the electrical principles involved in lighting, the following definitions are offered. In some case, errors are allowed so the definition might be straight forward and convey the general meaning of the term. Comparisons to familiar mechanical terms are also used.

1. Voltage - Imagine water pressure. Voltage is present at a supply point in the same way that water pressure is present at a faucet that is turned off.
2. Current - Imagine water flow. Current is the movement of electrons (water droplets) through a conductor.
3. Electron - Imagine a water droplet. An electron is a microscopic particle with a charge that is present in all material.
4. Conductor - Imagine a water pipe. A conductor is a material which permits the flow of electrons/current as a pipe conducts the flow of water.
5. Wattage - Imagine the amount of water flowing times (X) the water pressure; current (electron movement) times (X) the voltage. Wattage results in heat, light, utility bills!
6. Frequency - In almost all lighting applications, voltage and current vary rapidly over a short period of time. Each time a pattern of variation is completed a cycle occurs. The number of times a cycle occurs each second is the frequency (Hertz) of the voltage and current. Voltage and current in the U.S.A. and most of the world, completes 60 cycles per second. (See Diagram A showing one voltage or current cycle.)
7. Power Factor - Power factor is the time difference between the presence of voltage and the flow of current. Think of air in a water line. You "turn on" the faucet and there is pressure (voltage), but a burst of air is all that comes out before the water (current) flows.

   Power factor is high (90% or better) when there is almost no delay in the flow.

   Power factor is normal (approximately 50%) when current does not start until point "N" on Diagram A. (Page 8)
8. Open Circuit - Imagine a turned off switch or faucet with no current flow or water flow.
9. Short Circuit - Imagine a turned on switch or wide open faucet with maximum current flow or maximum water flow.
10. Resistance - Imagine a nozzle on a water hose. Resistance limits or controls the flow of current.
11. Watts Loss - Watts loss is the difference between the amount of power supplied a device (ballast and lamp) and the amount of power actually used by the lamp itself.

B. HID Lamps

1. Physical Characteristics

Before discussing the actual operation characteristics of high intensity discharge (HID) lamps, it is helpful to examine and identify their physical components. (See Diagrams B, C and D.) Diagram B represents the typical configuration of a mercury vapor or metal halide lamp. Diagram C represents a high pressure sodium lamp. Diagram D represents a low pressure sodium lamp. (Illustrations are on page 8.)

The basic elements of all lamp configurations are similar. Each lamp has a protective outer glass envelope. This jacket:

a) Provides mechanical stability to the internal components.
b) Seals the arc tube from the environment.
   i) With mercury and metal halide there is a fill of hydrogen gas between the arc tube and the outer envelope which absorbs ultraviolet radiation the source produces.
   ii) High pressure sodium lamps and low pressure sodium have a vacuum between their arc tubes and outer envelopes to isolate the arc tubes from changes in ambient temperature.
c) Provides a surface for the application of color correcting or diffusing phosphors (deluxe mercury or diffused high pressure sodium).

Each light source contains an arc tube. The size, configuration, and material used in the arc tube varies dramatically from one source to another. However, the basic function, that of containing the materials that will generate light, remains the same. In each light source's arc tube there is a fill of a rare gas along with the basic light producing element of the lamp. Mercury contains a small deposit of mercury; metal halide contains mercury along with several other elements. High pressure sodium contains a combination of mercury and sodium, while low pressure sodium contains the element sodium alone.

Inside each arc tube there are at least two electrodes, one located at each end of the arc tube. These electrodes release electrons (see definition) which flow through the material deposited in the arc tube, resulting in light output.

The arc tube supports serve to provide the arc tube with mechanical rigidity as well as providing a means for controlling the operating temperature of the lamp.

2. Operating Characteristics

(Please review definitions as you read through this section.)

As we discussed under physical characteristics, each lamp contains at least two electrodes, one at each end of the arc tube; a fill or rare gas (usually argon or xenon); and a deposit of mercury, sodium or a combination of materials for producing light. While inoperative, the lamp is an open circuit (there is no current flow between the electrodes).

Electrical *(page 4 of 8)*

When sufficient voltage is applied to the electrodes of the lamp, electrons are produced which move from one end of the arc tube to the other. As they move, they collide with the molecules of the rare gas in the arc tube and produce heat and some light. During this time, the lamp becomes a short circuit. As the heat generated by the current flow in the rare gas builds, the material deposited in the arc tube begins to vaporize. Over a period of minutes, the amount of material contained in the arc increases (color and intensity of light changes) until the material reaches an equilibrium point. Now the light output and lamp characteristics stabilize. The lamp has developed a resistance which limits its current flow.

3. Lamp Characteristics

	MERCURY	METAL HALIDE	HIGH PRESSURE SODIUM	LOW PRESSURE SODIUM
Wattage Range	50-1000	175-1500	50-1000	35-180
Lumens/Watt	45-63	80-104	83-140	137-180
Life (hours)	24,000	1,500-15,000	20,000-24,000	18,000
*Color	blue/green (clear lamp)	red/blue (approaches sunlight)	golden	yellow
	blue/red (phosphor coated)			
Overall Length	5 1/8"-15 3/8"	8 5/16" - 15 3/8"	7 5/8" - 15 1/16"	12 3/16" - 44 1/8"

* Specific color indexes (color temperature) are available. The above is intended to provide a "feeling" of the relative color (spectrum) of light from the various sources.

C. Ballast

1. Need for Ballast

The ballast performs several functions which are important to the operation of an HID lamp (High Intensity Discharge Lamp):

a) Current Limiting - The most basic function performed by a ballast is to limit the flow of current through the lamp. As mentioned previously, when the lamp strikes and begins operation, it is a short circuit. A ballast (inductor) connected with the lamp acts to limit the current flowing to the lamp to keep it from destroying itself as the lamp resistance develops. Without the limiting capability of the ballast, the lamp would consume (draw) more and more current and explode.

b) Voltage Transformation - HID lamps require a variety of voltages to cause them to strike or begin conduction. The most common voltage required by HID lamps is approximately 240 volts. Since, in many instances, this voltage is not available, transformers are used in ballasts to transform or change the voltage from the available value to that required by the lamp. For instance, a transformer designed to operate a 400 watt mercury lamp with a 120 volt supply will step the available 120 volts up to approximately 240 volts to start the lamp.

c) Regulation - As mentioned in our brief review of lamp operation, HID lamps reach a point of equilibrium in a short period of time after striking. Changes that affect the temperature of the arc tube, such as changes in the voltage supplied to the lamp through the ballast, can produce significant variations in a lamp's wattage and light output. Ballasts act to reduce this variation by absorbing part of that imput.

d) Power Factor Correction - A basic ballast and lamp combination is a normal power factor device. That is, for a given wattage, more than twice as much current is required to operate the lamp and ballast as would be required to operate an incandescent lamp with an equivalent wattage rating. To compensate for this, some ballasts are designed so that they always use a capacitor, and are high power factor.

2. Ballast Types

(To accomplish the functions outlined, five different types of ballasts are used. Not all of them are available with all HID sources on the market today. The following is a brief description of each type of ballast.)

a) Reactor - Reactors are the simplest type of ballast. They consist of a single coil of wire on a core of steel. Functionally, they act as current limiters and provide some lamp wattage regulation. Reactors are normal power factor devices and require the addition of a capacitor for high power factor operation. The units are designed for ± 5 per cent input voltage variation and limit or regulate lamp wattage to a ± 12 per cent variation within that range. Characteristically, they require higher currents for lamp starting than during normal lamp operation. Regulation Example: If a 240 volt, 400 watt reactor voltage varies from 228 to 252 volts (± 5%) the wattage will vary from 352 to 448 volts (± 12%).

b) Autotransformer (lag Auto or Lag) - In terms of performance, autotransformer ballasts exhibit the same operating characteristics as reactors. The ballasts consist of two coils on a core of steel. Together, the coils transform the line voltage to meet the lamp requirements, and limit lamp current.

c) Constant Wattage Auto (CWA, Auto-regulator, or Regulated) - The CWA ballast consists of two coils on a core of steel and a capacitor. These ballasts perform the basic functions of current limiting and voltage transformation. In addition, CWA ballasts are always high power factor, and have starting currents that are less than operating currents. However, in regard to regulation, they offer significant improvements over the preceding ballasts. CWAs are designed for a

± 10 per cent input voltage variation. Over this range, they will maintain lamp wattage within ± 5 per cent, a four-fold improvement over autotransformers and reactors. This type of transformer is most commonly used with area, sports, and indoor lighting.

d) Constant Wattage (Isolated Regulated-Premium Constant Wattage) - In addition to current limiting and voltage transformation, constant wattage (CW) ballasts provide the best lamp wattage regulation available. Designed to operate over a voltage range of ± 13 per cent, these ballasts will maintain lamp wattage within ± 2½ per cent. They are high power factor and have lower starting current than operating current. These units are similar in construction to CWA ballasts.

e) Constant Voltage (High Pressure Sodium Premium Regulated) - Close lamp wattage control is difficult to achieve with high pressure sodium (HPS) lamps. To meet HPS lamps' requirements with ± 10 per cent input voltage variation, constant voltage transformers are often used. These transformers maintain lamp wattage within ± 10 per cent voltage variation. They are high power factor units and have lower starting than operating current requirements. The constant voltage transformer consists of three isolated coils on a core of steel.

