Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE DIVISION

ENERGY-EFFICIENT H.I.D. SOLID-STATE BALLAST:
Phase II Final Report

June 1983

APPLIED SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

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ENERGY-EFFICIENT H.I.D. SOLID-STATE BALLAST:

PHASE II FINAL REPORT**

Lighting Systems Research
Lawrence Berkeley Laboratory
University of California
Berkeley CA 97420

June 1983

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*Phase I Final Report, LBL-19858

**Jefferson Electric Division
Litton Industries, Inc.
Bellwood, Illinois 60104

Subcontract No. 4502310

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ABSTRACT

The following report presents the results of Phase II, Development of Solid State 150 watt High Pressure Sodium Ballasts. Basically, the objectives of the development program were accomplished, i.e., greater than 90% efficiency, greater than 90% power factor, regulation equivalent to ferro-magnetic ballasts, and energy savings sufficient to warrant the further development of the solid-state HPS ballast for commerical production and marketing.

1.0 INTRODUCTION

Phase I of Subcontract No. 4502310 was completed with mixed results, i.e., the efficiency of the solid state 150 watt HPS ballast averaged 84.8% for six prototype ballasts vs 80% for conventional core/coil ballasts.

Regulation varied from -11.9% to +0.7% for +/- 10% rated input voltage. Standard core/coil ballasts have +/- 11% regulation with +/- 5% rated input voltage.

As a result of the above, Phase II was initiated to include circuit design changes, i.e., reducing internal losses by improved component selection, redesigning portions of the circuit, and frequency selection for optimum efficiency and power factor.

2.0 OBJECTIVES

2.1 BALLAST DESIGN CHARACTERISTICS

2.1.1 ENERGY EFFICIENCY

To design a solid state 150 watt high pressure sodium lamp ballast system with an efficiency of 88%;i.e., optimum 170 input watts.

2.1.2 NOISE

No audible noise

2.1.3 ESTIMATED LIFE

Conventional ferro-magnetic ballasts are rated at 60,000 hours average life. Solid state devices generally are rated between 30,000 - 40,000 hours meantime between failures, MTBF. By encapsulating the solid state ballasts to protect it from environmental factors, the objective is to obtain 60,000 hours MTBF.

2.1.4 POWER FACTOR

90% or more

2.1.5 THIRD HARMONIC DISTORTION

No significant effect is anticipated based upon results experienced in the design and testing of solid state flourescent ballasts.

2.1.6 RADIO FREQUENCY INTERFERENCE

Ballast will be designed to meet the criteria of MIL-STD-461.

2.1.7 SAFETY

Will be designed for eventual Underwriters Laboratories recognition. Unit will be encapsulated and totally enclosed in a metal case and cover for fire hazard protection.

2.1.8 RELIABILITY

Reliability can be evaluated only on the total lighting system, i.e., ballast and lamp performance, and is affected by environmental conditions and component performance.

2.1.9.1 Lamp aging and failure probably will affect ballast reliability. Lamp arc voltage increases with age or when lamp is inoperative.

2.1.10 ENVIRONMENTAL CONDITIONS

Humidity and temperature are two primary detrimental factors to ballast life. To counteract these factors the ballast will be encapsulated and protected in a metal housing.

2.1.11 Component selection will be a major factor in affecting reliability.

2.1.12 BALLAST COST

The objective is to design a solid state ballast which will be competitive to ferro-magnetic ballast based upon life cycle costing.

2.2 CRITICAL DESIGN TARGETS

2.2.1 Properly start and sustain lamp in operation.

2.2.2 Special attention to following phenomenon:

a. Visual lamp flicker

b. High lamp Re-ignition voltage

c. Lamp Extinction

d. Unusual sensitivity to line voltage fluctuations

e. Minimum pulse voltage to start lamp

f. Maximum pulse voltage to prevent lamp destruction

3.0 ENGINEERING REPORT

3.1 TEST SET-UP

The equipment was arranged in accordance with that schematically represented in figure one. All of the equipment used was in recent calibration and the calibration was cross-checked with instruments of the same type in the case of the Westons, oscilloscope and Data Precision.

The comparison indicates the instruments agree within one percent for voltage and current readings and two percent for wattage readings.

The lamp was placed into a compartment one foot, by one foot, by one foot with one end open in order to shield the high intensity lamp from eyes. The inside of the compartment was flat black, this insured that a significant amount of energy was not reflected back through the arc, which could increase the tube arc temperature and voltage.

