CAR LIGHTING BY THE INDIRECT SYSTEM

BY

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AND
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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

HERBERT GLENN DERRY AND WILLIS GAYLORD GORDON

ENTITLED: CAR LIGHTING BY THE INDIRECT SYSTEM

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

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Instructor in Charge

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HEAD OF DEPARTMENT OF ELECTRICAL ENGINEERING
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CAR LIGHTING BY THE INDIRECT SYSTEM

I. INTRODUCTION.

The object of this thesis is to show that the indirect system of lighting can be applied to cars, and to prove its successful operation and superiority as a car lighting system, by actual tests.

To Professor Morgan Brooks, whose enthusiasm and valuable suggestions have aided materially in the production of the thesis, and to the National X-Ray Reflector Co., who furnished the fixtures and much valuable information, the writers wish to express their warmest appreciation.
CAR LIGHTING BY THE INDIRECT SYSTEM.

The proper lighting of railway cars is a matter which has received but little of the attention which its importance deserves. The development of lighting systems from the old time methods of tallow candles and kerosene lamps has been slow and with very little attention to the effectiveness of the illumination.

The introduction of Pintsch gas lighting was a great improvement and in many ways it is very satisfactory. Very little attention is necessary for its upkeep, and the first cost is comparatively small, but it can hardly be considered as a successful and proper method of lighting for first class trains.

That electricity is becoming the popular lighting medium is shown by the following:

About 25% of the 50,000 passenger coaches in use at the present time are lighted by electricity. Of these, about

55% have the axle generator system;
30% have the head end system;
2% have turbine sets;
13% have the straight storage system.

The present method of lighting cars by electricity is in many ways superior to gas lighting, but it also has its disadvantages. Steam railway cars up to the present, have been equipped almost invariably without reference to delivering the most useful illumination for the money expended, and this too,
in spite of the fact that frequently the source of current supply is a storage battery of limited capacity. If more attention were paid to the efficiency after the current was delivered to the lamps, it would materially help out in the amount of useful service that could be obtained from a given size of storage battery. In the case of electric cars where the installation of an expensive car lighting equipment is not necessary, it is not so much the question of efficiency as of general effect, and good illumination without a blinding glare.

A car, to be well lighted should have enough light for comfortable reading (2 to 3 foot candles) in all parts of the car, and should have the source of light well out of the line of vision of a person sitting or reclining in the car. No violent variation in light, or great difference can be allowed. Probably the best results obtained so far have been in the use of individual lights at the side of the car, above the seats, and two or three clusters suspended some distance from the ceiling for the general illumination. This, however, does not give the desired effect, as the individual lights are in a direct line of vision of a person entering or sitting in the car.

The indirect system has overcome similar difficulties encountered in interior lighting, and there should be no reason why it cannot be used to solve the car lighting problem. Up to the present it has not been used, and it is only recently that anything in this line has been attempted. A short time ago a private car on the Frisco lines was lighted by a semi-indirect system. The results obtained were very satisfactory.
The construction of a railway car does not make the most ideal conditions for indirect lighting but the later types of cars are much more adapted to this system than the older ones. The interiors are being made lighter in color than heretofore, and the ceilings are of a more uniform curvature.

From the standpoint of design, the effect of indirect illumination may be seen from the following drawings, which show the distribution of light. Plate No. 1 shows the cross section of an Illinois Traction System car #517 fitted with type E100, distributing reflectors, made by the National X-Ray Reflector Co. of Chicago. The fixture is placed at a height such that the outside reflected rays strike the sides of the car 30 inches from the floor. This, of course, does not mean that there will be no light reflected to the sides above the 30 inch line, but that the outside brightest rays will strike at a height not greater than 30 inches.

Plate 2 shows the longitudinal section through the main part of the car. In both cases, the light distribution is more uniform than could be obtained by any direct system. The vestibules and toilet rooms, however, may be lighted by the direct system, since it is not always advisable to use indirect lighting in small places.

The specifications for the illumination of the main part of the car are as follows:

3 E451 1/2 fixtures with E100 reflectors.
Distance from ceiling—-21"
Distance center to center—-12'-9"
Distance center of end fixture to end of car —-6'-4 1/2"
Toilet Room.