3. General Operating Principles

(A basic understanding of the general operating principles of ballasts as the four ballast functions are performed is useful. Again, freedom is taken in the use of terms and comparisons in the interest of conveying a basic understanding in simple terms.)

a) Current Limiting - The simplest ballast, the reactor, consists of a core of steel on which many turns of wire (conductor) are wound. The coil of wire of the reactor is put in series within the lamp and has voltage connected to it. When the lamp strikes (turns on), current (electrons) begins to flow through the conductor. The flow of curent in the conductor generates a force (magnetic field) in the wire and steel that tends to increase the "resistance" of the reactor and limit the flow of current (in the way a partially closed faucet limits water flow). As the lamp warms up and more material enters the arc stream, the lamp develops its own resistance. This "lamp resistance" reduces the amount of current and, in turn, the current reduction reduces the ballast "resistance." This process continues over a period of time (several minutes) until the lamp has stabilized. After this point, the reactor plays only a small part in the continuing lamp operation. During the warm up, the ballast has experienced a gradual "resistance" reduction similar to the gradual opening of a nozzle on a water hose. At the same time, however, the faucet (lamp) allowing water flow in the hose has gradually been closed, and has increased in resistance.

Electrical ***(page 7 of 8)***

b) Voltage Transformation - All ballasts other than reactors perform voltage transformation, changing the voltage supply by the ballast to the value required by the lamp. Voltage transformation occurs in ballasts with a steel core and at least two coils. Power is supplied to one of the coils (a primary) and current begins to flow. This current flow produces a magnetic force field in the steel which wraps around the second coil (secondary). This force field on the secondary coil develops a voltage that is roughly equal to the ratio of the number of primary turns to secondary turns. That is, if 120 volts is applied to a 100 turn primary, a secondary with 200 turns will develop twice that voltage or 240 volts!

c) Regulation - By subjecting the steel core of a ballast to high amounts of "magnetic force", you can also change the ratio at which voltage is transferred (as described above). That is, a ballast can be designed to have one voltage transfer ratio at one input voltage, but as the input voltage varies further, the core becomes "overworked" (saturated) by magnetic force. The result is that additional changes in the primary are not seen in the secondary. This basic principle is used in the design of all regulated ballasts, isolation of the secondary (lamp) from changes in the primary (power supply).

4. Ballast Characteristics for H.I.D. Sources:

BALLAST TYPE	REACTOR	AUTO	REGULATED AUTO (CWA)	CONSTANT WATTAGE (CW)	CONSTANT VOLTAGE
Typical Line Voltage	240	120	* *	* *	* *
% Lamp Wattage Change	± 12%	± 12%	± 5%	± 2½%	± 10%
% Input Voltage Change	± 5%	± 5%	± 10%	± 13%	± 10%
Power Factor (P.F.)	50%	50%	90%	90%	90%
Capacitor	— *	— *	Std.	Std.	Std.
Mercury Vapor	X	X	X	X	—
Metal Additive	—	—	X***	—	—
Metal Additive (for approved mercury ballast)	—	—	X	X	—
High Pressure Sodium	X	X	X	—	X
HPS (No starting circuit, mercury ballasted	X	X	—	—	—
Low Pressure Sodium	—	X**	—	—	—

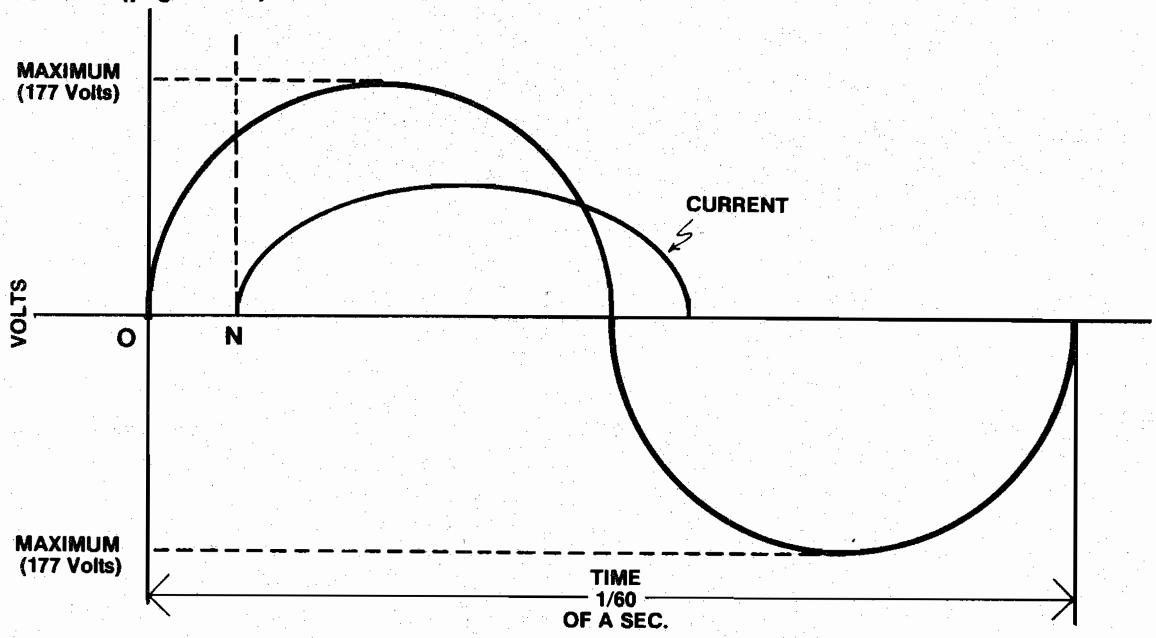
NOTE: "X" indicates equipment that is normally appropriate for a given source.

* Capacitor required for high power factor only.

** All voltages.

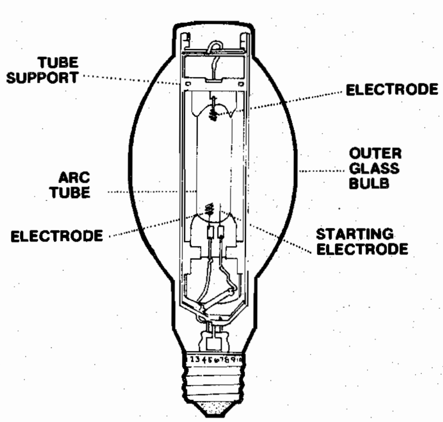
*** Specially designed CWA type ballast for metal additive lamps.

Electrical *(page 8 of 8)*



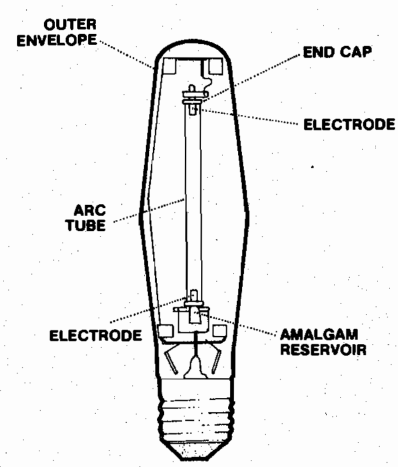
This illustration represents a 120 Volt Waveform. The voltage ranges from Zero to 177 Volts to Zero to 177 to Zero 60 times a second. The average voltage is 120 Volts.

DIAGRAM A



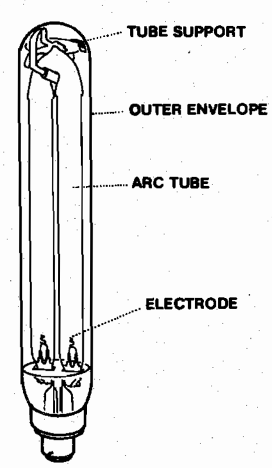
MERCURY OR METAL HALIDE LAMP

DIAGRAM B



HIGH-PRESSURE SODIUM LAMP

DIAGRAM C



LOW-PRESSURE SODIUM LAMP

DIAGRAM D

Tues. 4-15-80
10:15 A.M.

Bill Brenning went up in bucket with Power Company to shut refractor door that was hanging open at S263 Sta. 750+50. He checked lamp voltages on both sides at 118V and line voltage at 420V. He tapped lamps on both fixtures and found they were all right but one side was affected but the air made the lamp act like there was a vacuum leak in the envelope.

New dry type transformer installed at service pole A12 was defective besides being too small.

The coverplate on S288 was missing and the wires were messed up. A 10 inch length of wire was missing from one cable leaving only the rubber exterior.

Two luminaires were missing from S287 Sta. 785+50. The Power Co. men said that the pole was hit by a vehicle and both units came off. GE fixtures provided by the Power Co. were installed after restringing wire to the west side. A Westinghouse lamp was put in the west side and a GE on the east.

Lamp on west side S286 Sta. 782+50 was out. Both sides received GE lamps picked up when Dexter got the luminaires. The unit that was out had a bad starting board. A Sylvania lamp ran up to 75V while the GE lamps ran to 125V. Bill could step them out by tapping them. We could also rap the bottom of the pole and they would go out. The lamp voltage would go to 150V when they would blink out which indicates that the ballast should be sufficient. When it was observed that they cycled without our assistance, the GE lamps were replaced with Westinghouse.

Both luminaires on S285 were burning so we skipped that one.

S284 Sta. 776+30 had luminaire on west side out. Both sides replaced with Westinghouse lamps. The lamp on the west side went up to 108V but the one on the right went to 125V and Bill thought the ballast was probably high.

The whole line that S276 is on threw the breaker twice. I don't believe it was immediate but after a short time. The breaker was replaced and it seemed to cure the problem.

Bill checked two of the new GE design lamps on S286 and they stepped out but not quite as easily as the earlier ones.

S208 Sta. 451+87 has fixture out on the south side. It also had a starting board failure.

The 7 fixtures on the Kelly overpass were out. I think the numbers are S190, S192, S193, S194, S199, S200 and S201.

S189 Sta. 439+20 has a fixture out on the south side. It was unplugged at the base and had never been on.