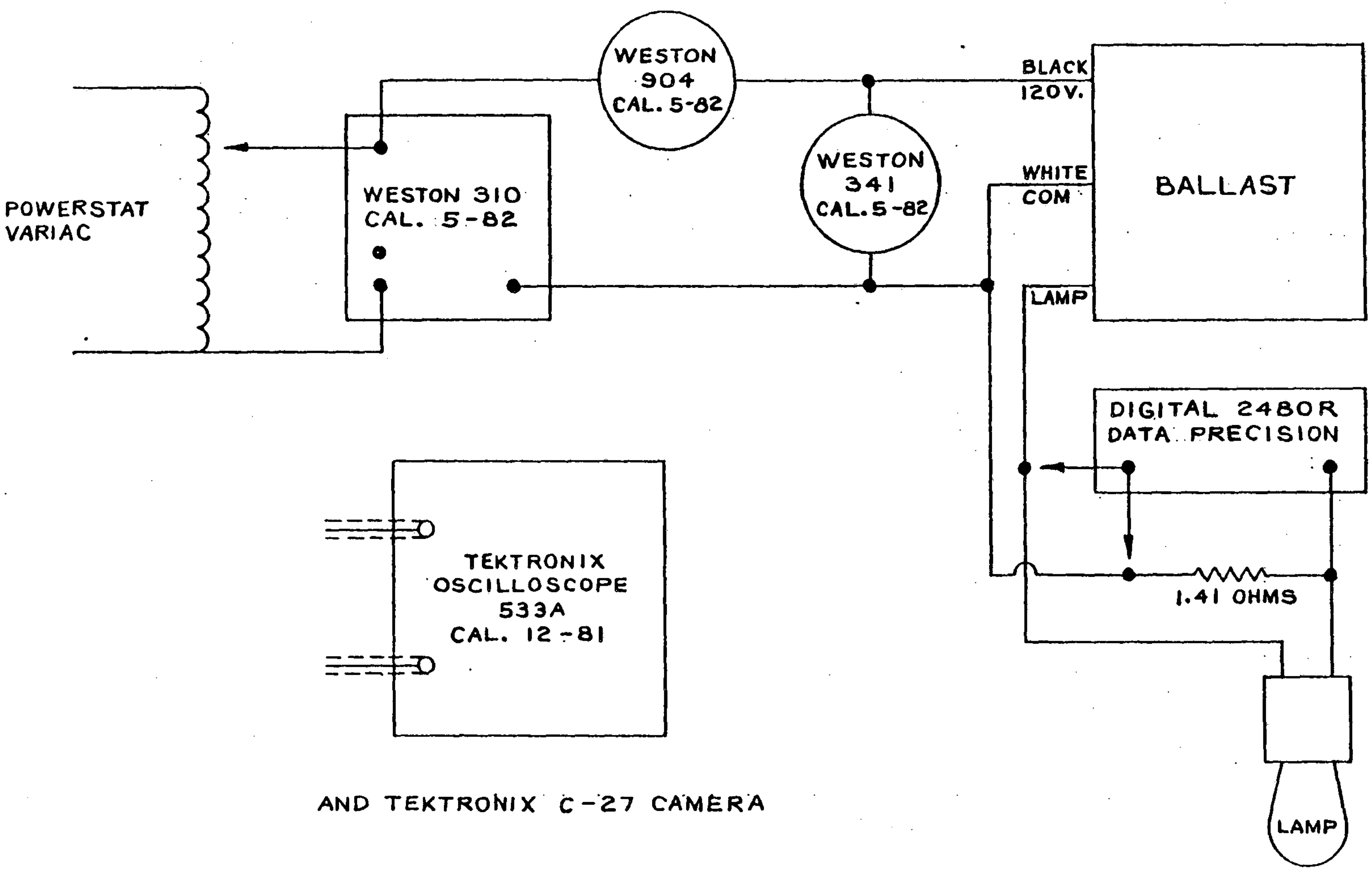


FIGURE I TEST DIAGRAM

When it was necessary to operate the High Pressure Sodium lamp at higher arc voltage, an aluminum foil was wrapped around the lamp.

All the tests were made with 150 watt S55 High Pressure Sodium General Electric Lamp, always mounted in a vertical position, base up.

The fifteen samples of electronic ballasts are completely epoxy encapsulated, moisture sealed and are suitable to operate in ambient temperature up to 50° Centigrade.

All the samples were placed on a test bench and operated in open air as free from draft as practicable, at an ambient temperature of 25° +/- 2° Centigrade.

3.2 TEST PROCEDURE

Each lamp used in the experiments was burned in 100 hours at 150 watts before testing began. The lamps were allowed to stabilize for 15 minutes before data was recorded.

To obtain the point where the ballasts started the lamps, the input voltage was slowly raised until arc current was achieved and that voltage recorded.

The starting currents were measured 15 seconds after lamp operated, this is a general ANSI requirement for all High Intensity Discharge lamps.

Lamp current was measured with a digital voltmeter across 1.41 ohms resistor, constructed for very high watts rating, not to generate any appreciable temperature rise. After 15 minutes of uninterrupted lamp operation, data was recorded where the voltage output was measured with a digital voltmeter across the lamp; second measurement was made across the above resistor.

Product of the two readings is calculated as lamp wattage for high frequency output. Conventional ferro-magnetic ballasts with 60hz output are measured with standard watt-meter.

Other input parameters were measured directly with Weston meters. The pictures which are representing input and output wave shapes were taken, using a Tektronic Oscilloscope type 533A and C-27 camera.

3.3 TEST RESULTS - PHASE II

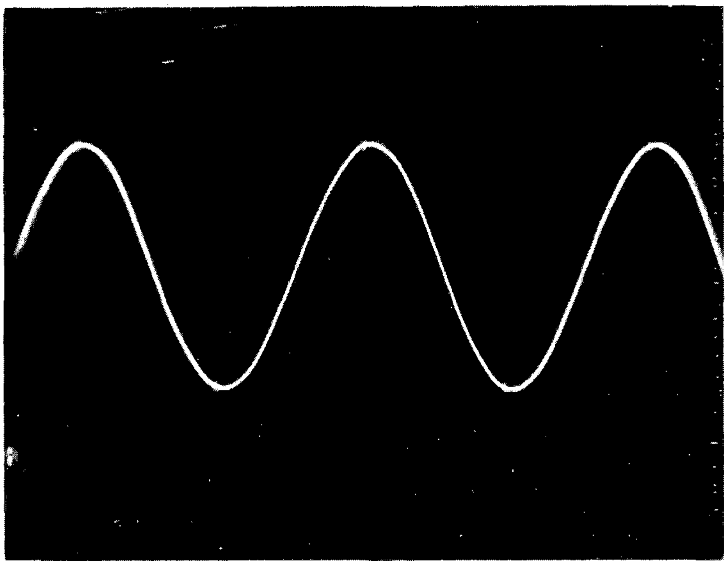
ELECTRONIC BALLAST

In the following pages we have included various wave shapes pictures at open circuit as well as at the lamp operation; which should give some additional information in the Lawrence Berkeley Laboratory(LBC) analysis.

Complete electrical data, including regulation, is given for six electronic ballasts, and since we are submitting fifteen of the sample ballasts, the test data is given for all units to help Lawrence Berkeley Laboratory with its verification of the electrical performance.