S184 Sta. 424+70 north fixture is out. There was a 250 watt lamp in unit. He also had to replace the starting board. Both showed signs of overheating.

S181 Sta. 415+70 south fixture is out because of a bad starting board. Bill relamped with Sylvania because the support rod was bent although the lamp was good.

S180 to 189 circuit breaker kicked out. This morning when the power crew got back from turning units on, they told us that several breakers were 10 or 15 amp.

S167 Sta. 403+50 had both fixtures out. Wiring in base had been pulled and messed up. The north unit was still out after the wiring was fixed. The primary was shorted to shunt. The unit was replaced with GE fixture and a Westinghouse lamp.

Wed. 4-16-80
9:30 A.M.

The bucket truck set up on the first pole, S246 Sta. 709+43. The refractor door is open and reflector gone. The unit was replaced with a H.L.&P. GE fixture and Sylvania lamp.

We passed 6 poles S259 Sta. 739+30 to S254 Sta. 724+40 (McCarty Dr. to RR overpass). H.L.&P. men found access door on S255 gone and the wires dangling and ripped from the connectors. He checked lines and found an open neutral. We started checking up the barrier and found standard S253 Sta. 721+60 completely gone with the wires sticking out of the conduit. H.L.&P. worked on it while we checked the cycling units. They found part of the problem with the lines but one fixture was smoking and there was still circuit problems.

Unit S245 Sta. 706+40 north was cycling. It was found to be a GE lamp with a voltage of 140. The unit was relamped with Sylvania.

S252 Sta. 718+40 north is cycling. It was a Sylvania lamp with a voltage of 135 but Bill couldn't walk it out. There was a start of a crack and that might make it voltage sensitive. The men were working on the line where the standard was missing and a variation could have been there.

S238 Sta. 694+70 south was out. The capacitor was bad. Bill also replaced the starting board and lamp in case there might have been damage to the system. The support rod in the lamp was bowed but it probably would check OK.

So far problems have been limited to a small percentage component failure but mainly circuit problems.

Fixture on S228 Sta. 675+00 south is out. Outside envelope of lamp leaked vacuum causing failure of lamp.

S226 Sta. 669+40 south fixture is out. It is a GE 400 watt MV fixture. The unit was replaced with H.L.&P. GE fixture and Sylvania lamp.

One of the H.L.&P. crew noticed standard S236 was leaning and that the nuts were loose. The nut on south side is about 1½" above the base plate and does need to be tightened.

S225 Sta. 666+50 has fixture out on the north side. Bill replaced a bad board and relamped with a Sylvania even though the GE lamp looked new as a precaution.

S221 Sta. 654+60 fixture on the south side is out. Bill replaced the starting board.

we noted wires hanging out of the ports. When we passed Gellhorn, we watched the GE fixtures as we passed. There had been quite a few replaced with the H.L.&P. fixtures. Since both are GE the way to identify is DHT have leveling devices while H.L.&P. does not. The H.L.&P. also has a power door that our doesn't.

The standard where we are is at the end of a section. The ones south won't light because of a burned out line. The problem with the H.L.&P. fixture on the west was handling damage causing the power connections to the ballast to burn out. The lamp was an old GE basedown with metal and caps. The voltage was 145 but didn't walk out with vibration even though the voltage would be out of the trapezoid. The fixture was relamped with a Westinghouse which ran at 85 volts. The Sylvania lamp in the DHT fixture on the other side is running at 95V. Both are vibration stable.

The third standard south of the overpass with a sign bridge just before it with a Market St. exit on it had a fixture on the east side out. Bill found a bad starting board but it probably was ruined because the lamp couldn't be screwed in the socket far enough and had arced to the contact. There was a broken weld in the lamp but was probably caused by the heat from the arcing at the lamp base. The unit on the other side had a Sylvania lamp which ran at 90 volts.

H.L.&P. told us that they had been on this section three times and they had 8 to 10 fixtures each time. The manufacturers had picked them up without notifying DHT.

Thurs. 9-17-80
9:30 A.M.

The bucket truck set up on S166 Sta. 400+60. The fixture on the south side is out. The primary was shorted out. H.L.&P. replaced with their GE fixture and a Sylvania lamp. The access cover was missing on this and wires were laying on the ground. The luminaire had signs of fire or extreme heat near the leads of the capacitor but wasn't related to the heat from the shorted primary. The heat damage from the shorted primary was confined to the primary.

This circuit is wired phase to phase with only one phase fused. When one side goes it leaves partial voltage on the line and current increases causing a burn out. Both phases should be fused to prevent this. Down the line the wiring was phase to ground.

S61 Sta. 320+00 with fixture was out. The starting board was bad.

A second MV unit was noticed at the 59 interchange.

H.L.&P. still hasn't been able to get a drive to lower the high mast unit.

10:50 A.M.

We went to intersection at Irvington to turn on power at service pole A1. S25 Sta. 269+35 didn't have any lights on but S19 Sta. 266+41 was on with none to the west of that on. The ones to the east S26 did come on. H.L.&P. opened cover plate on S19 and found wire to the rest of the line disconnected where it should have been at the connector. The wiring so far has been very poorly done. It appears to be largely due to the contractor. Too low an amperage breaker and connections like we have seen are uncalled for. H.L.&P. claims not to have done any work but the MV fixture we pulled had a power door and they had also reworked the service poles.

S15 Sta. 263+88 was cheked and the H.L.&P. men said it was dead ended. They pulled a wire out with rat gnaw marks on it. There was electrical tape covering some of them and tape around the connector where the line was supposed to feed the lights to 45. At the next pole we found where they had run a green wire for a hot wire. The fixtures weren't working. The wire had #8 AWG Type MTW or THRH gas and oil resistant AWM styles 1318 & 1410 600 volts VW labeled on it.

1:30 P.M.

We started on 610 above Galena Park turnoff across from a warehouse at 2005. On the way here passing the ITT fixtures, we observed many access doors missing with some loose. There were several spots that

ATTACHMENT J

GENERAL ELECTRIC

LIGHTING
SYSTEMS
DEPARTMENT

GENERAL ELECTRIC COMPANY, HENDERSONVILLE, NORTH CAROLINA 28739

June 24, 1980

Mr. Dexter Jones
State Department of Highways
and Public Transportation
P.O. Box 187
Houston, Texas 77024

Dear Dexter:

SUBJECT: 400W HPS Vibration Testing

Pursuant to the above, and at your request, we have tested the two luminaires and five of the seven lamps you sent.

The results are as follows:

ROADWAY LUMINAIRES

These M-400 type, 400W HPS units were manufactured in November of 1975. Examination revealed that one was o.k., the other had a failed ballast. The ballast failure was located in the start slot area of the secondary coil and was due to faulty insulation installation at the time of manufacture.

The defective ballast was replaced, and both units are being returned to you.

Before reporting on the lamp findings, I would like to take a moment to discuss our luminaire vibration testing procedure which is attached.

This procedure has as it's basis, a paper authored by Harold A. Van Dusen, Jr. and titled "Street Lighting Luminaire Vibration". The key part of this paper is Figure 2 which indicates that there is something less than a 5 percent probability that street lighting luminaires will "see" a 1g loading.

The testing procedure we use for all Roadway luminaires is a two part test consisting of a 4g loading for 5,000 cycles followed by a 2g loading for 100,000 cycles.

LAMPS

You sent us a total of seven 400W HPS lamps consisting of:

4 ea. of Sylvania manufacture
2 ea. of Westinghouse manufacture
1 ea. of General Electric manufacture

The vibration test procedure used was to mount the lamp (in it's worst position) rigidly on the vibration table, apply power to the lamp and wait for it to stabilize. The vibration table was set for 1/4 inch displacement and a frequency of 8 cycles/sec. (.82g) as a beginning point on each lamp. After the lamp stabilized, the frequency was incremented up to increase the g loading. Lamp stabilization was achieved each time before the table's frequency was changed. (attached picture shows vibration table set-up.)

The results are as follows:

SYLVANIA

1st. lamp (arrived with luminaires)
- stabilized at 90 lamp volts before vibration test began
- destructed at .82g loading (we believe that the arc tube came loose and shattered the envelope)

2nd lamp - stabilized at 88 lamp volts before vibration test began
- arc tube vibrated loose at 1.3g
- lamp was operating satisfactorily up to this point

3rd. lamp
- stabilized at 91 lamp volts before vibration test began
- stable operation was observed through 2.2g
- lamp dropped out at 2.5g (in excess of 140 lamp volts)

4th. lamp
- not yet tested

WESTINGHOUSE

1st. lamp
- stabilized at 102 lamp volts before vibration test began
- stable operation up to the 1.56g drop out point (in excess of 140 lamp volts)
- fracture of seal developed

2nd. lamp
- not yet tested

GENERAL ELECTRIC

lamp
- stabilized at 121 lamp volts before vibration test began
- operated through 1.3g
- dropped out when vibrated at 1.5g (in excess of 140 lamp volts)

Dexter, with the exception of the Sylvania lamp that broke and the two yet to be tested lamps, I'm returning the other lamps to you. As soon as we complete the tests on the remaining Sylvania and Westinghouse lamps, I'll forward the results to you.

I'm not sure that based on this small sampling of lamps that I can draw any firm conclusions. However, since your phone call in March, we have been working with the Lamp Department to improve the Lucalox lamp insensivity to vibration. Based on some preliminary results with prototype lamps, this improvement may well be possible. I'll keep you posted on developments in this area.

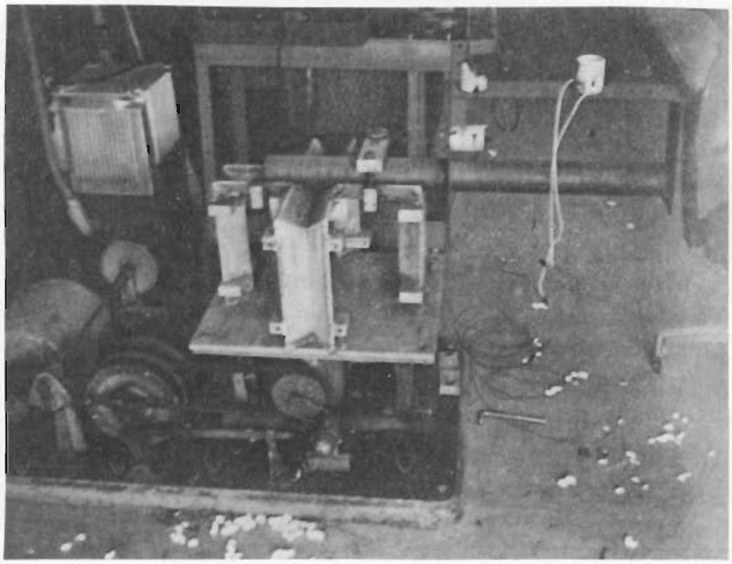
Jim Havard

Jim A. Havard
Specialist - Product Planning

JAH/th

Attachment

cc: James Stephenson
ADSD - San Antonio
Dan Gaines
Jim Darnell
Thad Bynum - State
Dept. of Highways and
Public Transporation
Austin, Texas 78701



SUBJECT	TAB	NO.
VIBRATION TESTING INSTRUCTIONS	Std. Test Method	06.326.

GENERAL

Dynamic stresses imposed on luminaires in service result from four principal causes:

1. Wind induced vibration of lighting structures such as luminaire and pole assemblies and floodlights on towers or poles.

2. Traffic induced movement transferred to the luminaire from a bridge or overpass, being generated by the passage of vehicles. A similar type of loading is experienced by floodlights and industrial type fixtures mounted in areas adjacent to heavy rotating equipment, gantry cranes, punch presses, etc.

3. Wind loading, particularly high velocity wind creating a dynamic pressure on the projected area of the luminaire.

4. Handling, shipping and accidental impact loading on the luminaire.

METHODS

Vibration testing provides a means of laboratory simulation for these conditions, but several modes of testing are required to cover the variety of conditions.

A. Sustained Vibration Endurance Tests:

This provides a measure of fatigue evaluation for wind induced and traffic induced types of vibration. Recommend 2g acceleration intensity measured at the luminaire center of gravity for 100,000 cycles at each of the three major axes (two horizontal and one vertical). Frequency and amplitude adjusted for the required 2g acceleration such that the frequency is not the fundamental resonant frequenty of the luminaire.

$$Ag = 2 = 0.0511 f^2 D$$

Where: Ag = Acceleration, g units
f = frequency, Hz
D = displacement, total excursion, inches

by G F Johnston

7-3

ISSUED BY THE	DATE ISSUED	SUPERSEDES ISSUE DATED	DISTRIBUTION	PAGE
Engineer-Design Standards	May 5, 1971	New	Eng'g S/S Std. Practice Manual	1 of 2

STANDARDS

B. High Loading Vibration Test:

This provides a measure of high velocity wind loading and low impact loading evaluation.

Recommend 4g acceleration intensity measured at the luminaire center of gravity for 5000 cycles at each of two major horizontal axes. The frequency and amplitude adjusted for the 4g acceleration such that the frequency is not the fundamental resonant frequency.

Additional References:

1. "Street Lighting Luminaire Vibration" Van Dusen, Illuminating Engineering, Feb. 1968.
2. "Vibration of Street Lighting Poles and Luminaires" EEI-NEMA Pub. SH67-53, Sept. 1967.

STANDARDS

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Street Lighting Luminaire Vibration

By Harold A. Van Dusen, Jr.

MOST outdoor lighting structures which involve metal poles and luminaires vibrate due to the action of moderate-velocity winds and sometimes due to other effects. The vibration may or may not be harmful to the luminaire depending on its intensity and on the dynamic strength (vibration tolerance) of the luminaire.

Luminaires can be designed to withstand the vibration levels that most commonly occur in service and it is the purpose of this paper to provide guidance in this area. This paper will deal primarily with the luminaire portion of the pole-arm-luminaire structure; however, this will involve discussion of the vibration phenomena of that entire structure. The paper will include suggested design values and will describe vibration testing methods.

Pole Vibration

Pole vibration is oscillatory mechanical motion of the entire lighting structure consisting of the pole, luminaire support arms, the luminaire, and any other objects supported by the pole. The structure vibrates as a system and any change in the geometry, weight distribution, stiffness or damping of any portion will influence the vibration characteristics of the entire structure.

The energy source causing vibration is usually wind acting on all or part of the structure and, in case of bridge-mounted structures, traffic vibration. Wind creates a relatively steady-state force approximately proportional to the square of its velocity, and in addition it will often generate an oscillatory force at certain wind velocities. When the oscillatory force corresponds to one of the mechanical resonant frequencies of the structure, vibration usually results.

An example of pole vibration illustrating two of the many possible resonant conditions is shown in Fig. 1. Fundamental mode represents the lowest resonant frequency condition for a given direction of motion. The second mode occurs at a higher frequency, generally three to ten times the fundamental. High bending stress occurs at locations of minimum displacement (nodes) and high acceleration forces occur at points of maximum displacement (antinodes).

Pole vibration generally occurs only at a resonant frequency when it is wind excited; however, it may occur at non-resonant frequencies when force-excited, such as with traffic induced motion.

Resonance

Mechanical resonance is somewhat analogous to a tuned electrical circuit. The resonant frequency is dependent on the mass and spring characteristics of the structure and will increase with increasing stiffness and decreasing weight.

Motion at a resonance frequency is stored energy and, once started, a pole may remain in motion for over 100 cycles while the amplitude slowly decays. A small force applied to the pole may cause only a very small deflection but if it is cycled at a resonant frequency the energy from each cycle will be added to the already stored energy. In this manner each cycle will be at a higher amplitude until a high value is reached where the energy absorbed by damping is equal to the input energy. There is very little damping at the lower resonant frequencies in the typical lighting structures and thus the intensity may build to a very high value. That is, there will be a high amplification factor.

Forces Acting on the Luminaire

The installed luminaire is usually located at a point of high displacement, where acceleration is the significant measure of intensity. Acceleration is conveniently stated in "g" units where g is acceleration due to gravity. An acceleration of one g on an object represents an inertia force equal to its own weight. An example would be an object resting on a bridge that is vibrating in the vertical direction. If bridge acceleration (vertical) is less than one g then the

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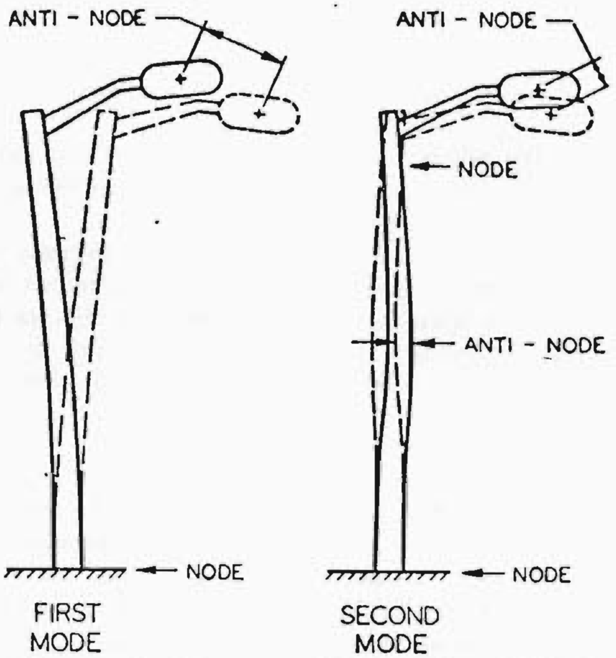

Figure 1. Typical resonant vibration modes of a lighting structure. Higher modes are possible but the first and second are the more predominant.

object will remain in contact with the surface but if intensity were to exceed one *g* then the object would bounce about on the bridge.

Typical luminaire acceleration due to wind excitation was determined in an earlier study.[1] Results of that study showed that most metal street lighting poles vibrate. Each individual structure tends to have a characteristic maximum vibration amplitude and this amplitude will occur over a substantial portion of its in-service time. Fig. 2 illustrates the probable maximum characteristic intensity at the luminaire. Acceleration values up to one *g* are fairly common but higher values are rare. A luminaire may accumulate millions of cycles at maximum amplitude per year.

Vibration frequencies generally range from .6 to 25 Hz with frequencies below about 4 Hz usually being associated with first mode resonance of the structure and the higher frequencies occurring at second, or sometimes higher, mode resonance conditions.

Vibration intensities substantially above one *g* are possible but not common. It would be unrealistic to design luminaires and structures to withstand the rare extreme intensities and it was suggested in the earlier paper that the extreme structures should be modified to reduce their characteristic intensity.

Traffic-induced vibration on a bridge is usually short bursts of motion at a forced input intensity, usually in the vertical direction, to the pole base. The intensity at the luminaire is dependent on the resonant frequency of the structure as related to the characteristic forcing frequency at the bridge attachment. Luminaire intensity may range from practically zero to extreme amplified values. The resonant frequency of the pole due to vertical excitation will not necessarily be the same as with wind-induced vibration. Resonant frequency will be very high when luminaire is centered over the pole and it will decrease with increasing arm length.

If the pole fundamental frequency is below the excitation frequency the luminaire will tend to stand still in space while the shaft and arm absorb the difference in displacement. At resonance, luminaire intensity will exceed bridge intensity. With a pole fundamental frequency much above excitation frequency, the luminaire motion will be the same as bridge motion.