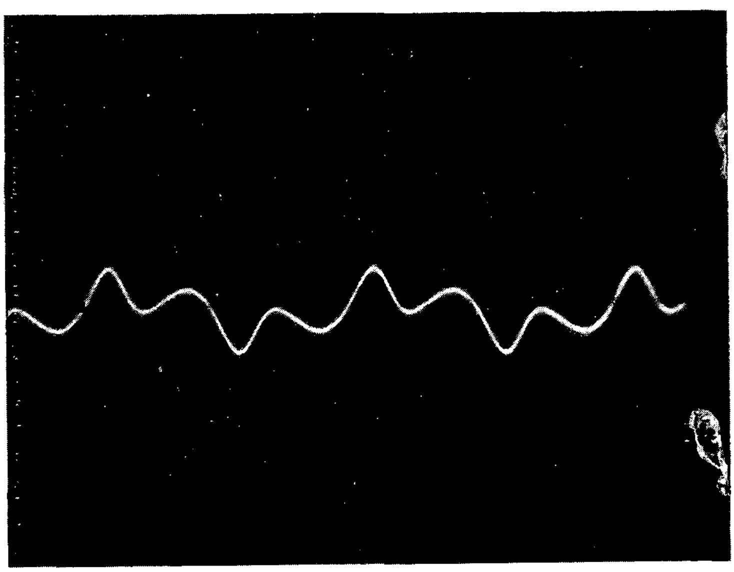
As a reference we are including Jefferson Electric Test Report for High-Reactance Autotransformer magnetic ballast designed to operate from any rated line voltage; also test report for Reactor Magnetic ballast designed to operate from 120 volts only.

TYPICAL INPUT WAVESHAPES OF HIGH FREQUENCY ELECTRONIC BALLAST AT OPEN CIRCUIT



Input voltage at
120V 60HZ line
5ms/div.
5V/div.

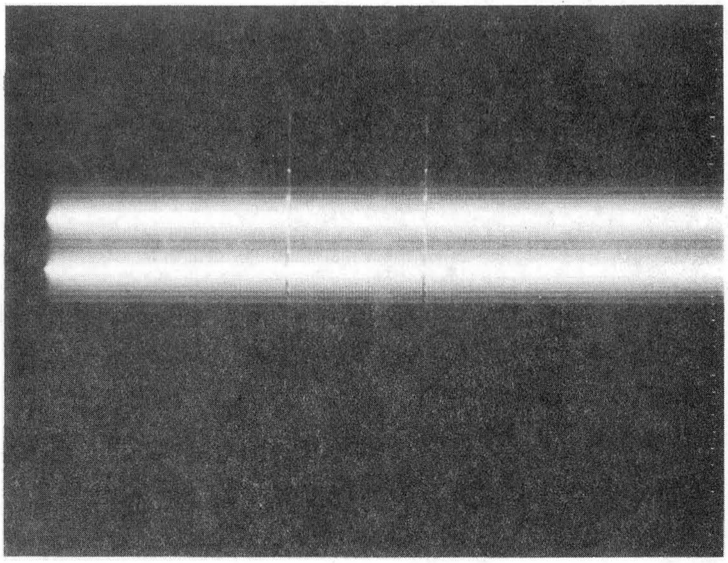
FIGURE II



Input current at
120V 60HZ line
5ms/div.
0.05V/div. across
0.1 ohm Resistor

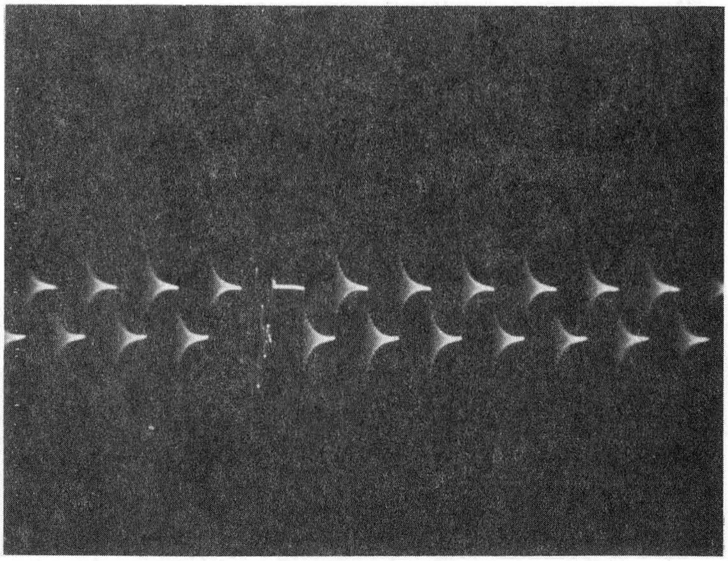
FIGURE III

TYPICAL OUTPUT WAVESHAPES OF HIGH FREQUENCY ELECTRONIC BALLAST AT OPEN CIRCUIT.



Output voltage at
120V 60HZ line
500V/div.
1ms/div.