Shock loads and miscellaneous forces occur due to handling, shipping, and in service. Experience has shown that a luminaire that can withstand a short duration (1000 cycle) high intensity dynamic test at 4 *g* can usually tolerate most loads of this nature.

Testing the Luminaire

Suggested luminaire vibration test criteria are:

1. Vibration fatigue test to simulate an infinite number of cycles (endurance limit number) at a force of 1 *g*.
2. Short-duration, high-intensity test at 4*g*.

Endurance limit is the stress value in which the "S-N" curve of a given material does not show a reduction in failure stress (*S*) as the number of cy (*N*) of load application increases. Such a curve is

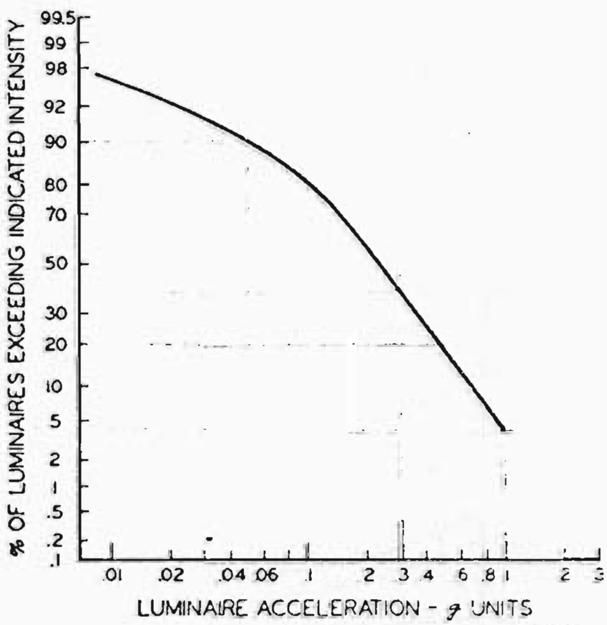

Figure 2. Wind-induced vibration intensity probability. Street lighting luminaires mounted on metal poles bration frequencies range from .6 to 25 Hz.

shown in Fig. 3. Not all materials have a true infinite-endurance-limit stress and for aluminum it is customary to use the stress at 5×10^8 cycles as the endurance limit.

A direct endurance test at 1 g for 5×10^8 cycles would require an impractically long time; over one year at 10 Hz. A different test method could be to measure the peak stresses resulting while the luminaire is subjected to 1 g vibration to determine that they are below the endurance limit. This can be accomplished with strain gauges but it requires knowledge of the location of the maximum stresses. These are usually very hard to find and measure directly in the complex shapes typical in luminaires.

The suggested test method is to vibrate the luminaire at an increased intensity to simulate endurance limit within a reasonable amount of time and then inspect the luminaire for evidence of fatigue damage. Overstressed areas anywhere within the luminaire will be automatically revealed in this manner.

A test where all the stress levels are increased by the ratio of fatigue stress at 10^5 cycles to endurance stress will closely simulate an endurance test if the test duration is that smaller number of cycles. Such a test run can usually be conducted in a time period of two to three hours.

Stress is proportional to acceleration; therefore, a value of test acceleration that will simulate the desired endurance limit acceleration in N number of cycles can be determined by

$$A_t = A_e \frac{S_N}{S_e} \qquad (1)$$

Where: A_t = acceleration to be maintained during the test.
A_e = acceleration endurance limit wanted. Usually 1 g.
S_N = fatigue stress to cause failure at N number of cycles.
S_e = endurance stress for the material involved.

The relationship of S_N/S_e (relative stress) for a number of materials commonly used in luminaire construction is shown in Fig. 4.

If the test luminaire, vibrated at an intensity determined by Equation (1) for N cycles, does not fail, then its endurance limit is at least as high as the intended value. If failure does occur, then the approximate endurance limit can be determined by:

$$A_e = \frac{A_t}{A_n} \qquad (2)$$

Where: A_n = acceleration that would be required for 1 g endurance at the observed failure number of cycles (n).

The luminaire should be mounted on the test machine with the same orientation in respect to vertical, and in a manner similar to its in-service mounting. There should be several complete test runs, each with input motion applied to a different major axis, such as the two horizontal and one vertical directions. The input intensity is adjusted so that acceleration (A_t) at the luminaire center of gravity (C_g) corresponds to the desired value.

The applied test frequency should not be higher than the fundamental resonant frequency of the luminaire in its test configuration (the resonant frequency may be very dependent on the test mounting device used).

With the above conditions the main structural dynamic forces within the luminaire (between the attachment fitter and the center of gravity) will be proportional to the indicated acceleration. Forces at individual components will be proportional to accel-

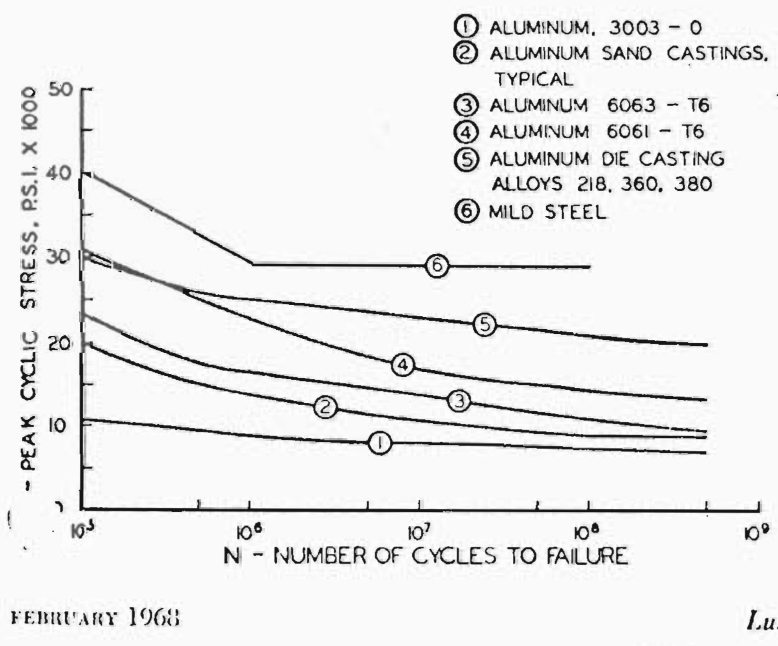

Figure 3. Typical fatigue strengths for various materials. Based on completely reversed bending stress.

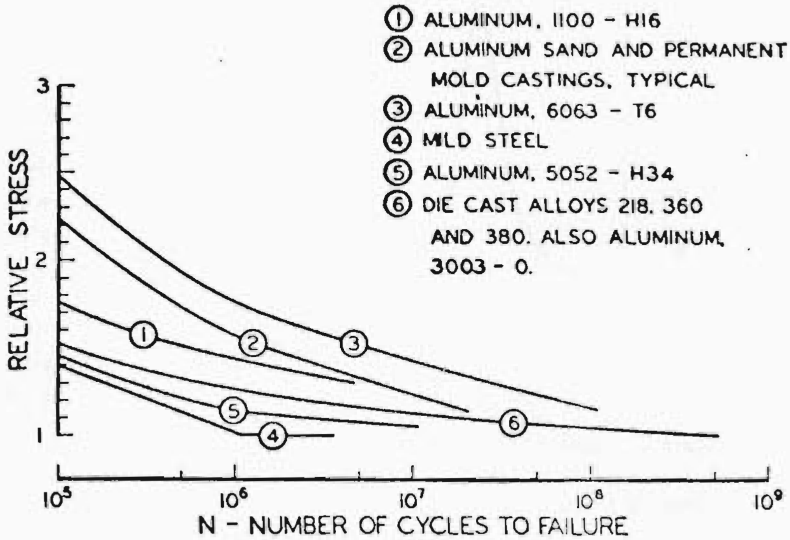

Figure 4. Fatigue stress relative to endurance stress for various materials.

eration indicated at those stations. At frequencies well below resonance the acceleration will be approximately constant throughout the luminaire.

If the applied vibration is above fundamental frequency then the main structural forces will not be proportional to acceleration at the C_g; however, localized forces will still be proportional to acceleration at their locations. At high frequency the luminaire center may stand still in space while considerable motion exists elsewhere.

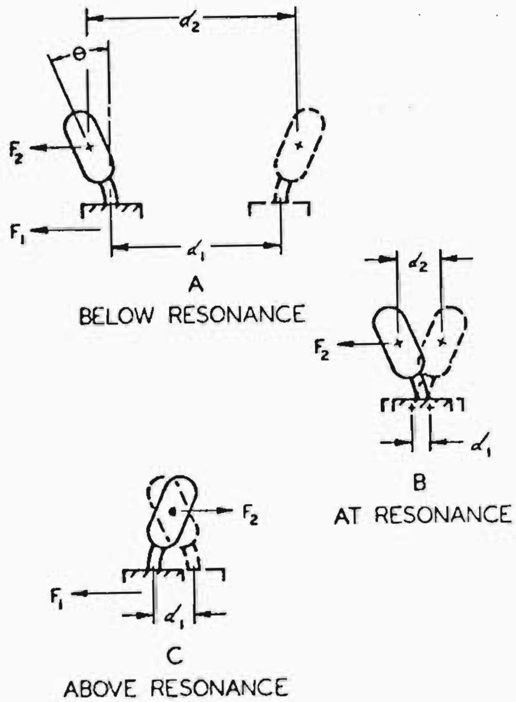

Figure 5. Response of luminaire on vibration exciter. At resonance the output and input displacements have a 90-degree phase relationship.