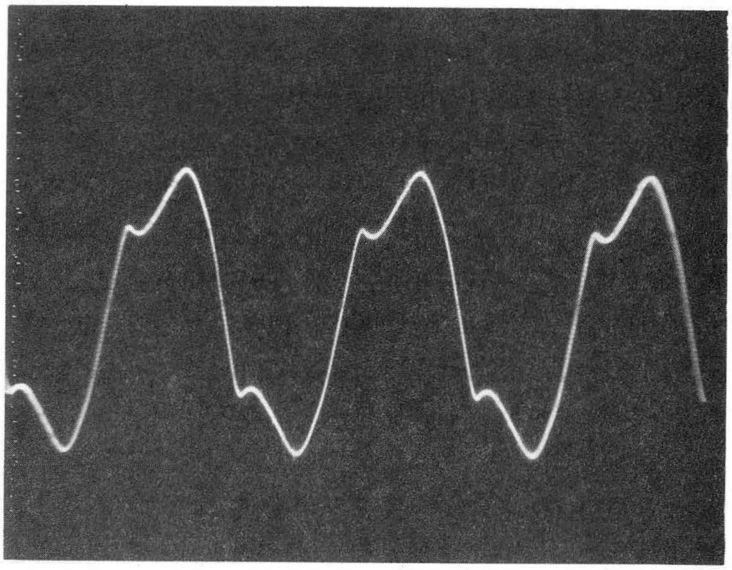
FIGURE IV



Output voltage for
120V 60HZ line input
500V/div.
1ms/div.
Expanded 20x

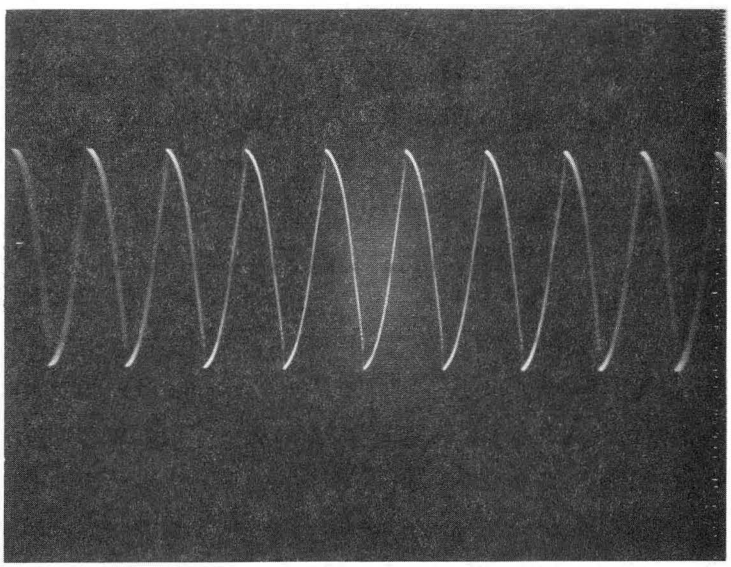
FIGURE V

TYPICAL WAVESHAPES OF HIGH FREQUENCY ELECTRONIC BALLAST OPERATING 150 WATT S55 H.P.S. G.E. LAMP



Input current at
120V 60HZ line
5ms/div.
0.05V/div. across
0.1 ohm Resistor

FIGURE VI



Output voltage at
120V 60HZ line
50V/div.
5ms/div.
Expended 100x

FIGURE VII

ELECTRICAL DATA WITH ± 10% LINE VOLTAGE VARIATION

JEFFERSON ELECTRONIC BALLASTS	INPUT				Starting After 15 Sec		OUTPUT			PERFORMANCE			OPEN CKT.	
	Line Volts	Line Amps	Line Watt	Power Factor %	Line Amps	Lamp Amps	Lamp Volts	Lamp Amps	Lamp Watts	Regulation %	Watts Loss	Efficiency %	Input Amps	Output Volts RMS
OPERATING 150W (S55) H.P.S. G.E.LAMP SAMPLE #1	108	1.57	161	95.0			51.4	2.932	150.7	-1.44	10.3	93.6	.32	136
	120	1.42	164	96.2	.96	4.28	51.8	2.952	152.9		11.1	93.2	.42	148
	132	1.33	167	95.1			52.3	2.961	154.9	+1.31	12.1	92.8	.47	157
OPERATING 150W (S55) H.P.S. G.E.LAMP SAMPLE #2	108	1.53	160	96.8			50.5	2.965	149.7	-1.64	10.3	93.6	.28	139
	120	1.41	163	96.3	.90	4.12	51.0	2.985	152.2		10.8	93.4	.36	149
	132	1.33	166	94.6			51.4	3.004	154.4	+1.45	11.6	93.0	.43	154

LAMP STARTING LINE VOLTAGE #1 - 93V; #2 - 92 Volts.

LAMP EXTINGUISHING LINE VOLTAGE # 1 - 72V; #2 - 70 Volts

TABLE I

Novem[illegible] 1982

Jefferson ELECTRIC COMPANY

ELECTRONIC BALLAST #1 OPERATING 150W (S55) H.P.S. LAMP

Regulation: Lamp Watts output as is effected during lamp life by the arc voltage changes.

Data with ±10% line voltage variations.

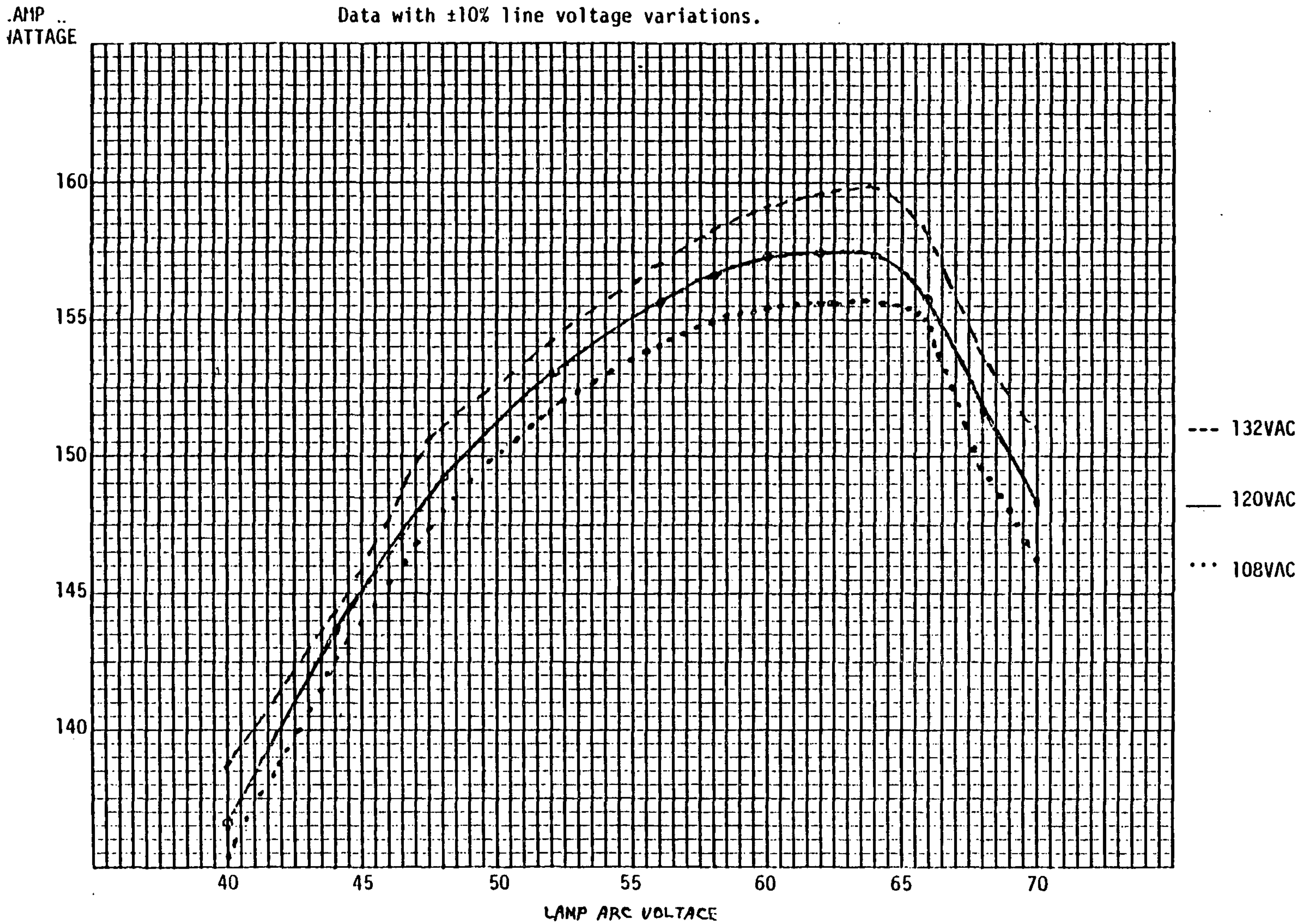


FIGURE VIII

ELECTRICAL DATA WITH ± 10% LINE VOLTAGE VARIATION

JEFFERSON ELECTRONIC BALLASTS	INPUT				Starting After 15 Sec		OUTPUT			PERFORMANCE			OPEN CKT.	
	Line Volts	Line Amps	Line Watt	Power Factor %	Line Amps	Lamp Amps	Lamp Volts	Lamp Amps	Lamp Watts	Regulation %	Watts Loss	Efficiency %	Input Amps	Output Volts RMS
OPERATING 150W (S55) H.P.S. G.E.LAMP SAMPLE #3	108	1.54	160	96.2			50.2	3.003	150.8	-1.50	9.2	94.3	.25	148
	120	1.41	163	96.3	.91	4.12	50.5	3.032	153.1		9.9	93.9	.31	162
	132	1.33	166	94.6			51.0	3.042	155.1	+1.31	10.9	93.4	.37	175
OPERATING 150W (S55) H.P.S. G.E.LAMP SAMPLE #4	108	1.55	160	95.6			51.4	2.951	151.7	-1.68	8.3	94.8	.26	130
	120	1.42	164	96.2	.92	4.14	51.8	2.978	154.3		9.7	94.1	.31	142
	132	1.32	167	95.8			52.2	2.992	156.2	+1.23	10.8	93.5	.36	150

LAMP STARTING LINE VOLTAGE #3 - 86V; #4 - 90 Volts

LAMP EXTINGUISHING LINE VOLTAGE #3 - 75V; #4 - 76 Volts

TABLE II

ELECTRICAL DATA WITH ± 10% LINE VOLTAGE VARIATION

JEFFERSON ELECTRONIC BALLASTS	INPUT				Starting After 15 Sec		OUTPUT			PERFORMANCE			OPEN CKT.	
	Line Volts	Line Amps	Line Watt	Power Factor %	Line Amps	Lamp Amps	Lamp Volts	Lamp Amps	Lamp Watts	Regulation %	Watts Loss	Efficiency %	Input Amps	Output Volts RMS
OPERATING 150V (S55) H.P.S. G.E.LAMP SAMPLE #5	108	1.53	158	95.6			50.7	2.969	150.5	-1.38	7.5	95.2	.23	168
	120	1.40	161	95.8	.92	4.12	51.0	2.993	152.6		8.4	94.8	.28	175
	132	1.33	165	94.0			51.6	2.989	154.2	+1.05	10.8	93.5	.33	198
OPERATING 150V (S55) H.P.S. G.E.LAMP SAMPLE #6	108	1.53	158	95.6			50.7	2.962	150.2	-1.70	7.8	95.1	.24	172
	120	1.40	162	96.4	.90	4.10	51.0	2.996	152.8		9.2	94.3	.30	176
	132	1.32	166	96.0			51.6	2.998	154.7	+1.24	11.3	93.2	.35	188

LAMP STARTING LINE VOLTAGE #5 - 93V; #6 - 92 Volts

LAMP EXTINGUISHING LINE VOLTAGE #5 - 71V; #6 - 70 Volts

TABLE III

ELECTRICAL DATA WHEN OPERATING 150W (S55) H.P.S. G.E. LAMP

JEFFERSON ELECTRONIC BALLASTS	INPUT				Starting After 15 Sec		OUTPUT			PERFORMANCE			OPEN CKT.	
	Line Volts	Line Amps	Line Watt	Power Factor %	Line Amps	Lamp Amps	Lamp Volts	Lamp Amps	Lamp Watts	Regu- lation %	Watts Loss	Effi- ciency %	Input Amps	Output Volts RMS
SAMPLE #7	120	1.40	161	95.8	.93	4.24	50.6	2.992	151.1		9.9	93.8	.38	149
SAMPLE #8	120	1.45	164	94.3	.95	4.15	51.5	2.976	153.3		10.7	93.5	.29	162
SAMPLE #9	120	1.40	162	96.4	.90	4.12	50.8	2.992	152		10.0	93.8	.30	158
SAMPLE #10	120	1.41	160	94.6	.96	4.16	50.2	2.988	150		10.0	93.7	.28	165
SAMPLE #11	120	1.40	160	95.2	.92	4.10	50.9	2.967	151		9.0	94.4	.30	170
SAMPLE #12	120	1.40	162	96.4	.93	4.18	51.1	2.996	153		9.0	94.4	.28	167