Response of the Luminaire

A hypothetical luminaire is shown mounted on a vibration exciter machine in Fig. 5, and its frequency response curve is illustrated in Fig. 6. It is shown being vibrated well below resonance (A), at resonance (B), and above its fundamental resonant frequency (C). In each case the input intensity from the exciter is adjusted to result in identical inertia forces (F_2) acting to bend the luminaire. The symbols used in the illustrations are:

F_1 — peak input force from exciter.

F_2 — peak inertia force acting at luminaire C_g.

θ — deflection of luminaire and its test mounting due to force F_2.

d_1 — input displacement, peak-to-peak, corresponds to exciter table displacement in the illustration but is more strictly the total C_g displacement when measured under static conditions).

d_2 — luminaire (output) displacement, peak-to-peak.

f_1 — fundamental resonance frequency.

At frequencies not greater than f_1 the force F_2 is proportional to the C_g acceleration. Acceleration, at any one frequency, when motion is a sine wave, is dependent on displacement and frequency. The latter are the only factors that normally need to be measured in a luminaire vibration test. The formulas are:

$$F = WA \quad (3)$$

$$A = \frac{4\pi^2 f^2 d}{2_g} = .0511\, f^2 d \quad (4)$$

Where: F = force, pounds
W = luminaire weight, pounds
A = acceleration, g units
f = frequency, Hz
d = displacement, peak-to-peak, inches

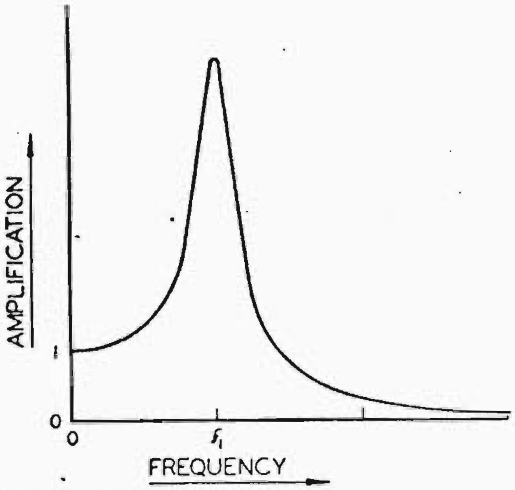

Figure 6. Typical frequency response of luminaire and its test mounting. Some luminaires have additional resonance peaks at higher frequencies.

g = gravity acceleration, 386 inches/second²

At frequencies above fundamental, the C_g acceleration may drop to zero. If testing must be conducted in this region then use an input displacement that results in the same deflection as would occur at the same g loads at low frequency. This is an approximation at best, because higher order effects occur at higher frequencies in many luminaires. Additional r ance peaks may occur and motion directions may also differ.

Amplification at resonance is a convenient indicator of the amount of damping in the luminaire and its test mounting. If resonance amplification exceeds 1.5 then:

$$H = \frac{50}{\text{amplification}} \qquad (5)$$

Where: H = damping, per cent of critical damping.

Amplification = ratio of d_2/d_1.

Typical values of amplification observed in luminaire testing range from two to 80. Typical fundamental frequencies range downward to about 3 Hz with values around 10 to 15 Hz being quite common.

If it is desired to obtain a resonance curve of the luminaire itself, then its test-mounting structure should be made sufficiently stiff so that the mount resonance, when supporting an equivalent concentrated weight as the luminaire at the same center, will be higher than the luminaire frequencies of interest. Resonant frequency of the mount can be estimated by the following relationship where y is the single amplitude deflection due to a force equal to the concentrated weight, *i.e.*: one-g static force:

$$f_1 = \frac{3.13}{\sqrt{y}} \qquad (6)$$

Luminaire vibration testing poses test equipment problems due to the low frequencies involved. A desirable frequency range for the vibration machine is 2 to 25 Hz. Low test frequency involves high amplitude at the luminaire. As an example, 12.25 inches displacement is required to attain 2.5 g at 2 Hz whereas most commercial vibration machines are designed with 5 to 10 Hz as the lowest frequency and with maximum table displacements less than one inch. Testing can be accomplished with small table displacement by making use of resonance amplification at the luminaire, but testing below resonance is preferable.

Some of the more common types of commercially available vibration machines are:[2]

1. Positive displacement (crank drive) types. Displacement and frequency are adjustable.
2. Reaction type, using rotating off-center weights. Force and frequency are adjustable.
3. Electro-dynamic types. These are very flexible in application but are usually limited to higher frequencies.
4. Special types, including hydraulic cylinder driven. This latter could be easily designed to cover the preferred frequency and displacement range.

The positive displacement type requires a very massive foundation. The author uses a machine of this type which has table motion in the horizontal plane. Frequency range is 4 to 60 Hz, displacement is zero to .125 inch, and load capacity is up to 150 pounds at 6.6 g. It is driven by a 1.5 hp motor. (The frequency was modified from an original 10 Hz lower limit.) An accessory rocking platform was constructed to provide motion in the vertical plane and to allow input displacement values up to .5 inch. Various test mounting configurations on this machine are illustrated in Figs. 7, 8 and 9.

The typical reaction type machine uses contra-rotating off-center weights such that a cyclic force is generated in a single direction. Frequency and amplitude are similar to the crank type machines but load rating is often higher. A significant advantage of this type of machine is that there is no reaction force acting on the foundation so a heavy mass is not required. A disadvantage is that the load mass must be centered in line with the force axis.

Intensity can be measured with an accelerometer; however, a strain gauge type rather than the common crystal accelerometer is generally required at the low frequencies. Other electrical transducers that could be used are velocity or displacement transducers. An advantage of electrical transducers is that the data can be displayed on a recorder where both frequency and intensity can be determined, and in-

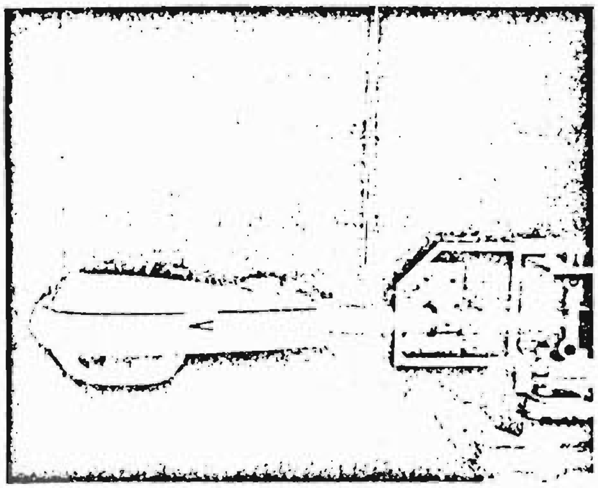

Figure 7. Luminaire mounted on special rocking platform for vibration in vertical plane. Input displacement is total static displacement at Cg. Output displacement is dynamic motion at the same location.

tensity of other than sine wave motion can be evaluated.

A very simple intensity measuring device is the vibrating wedge or "V-scope" technique for measuring displacement as illustrated in Fig. 10. This is difficult to use below 10 Hz; however, some observers can use it at lower frequencies. A method suitable for high amplitude at low frequency is to support a pencil so it touches a marking surface attached to the specimen. The length of the resulting line, representing the displacement, can then be measured af stopping the motion.

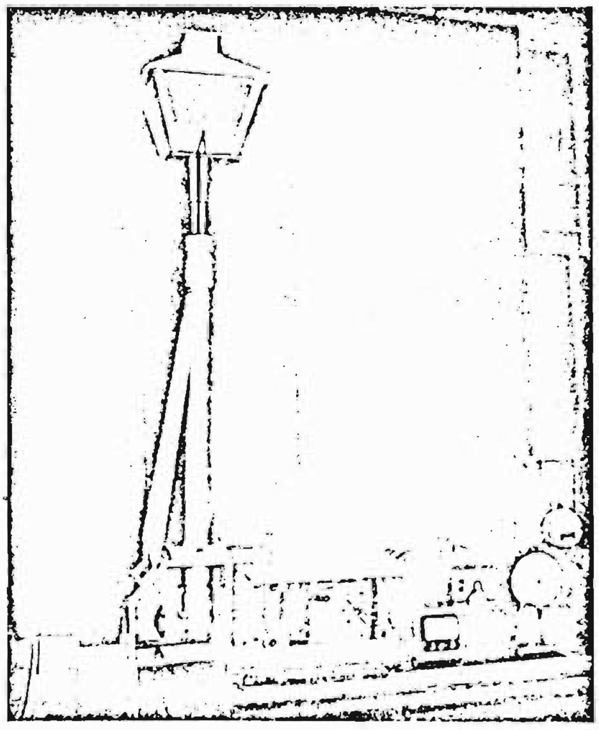

Figure 8. Extension column used to amplify input displacement. The column may be used in either the vertical or horizontal direction.

The luminaire should be tested while mounted in its normal orientation in respect to vertical. The steady state 1g downward force due to gravity will be added vectorially to the vibration force in service and the test will be more valid if the luminaire is similarly oriented in respect to the static acceleration.

Luminaires should preferably be tested in each of their three major axes (two horizontal and one vertical); however, the vertical axis test would rarely be required with pole-top mounted luminaires.

Luminaire vibration intensity should normally be measured at its overall center of gravity; however, some pole-top luminaires have a well defined second mass-spring system in which a substantial portion of the luminaire is supported by springy arms from the mounting fitter. This type should be additionally tested as if the second, arm-supported, portion were a separate luminaire with its intensity being measured at its C_g.