TABLE IV

ELECTRICAL DATA WHEN OPERATING 150W (S55) H.P.S. G.E. LAMP

JEFFERSON ELECTRONIC BALLASTS	INPUT				Starting After 15 Sec		OUTPUT			PERFORMANCE			OPEN CKT.	
	Line Volts	Line Amps	Line Watt	Power Factor %	Line Amps	Lamp Amps	Lamp Volts	Lamp Amps	Lamp Watts	Regulation %	Watts Loss	Efficiency %	Input Amps	Output Volts RMS
SAMPLE #13	120	1.42	161	94.5	.92	4.17	51.0	2.970	151.5		9.5	94.1	.30	190
SAMPLE #14	120	1.41	160	94.6	.93	4.14	50.6	2.971	150.3		9.7	93.9	.29	160
SAMPLE #15	120	1.40	160	95.2	.90	4.12	50.4	2.991	150.7		9.3	94.2	.32	172

TABLE V

JEFFERSON ELECTRIC
Litton

840 S. 25th Avenue, Bellwood, Illinois 60104 312 626-7700

ENGINEERING TEST REPORT

PURPOSE OF TEST:

To measure thermal and electrical performance characteristics of the Jefferson 150 Watt High Pressure Sodium (Low Arc Voltage Lamp) High-Reactance ballast operating on test bench in open air.

BALLASTS:

Jefferson Catalog No.:	842-1860-047	120/208/240/277 Line Voltage
	842-1861-047	120/240 Line Voltage
	842-1862-047	120 Line Voltage
	842-1863-047	240 -"- -"-
	842-1864-047	208 -"- -"-
	842-1865-047	208/277 Line Voltage
	842-1866-047	277 Line Voltage
	842-1868-047	480 Line Voltage

All ballasts are employing the same primary and secondary coils, the same lamination and stack except 480V design which has different coils and stack, but the same lamination.

Each Hi-Rx ballast is utilizing Class "H" (180°C) "H565" Jefferson insulating system. The ballasts are using starting circuit Catalog No. 232-088 and for H.P.F. correction 14 mfd at 280 V.A.C. Capacitor for all ballasts except 480V which is utilizing 4 mfd at 480 V.A.C.

GENERAL TEST CONDITIONS:

Each Hi-Rx ballast core & coil selected at random was placed on test bench and operated in open air as free of drafts as practicable at an ambient temperature of 25°C ± 2°C. A standard 150 Watt H.P.S. (S55) lamp was chosen at close to nominal arc voltage.

Complete electrical performance data was recorded after lamp and ballast had operated for 15 minutes at rated line voltage and the power factor corrected.

Coil temperature was determined by change of resistance method after lamp and ballast had operated over night with regulated rated line voltage. Final reading was taken after thermal stability of core and coil was indicated by thermocouple method.

Basic electrical performance and individual component temperature and ambient air were measured and recorded immediately prior to shutting ballast down for change of resistance measurements.

TEST RESULTS:

Complete electrical and thermal performance data for the ballast operating the 150 HPS (S55) lamp in a vertical position at nominal line, is shown in attached table.

CONCLUSION AND COMMENTS:

Results are typical only when all test conditions such as ballast position, environment, capacitor value, lamp and component position, lamp arc voltage, etc. are reproduced. Test data does show typical performance variations that exist on units of various voltage design. Slight additional variation should be expected from unit to unit on any production run.

Marion Rosiak
H.I.D. Proj. Eng. Manager

MR/bp

Report No. 06-TT-842-186*-047
Page 1
May 1980
480V Design Added
October 1980

ELECTRICAL DATA

Catalog No.	842-1860				
Catalog No.	842-1861		842-1865		
Catalog No.	842-1862	842-1863	842-1864	842-1866	842-18
Line Voltage	120	240	208	277	480
Line Current	1.71	0.85	0.90	0.74	0.43
Line Wattage	185	186	173	185	186
Power Factor	90%	91%	92%	90%	90%
Watt Loss	35	36	33	35	36
Lamp Voltage	53	53	50	53	55
Lamp Current	3.5	3.5	3.4	3.5	3.3
Lamp Wattage	150	150	140	150	150
Capacitor MFD/Voltage	14/276	14/276	14/270	14/277	4/480
Regulation*	11%	11%	10%	11%	11%
Max. Leakage Current	0.12	0.18	0.16	0.20	0.34
O.C.V. RMS	125	125	121	125	128
Line O.C. (With Cap.)	2.85	1.43	1.52	1.20	0.6
Line Sec Short Circuit	1.70	0.90	0.96	0.80	0.5
Start/Exting. Line Volt	71/72%	69/71%	73/74%	70/72%	73/70%

THERMAL DATA

Line Voltage	120	240	208	277	480
Line Current	1.74	0.86	0.90	0.75	0.44
Line Wattage	190	190	175	190	190
Power Factor	91%	92%	93%	91%	90%
Watt Loss	40	40	35	40	37
Lamp Voltage	52	52	49	52	58
Lamp Current	3.52	3.52	3.42	3.52	3.3
Lamp Wattage	150	150	140	150	153
Temperatures:					
Pri Rise (Tap-Com)	70°C	73°C	69°C	74°C	71°C
Pri Rise (Tap-Line)	76°C	85°C	78°C	82°C	79°C
Pri Rise (Line-Cap)	82°C	72°C	73°C	-"-	-"-
Sec Rise (Tap-Lamp)	72°C	74°C	69°C	72°C	71°C
Core Surface Temp	91°C	92°C	89°C	91°C	88°C
Room Ambient Temp.	25°C	25°C	25°C	25°C	25°C

B3 *Regulation given as mean average with a ± 5% line voltage variation.

JANUARY 1981

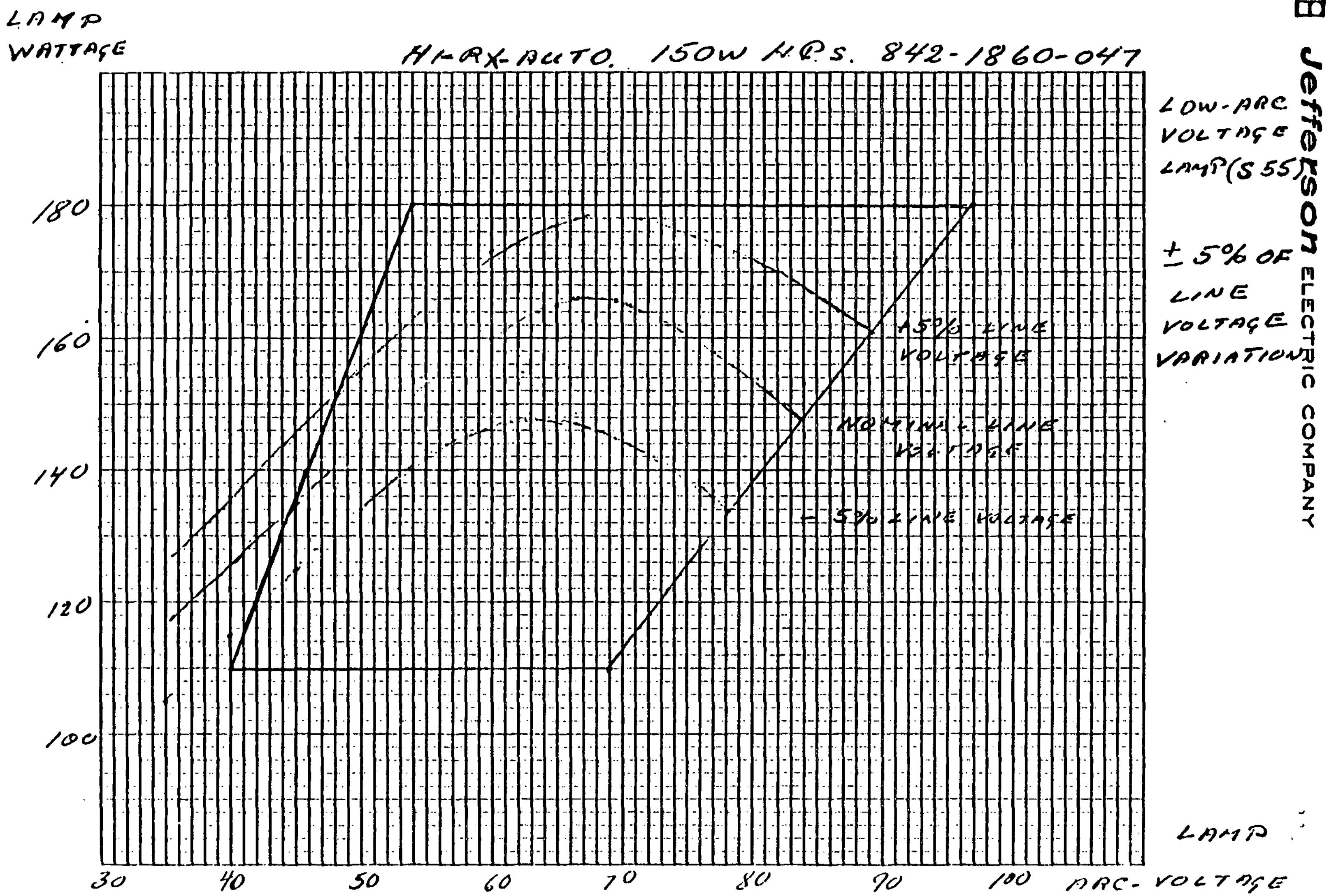


FIGURE IX

JEFFERSON ELECTRIC
Litton

840 S. 25th Avenue, Bellwood, Illinois 60104 312 626-7700

ENGINEERING TEST REPORT

PURPOSE OF TEST:

To measure thermal and electric performance characteristics of the Jefferson 150 Watt H.P.S. (S55) Reactor Ballast operating on test bench in open air.

BALLAST:

Jefferson Catalog No. 840-1862, 120 volts reactor is utilizing Class 180°C (H565) insulating system. Design as core and coil type to operate one 150 Watt H.P.S. (S55) low-arc voltage lamp, must be used with starter catalog No. 232-088 and for H.P.F. correction with 55 mfd. 120 VAC capacitor.

GENERAL TEST CONDITIONS:

Ballast Core & Coil, selected at random, was placed on test bench and operated in open air as free from draft as practicable at an ambient temperature of 25°C ± 2°C.

For high power factor correction a capacitance decade box was used adjusted to 55 mfd and the unit operated at rated line voltage, a standard 150W H.P.S. (S55) reference lamp in vertical position.

Coil temperature was determined by change-of-resistance method after lamp and ballast had operated overnight with regulated rated line voltage. Final readings were taken after thermal stability of the core & coil was indicated by thermocouple method.

TEST RESULTS:

See Page 2.

Litton

TEST RESULTS:

POWER FACTOR	NORMAL	*CORRECTED
Line Voltage	120	120
Line Current	3.4	1.56
Line Wattage	170	170
%Power Factor	41%	91%
Capacitor	-	55 mfd @120VAC
Lamp Voltage	53	53
Lamp Current	3.4	3.4
Lamp Wattage	150	150
Watt Loss	20	20
Starting Line Current	4.7	2.2
Exciting Current	0	2.5
Core Temperature	80°C	80°C
Coil Temp. Rise	70°C	70°C
Room Ambient	25°C	25°C

*Power Factor corrected with 55 MFD Capacitor across 120 Volt Line.

CONCLUSION AND COMMENTS:

Power Factor above 90 percent is often desirable in lighting circuits to provide economical wiring and to meet local utility requirements. The basic reactor ballast is operating the lamp by inductive reactance, resulting in Normal Power Factor.

Test results are typical only when all test conditions such as core & coil position and environment, lamp arc voltage, etc..... are reproduced. Slight performance variations are to be expected from production ballasts and from ballast to ballast on any production run.

Marion Rostak
H.I.D. Eng. Proj. Mngr.

MR/bp

3.4 EFFICIENCY

We had originally anticipated approximately a ten percent reduction in the input power to produce a ten percent improvement in light output.

This approximation was based on two conclusions. First, we felt that a high frequency ballast could be made 90 percent efficient, this represented an increase in efficiency of just over ten percent when compared with standard 60 Hz units. Second, we anticipated about a ten percent improvement in lamp efficiency due to operation at higher frequency. We had good reason to believe this. We had seen high frequency power improve the efficiency of other types of lamps and an Illuminating Engineering Society Article written in 1969 by a Mr. John Campbell indicated that there was approximately a ten percent advantage in efficiency when operating a 400 watt High Pressure Sodium lamp at 20 KHz as compared to 60 Hz.