While testing the luminaire, the lamp and all components should be installed. Fatigue tests should be at low frequency; however, frequencies up to 25 Hz should be investigated to determine if any lightweight components, such as a lamp and socket assembly, resonate within that frequency range. If they should be separately fatigue-tested at t. . resonant frequencies to determine if they have satisfactory endurance at 1g input to their mountings. Such a test may be facilitated by clamping the luminaire rigidly to the machine table so that intensity at

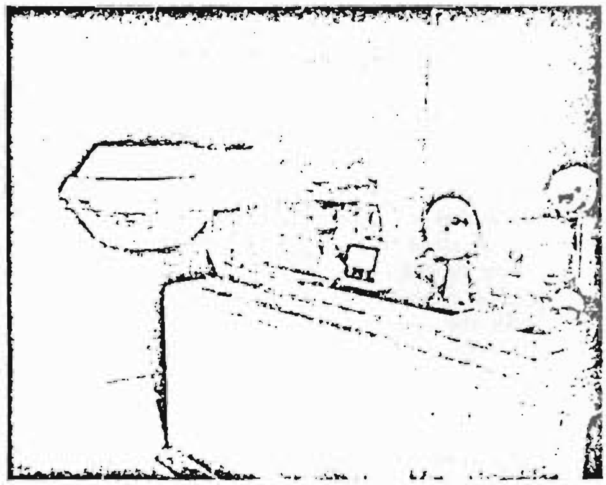

Figure 9. Luminaire being vibrated in the horizontal plane. Resonance amplification due to pipe arm and luminaire deflection allows high luminaire displacement. Luminaire may be positioned for vibratin either its broadside or longitudinal axis.

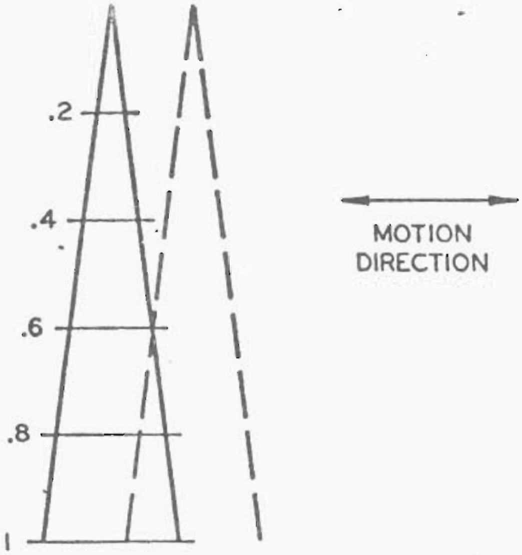

Figure 10. Vibrating wedge method for measuring displacement. This is a triangle drawn on paper and cemented to the test specimen. Width at various sections is shown by the numbers. During the test a second triangle will be seen due to eye persistence (simulated by the dotted figure in the illustration). The intersection point is the peak-to-peak displacement.

the luminaire can be more readily controlled at higher frequencies.

Analysis of Results

A common type of vibration failure is fatigue cracking within the main load-bearing structure of the luminaire. If the luminaire is being tested at resonance when a significant fatigue crack occurs, then the spring and damping characteristics usually change sufficiently to noticeably reduce the vibration amplitude. This serves as a convenient indicator that damage has occurred.

Fatigue cracks grow progressively as brittle breaks and usually there is no evidence of stretching or yielding of the material as would occur in static testing. Ductile materials behave more like brittle materials and the presence of stress risers such as holes, notches, rough edges, etc., become very significant.

Other effects such as loosening of bolts, chipping of glassware, etc., are not fatigue effects and if such failures occur during an accelerated fatigue test their significance should be evaluated separately with the following criteria in mind:

1. There should be no tendency for parts to loosen when subjected to 1g vibration over a long time period.
2. The luminaire should remain serviceable after at least a single cycle 4g test (all axes) as represented by static load testing or preferably after a 1000-cycle 4g dynamic test.

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3. Den Hartog, J. P., *Mechanical Vibrations*, Fourth Edition, McGraw-Hill, New York, 1956.
4. "American Standard Method for Specifying the Characteristics of Pickups for Shock and Vibration Measurement," Z 24.21-1957 United States of America Standards Association, New York, 1957.

DISCUSSION

KURT FRANCK:* A changing environment for street luminaires has increased the number of design parameters: The use of street luminaires, pole and all, has been increasing along the freeways and expressways which might be called a "rural" environment. Cost of materials and shipping, along with the physical effort of handling the heavy poles and luminaires, has forced substantial reductions in the weight of each of these.

This lighter assembly is subjected to greater vibrations in the "rural" environment. First, the wind, without building and tree surrounds that break the effect, is free to move at much higher velocities and in gusts. Second, the expressway is built to move trucks and cars at greater speeds than attained on the city street. These higher velocities, especially in trucks, create more vibration.

The author elaborates well on the vibration phase. We would expect the curve in Fig. 2 to change shape as the "rural" usage of street luminaires increases, with fewer in the range of .01 to .04g units and a larger number in the range from .02 up to .3g.

Compared to the author's work, our vibration analyses have been somewhat different. We have used frequencies greater than the resonant values of the units under test. Our earlier work was at 33 hertz with a value of .75g. We found that this g value was exceeded in some severe industrial areas and occasionally a new luminaire that passed the .75g value failed at Underwriters' Laboratories. We now test most industrial units at 1.5g and 33 hertz and find no vibrational failures in the field. On the basis of these tests on industrial luminaires we have used the same methods on outdoor lighting units with satisfactory results.

Two questions: Even though hurricanes and earthquakes

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are of rarer occurrence than ordinary wind and truck vibrations we would expect that they would still have to be taken into account in the design. Do the answers obtained by the author's present vibrational test methods give sufficient data to design for the more complex whipping and jerking types of vibration? Further, have instruments such as noise level measuring equipment been adapted to the measurement of the complex vibrations that occur in practice in order that one may simulate these motions in the actual tests?

FRANCIS CLARK:* Although I have no comments about vibration of the pole or the lighting fixture, I do want to make some observations about the effects of vibration on lamps and lampholders. One comment pertains to the physical size and construction of the lamp. Apparently a vulnerable point in lamp structure exists when the glass envelope is too large in relation to the size of the base, and vibration may cause these two parts to separate. The sturdiest construction seems to result when the base is made as large as is practical. Thus, with wattages increasing and bulb sizes necessarily increasing also, it would seem advantageous for the fixture designer to plan, not only for the larger envelope, but for larger bases as well. He might encourage the lamp manufacturer to incorporate these larger bases in his product. Another comment pertains to the thread used on lamp bases and in lampholders. A machine thread is certainly too costly but it would hold these parts more firmly together than does the rolled thread now in use. Vibration tends to loosen the lamp and gradually back it far enough out of the lampholder so electrical contact is lost. Manufacturers might cooperate in providing a base with a small rounded protrusion located in such a manner that, when the lamp was fully tightened, it would seat securely in one of a series of dimples in the lampholder. Vibration would not then dislodge the lamp, but a firm twist would make removal easy enough. Now for a favorable comment. Internal lamp failure resulting from vibration is almost nonexistent. So it must be that design and construction of arc tubes, leads, filaments, etc., make them sturdy enough to withstand greater vibration than is usually met in the field. In addition to the previous suggestions, perhaps more attention should be given to improving the sturdiness and rigidity of the lampholder mounting within the fixture. In some cases lampholders are fastened to sheet metal stock so flexible that the effects of vibration are actually amplified. For luminaires that are to be mounted in areas of known high vibration—exposed bridges, etc.—perhaps cushioned lampholders should be specified.

W. A. WEIBEL:** It is good to see that Mr. Van Dusen is continuing his work in this important field and he is to be commended on this, his latest paper.

On page three of the preprint, Mr. Van Dusen states: "The suggested test method is to vibrate the luminaire at an increased intensity to simulate endurance limit within a reasonable amount of time and then inspect the luminaire for evidence of fatigue damage."

Question 1: Was this inspection solely visual, with the unaided eye, or were magnification, X-rays, dyes, or magnetic means used?

Question 2: Was any attempt made to evaluate degrees of failure or was a given test terminated at any sign of fatigue failure?

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J. E. WAGNER:* Mr. Van Dusen is to be complimented for another timely paper on vibration. This subject deals with a problem becoming more acute as higher mounting heights and longer bracket arms are being employed.

The author states "It would be unrealistic to design l[illegible] naires and structures to withstand the rare extreme inte[illegible]ties" and that "the extreme structures should be modified to reduce their characteristic intensity."

This may have been true in 1965 (when his paper on pole vibrations was given) but the present American Highway Safety Act will make mandatory the design and use of just such "rare extreme intensities." Thus all the more reason for this timely study.

The author also emphasizes that "a direct endurance test at one g for 5 x 10^8 cycles would require over a year to complete at 10 Hz." and he has suggested a test method of vibrating the luminaire at an increased intensity to simulate endurance limit within a reasonable amount of time. Such a test, it is claimed, can generally be run in a two to three hour period.

Enough may have been learned through previous tests on yearly modified conventional luminaires to make this general statement, but it is questionable whether new exotic luminaires, many of large mass and projected area, could be given an accelerated life test over such a short period of time with the assurance that the unit is going to hold up for a life span of 20 to 30 years.

If such a luminaire were vibrated at a uniformly increasing intensity until it failed, could this failure be related to a direct endurance test?

Luminaires are occasionally mounted or suspended from the steel under-deck of a highway or railroad bridge. The latter involves operating under conditions wherein both the frequency and amplitude vary widely. Shock absorbing devices are often used in an attempt to eliminate vibration but they frequently do not solve the problem. Has the a[illegible] investigated this problem and does he have any suggestions as to which type of device would be most practical? Further, can such bridge vibration be readily measured so it could be duplicated in the lab?

Another common problem is that of unlatching of the "refractor-refractor holder assembly" which allows the assembly to swing open and in many cases results in hinge failure.

Cannot this latching problem be solved by vibration testing? Also, cannot the luminaire manufacturer beef up the hinge assembly to prevent its failure under accidental unlatching?

D. E. HUSBY:** Mr. Van Dusen must be complimented an[d] given thanks for providing guidance means for luminair[e] and pole design and application. He provides a good guide in a general way, on how to evaluate design and performanc[e] of the luminaire, but it should be made clear that the de[-] signer's judgments must be well founded and made from posi[-] tions of knowledge, since the guide could serve to prov[e] erroneous assumptions on the designer's part. Mr. Va[n] Dusen assumes that all designers are as knowledgeable a[s] he, and this is just not fact. I would like to see a little mor[e] material discussed relative to the resonance excitation fr[e]quency as created by bridge traffic. It is felt that if the tren[d] to longer mounting arms is continued with respect t[o] bridges, there will be a marked increase in "bridge type" failure. This is the excitation frequency generated by [illegible]

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**Westinghouse Electric Corp., Cleveland, Ohio

hour types of traffic where vehicles are spaced at essentially equal intervals and are traveling at essentially equal speeds. These conditions could create much more severe amplitudes of vibration and magnitudes of force than the wind-induced ct.

.Mr. Van Dusen touches it lightly, but should have expanded upon the vibration effects on internal parts of a luminaire. Here, it is agreed, the designer must consider each individual item carefully since, unless the part is made permanently part of the luminaire whole, much internal damage can be done by resonant and harmonic frequencies much higher than those of the luminaire proper.

Before the accelerated test at high "g" loading is run, one must be certain that no item in the overall construction will fail due to the shock of this higher value, but could be expected to give good service at the one-g value. Such an item could be the relay of some photo controls, for example.

All considered, this paper can be used by the designer to support his theories and add credence to his own laboratory findings. It also calls attention to the need for complete laboratory testing of today's luminaires and complete analysis of each functional part or material.

C. FRIAR:* Any research which explores cause and effect in streetlighting pole and luminaire vibration is to be commended. Knowledge in this field is not only limited, but contains many areas which are little understood. Persons interested in the behavior of pole-luminaire systems will appreciate Mr. Van Dusen's efforts.

Mr. Van Dusen's previous paper was concerned principally with the pole, this paper with the luminaire. Of general interest to the discussion are the several causes of vibration to the pole-luminaire system. Of particular interest is vibra-·· attributed to luminaire shape.

.hen air flows by a cylindrical shape, vertices are shed on the leeward side in a regular manner. These vertices are alternately clockwise and counter-clockwise, and are associated with an alternating sidewise force. The phenomenon is called a Kármán vortex trail, and induces a vibration at right angles to the wind. The frequency of the eddy shedding is a somewhat exact frequency dependent on the diameter of the cylinder and the velocity of the wind. Difficulties arise when the frequency of eddy shedding coincides with the natural frequency of the structure itself. Then a resonance occurs which may be destructive.

There is a lift and drag effect for elongated and symmetrical cross sections, which for want of a better term has been called a wind motor effect. Long recognized in aeronautical design is the effect the angle of the wing has on lift. The lift effect depends on the angle the wing makes with the wind. There are angles where the wing suddenly loses most of the lift effect. If a luminaire were so shaped that the angles of its surface were shaped to be near the critical angle, an alternating lifting and dragging of the luminaire could result under any wind. High amplitude vibraton can result as the luminaire alternately tries to fly and stalls.

Some of the exotically shaped luminaires are highly susceptible to alternate filling and spilling effects. If the luminaire is open faced or bucket shaped, the system can move forward and backward as the wind fills and spills from the luminaire. High amplitudes can result from this effect with resulting detrimental effect on the system.

It is extremely difficult to explain in general terms actions ·h are complex, and which essentially are unexplored.

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Similarly, it is extremely difficult to discuss a subject which does not lend itself to easy understanding. There are statements in the paper which are not in accord with observations and research made by individuals in the discusser's organization who are studying this problem. For example, there is disagreement that high bending stress occurs at locations of minimum displacement. In the second and third modes, the highest bending stress occurs where there is maximum bending. And, aside from where the pole is fixed to the ground (a point of minimum displacement) the maximum stress occurs where the displacement is greatest.

The statement that stress is proportional to acceleration is misleading, for this implies that stress is directly proportional to acceleration. Our investigations would indicate that there is no true relationship between stress and acceleration for a pole-luminaire system. We have noted that the relationship is affected by type vibration and by the bending which is represented by the amplitude of this acceleration.

The illustrations of vibration below resonance, at resonance, and above resonance do not agree with observations made by the discusser's research department. The illustrations may be indicative for one or two applications of an applied frequency, but there are many applied frequencies, which will start out as the author has illustrated in his Fig. a, then approach the point of zero bending and then vibrate as his Fig. c and then back again. Any vibration imposed above the resonance does the same thing, starting with Fig. c, then Fig. a, and back again, repeating. At resonance, the system first resembles the author's Fig. b, although the amplitude continues to increase until either damping is equal to an input vibratory energy or until the system is destroyed. The latter usually occurs.

H. A. VAN DUSEN, JR.:* I wish to thank the discussers for their thoughtful comments on this paper. They have added many valuable observations.

Mr. Friar lists a number of possible methods by which wind-induced vibration may be generated. I support his comments that the classical Kármán vortex phenomenon is only one of a number of processes by which wind energy causes vibration of lighting structures.

My statement that stress is proportional to acceleration applies to the luminaire and its mounting tenon while it is being tested at a frequency not higher than its fundamental resonance frequency. It does not apply to the entire pole-luminaire system but only to that portion of the system that can be assumed to have a single degree of freedom. That is: a single mass supported by a spring member. The stress at the base of a pole is not necessarily proportional to acceleration at the luminaire.

Mr. Friar, in discussing the illustrations of luminaire vibration in Fig. 5, mentions phenomena that can often be observed at higher than the fundamental resonance frequency; however, as stated in the text, the illustrations apply to fundamental frequency. At high frequencies there will be many higher mode resonance conditions.

Mr. Friar's reference to a point of zero bending is confusing, as normally this would only occur when either frequency or input displacement is zero. This might be a misinterpretation of the "above-resonance" condition illustrated in my figure 5c where output displacement is zero. If the input displacement is maintained at the same small value as had been used at resonance, and as bending will tend to decrease to the magnitude of input displacement, the bending angle may appear to be zero. In my figure 5c I have

*Author.

increased the input displacement as necessary to maintain the inertia force constant and at the same values as in illustrations a and b. Bending would consequently tend to be constant in all three examples.

Mr. Franck mentions a 33-Hz test frequency. This is an unusually high test frequency for cantilever mounted luminaires; however, it may be a suitable frequency for testing some of the components within the luminaire or for testing some wall mounted types of luminaires.

Mr. Franck asks if hurricane and earthquake loads should be accounted for in addition to the long time vibration loads. The maximum design wind load force should be considered as well as any other expected loads. These forces should be calculated and if they are greater than the forces used in the vibration test (see formula 3 in the paper), then the luminaire should be further tested for a single, or limited number of cycles, at an appropriately higher test load. The strength of the supporting structure should be separately evaluated for the application. The normal whipping and jerking type of motion is included in Fig. 2 in the paper and the tests account for such forces.

Mr. Wagner suggests a test whereby the luminaire is vibrated at a uniformly increasing intensity. It would be difficult to determine the fatigue endurance from such a test. On the other hand, this could be useful for evaluating the tendency for hardware to loosen and for evaluating other non-fatigue effects.

I have not investigated the case of luminaires that are directly mounted on the underside of bridge structures. I suspect that they are subjected to rather intense high-frequency vibration. The high-frequency components could be measured with a sound level instrument equipped with an accelerometer attachment. Rubber shock mountings should be effective for isolating the luminaire from the high frequency vibration. Mr. Franck had asked about the feasibility of using sound level instruments. This is an example of a possible application; however, the frequency range of most such instruments does not extend to the very low frequencies common to pole vibration.

I agree with Mr. Husby's statement, "The designer's judgment must be well founded." There are limits to what a vibration test can reveal. The validity and amount of information obtained is dependent on how well the test is conducted and how the results are interpreted.

Mr. Clark discusses one of the luminaire's internal components, the lamp. The rolled thread base does pose problems. Lamp loosening due to vibration is one.

The spring characteristics of the lampholder mounting will affect the resonant frequency and amplitude of the lamp and socket assembly. A relatively stiff lampholder mounting is generally preferable. The common usage of a gasket between the socket and reflector can provide some damping to reduce the amplification of lamp vibration.

The use of cushioned lampholders, especially if that cushion is a metal spring rather than an elastomer with high damping, should be done with caution. Such a device usually has a high amplification at resonance and a low resonant frequency, well within the normal pole vibration frequency range of .6 to 25 Hz. On the other hand, cushioned lampholders can isolate the lamp from the high frequencies likely to occur in some applications.

Mr. Weibel asks about methods for detecting fatigue damage. In a high-intensity vibration test if an invisible fatigue crack is just starting near the end of the test then just a few more vibration cycles will usually make the break very apparent. Visual inspection is generally adequate and the use of dye or magnetic methods for detecting such cracks is generally unnecessary.

Evaluation of the degree of failure is dependent on the designer's judgment. If damage has occurred by the end of the test the designer should satisfy himself that the test simulated the endurance limit of the material that was damaged. He should ask himself, "Is the luminaire still serviceable?" An analysis of the nature of a failure will often reveal easily accomplished methods for improving the design's resistance to vibration. It is in this latter area, when such testing is used to help the designer build better luminaires, that vibration testing has great value.

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