The construction of the 400 watt High Pressure Sodium lamp is somewhat different; it is longer, it has a larger diameter, but as we understand from lamp manufacturers, it is a 150 watt H.P.S. lamp made to a larger scale. The elements, as well as the methods of construction, are very much the same. Therefore, based on construction, we do not see a reason for the differences in efficiency versus frequency between Mr. Campbell's results and our own.

The actual efficiency increase obtained was between five to ten percent. All of this was due to increased efficiency of the ballast.

The efficiency of these ballasts was typically 85 percent. This was five percent below the target number of 90 percent. We feel the efficiency of these units can be improved from five to ten percent in future generations.

In Phase II of our Electronic or Energy Efficient H.I.D. Solid-State Ballast we were able to increase the efficiency by 9 percent when comparing to Phase I of initial design.

Taking into consideration all 15 samples made for this evaluation, the average efficiency for all the ballasts is 93.97 percent, which one can say is very efficient energy saving system.

3.5 HIGH POWER FACTOR

Ninety-five percent Power Factor is a noticeable improvement in the lamp ballasting system.

During the life time of all H.P.S. Lamps, operating from magnetic ballasts, it is almost impossible to sustain 90 percent Power Factor when H.P.S. lamps are getting older or are operating from above rated line voltages.

The same problem is overcome when we are using Electronic Ballast, designed to consider this particular requirement.

3.6 REGULATION

Regulation for the High Pressure Sodium lamps does not necessarily mean perfectly constant wattage. If we applied an exactly regulated 150 watt to H.P.S. S55 lamp, the light output would be at its rated value at first few thousand hours of operation but would appreciably degrade when arc voltage is between fifty-five and seventy volts, and more so when the lamp is reaching its end of life; eighty-ninety volts.

Therefore one of the solutions is to set a nominal arc voltage lamp at higher than nominal wattage. In addition permit the wattage to increase as the arc voltage goes up to compensate for the drop in actual light output. Our data indicates that at around 70 volts the curve of lamp watts vs lamp volts should be reversed to the down direction as a means of extending lamp life.

Regulation of light output, as one looks at available power supply which in most cases vary +/- 10 percent from rated line voltage is providing large, visible improvement in wattage variation (light output) which is less than two percent; the same variations apply to power consumed by the Electronic Ballast Lamp system.

In comparison the magnetic non regulated ballasts at rated line voltage +/- 5 percent have its output wattage (light output) vary approximately +/- 10 percent.

3.7 LAMP STARTING AND EXTINGUISHING

The starting of a High Pressure Sodium lamp consists of two steps. First, the ionization of the gas must be initiated by high voltage. Second, a sufficient amount of arc current must be provided in order to bring the lamp's light output up to rated value in as short a time as possible, yet not go outside the lamp specifications.

Based on the six samples tested, starting of the General Electric H.P.S. S55 lamp takes place at 75 percent (average) of rated line voltage and brings the lamp up to 90 percent of its related light output approximately in two to three minutes.

In actual application the most important factor is at what percent of line voltage the H.P.S. lamp extinguishes itself; in other words, what effect will a dip in the line voltage have. Our data indicates that the Electronic Ballast will sustain the lamp in operation at 60 percent of rated line voltage.

3.8 ACOUSTIC RESONANCE

Acoustic resonance for high pressure sodium lamps exists between 1.5KHZ and 4.0KHZ, and 26KHZ and 32KHZ. The design frequency range is between 15KHZ and 24KHZ. Percent lumens and lumens per watt are greatest over 15KHZ. (See IES Transaction Initial Characteristics of High Intensity Discharge Lamps on High Frequency power, John H. Campbell, Dec. 1969)

4.0 CONCLUSION

4.1 EFFICIENCY

The average efficiency of the six prototype ballasts when operated with G.E. lamps is 94%. The average efficiency of conventional high reactance autotransformer core/coil ballasts is 80%.

4.2 REGULATION

With plus or minus 10% rated input voltage the ballast output power varied from -11.9% to +0.7%. Standard core/coil ballasts have a +/- 11% regulation with a +/- 5% rated input voltage. See Jefferson Electric Engineering Test Report No. 06-TT-842-186*-047.

4.3 POWER FACTOR

The power factor averaged 95% for the six solid-state ballasts. Average power factor for ferro-magnetic ballasts is 90%.

4.4 ANNUAL COST SAVINGS
LIFE CYCLE COSTS

A. Annual cost savings
To determine the annual cost savings, average efficiencies must be used.

Solid state ballast -
120V Avg. 94%

$\frac{150W}{.94}$ = 159 input watts

Core and coil ballast
120V 79.8 - 80.0% Avg. 80%

$\frac{150W}{.8}$ = 188 input watts

4000 Hrs./Yr. X $.06/KWH X (.188 - .159)= $6.96/Yr.

B. Life cycle costs
Initial costs + replacements costs + operating costs

a. Core/coil ballasts

Expected life - 40000 Hrs.

Initial cost -	$ 30.00
Operating cost -	
4000Hr/Yr X $.06/KWH X .188KW X 10Yrs =	$451.20
LCC =	$481.20

b. Solid state ballast

Expected life - 30000 Hrs

Initial costs Approx. -	$ 40.00
Replacement cost - $70.00 X 1/3 unit	$ 23.00
Replacement labor	
$21.00/Hr X 1 Hr X 1/3 unit	$ 7.00
Operating cost	
4000Hrs/Yr X $.06/KWH X .159KW X 10Yrs=	$381.60
LCC =	$451.60

4.5 PROGNOSIS

Based upon an energy savings calculation of 15%, 159 watts vs 188 watts, the further development of solid state H.P.S. ballasts is practical. At this time only 15 ballasts have been submitted to LBL for corroboration of test results.

A field demonstration program is the next step, wherein several hundred units are installed in various manufacturers fixtures and at installations that would encompass different environmental conditions.

Upon satisfactory field results, plans for commercial production and marketing would be finalized.

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