1- Holophane hemisphere with 1- 60 watt lamp.

Front Vestibule.

1- Holophane hemisphere with 1- 60 watt lamp.

Ceilings to be finished in cream white.

With the above the illumination obtained will be about:

<table>
<thead>
<tr>
<th>Foot Candles</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.7</td>
<td>20%</td>
</tr>
<tr>
<td>2.9</td>
<td>28%</td>
</tr>
<tr>
<td>3.1</td>
<td>30%</td>
</tr>
</tbody>
</table>

The illumination of the vestibules and toilet room with the above fixtures would be from .6 to .8 foot candles.

Specifications for the lighting of the University of Illinois Test Car have been calculated as follows:

3- E1004 2 arm fixtures fitted with type E100 distribution reflectors using 60 watt lamps.

Fixtures to be hung 19 1/2" from the ceiling.

Plates 3 and 4 show the distribution of light for both sections of the car.

Calculations:

Dimensions. Small compartment. Large Compartment.

Floor 7' 6 1/2" x 11' 7' 6 1/2" x 82' 4"

Floor area 83 sq. ft. 169 sq. ft.

Effective lumens required for the area at 2.5 foot candles. 208 423

Lamps required 2- 60 watts 4- 60 watts.
Small compartment. Large compartment.

Lumens on plane
30" from floor.

@36% eff. 242 484
foot candles. 2.9 2.9

@ 28% eff. 260 520
foot candles. 3.1 3.1

The values of efficiency and effective lumens are those used by the National X-Ray Reflector Co.

It was thought advisable to conduct the tests using a ceiling similar to that of a modern car, as well as with the regular monitor ceiling. For this purpose the test car was fitted with a false ceiling bridging over the lower curvature below the ventilating windows. The illumination was measured with a Sharpe-Millar direct reading photometer on a plane 30 inches from the floor with 40, 60 and 100 watt lamps in the two fixtures in the large compartment. The false ceiling was made of cream colored rough finished card board and the fixtures hung 17 inches below it. The fixtures were wired for series operation and the power taken from the 500 volt trolley circuit, a rheostat being used in the circuit to maintain a constant voltage on the lamps. One fourth of the total drop was taken as the voltage per lamp. In order to determine the effect of variation of voltage, the intensity was also measured with the 60 watt lamps on three different voltages.

The results given below show the illumination on a plane 30 inches above the floor.
False ceiling using 4- 60 watt 112 volt plain tungsten lamps.

<table>
<thead>
<tr>
<th>Position</th>
<th>Foot candles at 112 volts.</th>
<th>Foot candles at 107.5 volts.</th>
<th>Foot candles at 100 volts.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.90</td>
<td>3.40</td>
<td>2.65</td>
</tr>
<tr>
<td>2</td>
<td>3.50</td>
<td>2.60</td>
<td>2.20</td>
</tr>
<tr>
<td>3</td>
<td>2.60</td>
<td>2.10</td>
<td>1.65</td>
</tr>
<tr>
<td>4</td>
<td>3.25</td>
<td>2.80</td>
<td>2.05</td>
</tr>
<tr>
<td>5</td>
<td>4.40</td>
<td>3.80</td>
<td>2.60</td>
</tr>
<tr>
<td>6</td>
<td>3.15</td>
<td>2.40</td>
<td>1.88</td>
</tr>
<tr>
<td>7</td>
<td>3.38</td>
<td>2.45</td>
<td>1.86</td>
</tr>
<tr>
<td>8</td>
<td>4.40</td>
<td>3.60</td>
<td>2.80</td>
</tr>
<tr>
<td>9</td>
<td>3.65</td>
<td>3.25</td>
<td>2.37</td>
</tr>
<tr>
<td>10</td>
<td>1.95</td>
<td>1.55</td>
<td>1.28</td>
</tr>
<tr>
<td>11</td>
<td>2.60</td>
<td>2.30</td>
<td>1.80</td>
</tr>
<tr>
<td>12</td>
<td>3.00</td>
<td>2.40</td>
<td>1.82</td>
</tr>
<tr>
<td>13</td>
<td>2.10</td>
<td>1.83</td>
<td>1.38</td>
</tr>
<tr>
<td>Average</td>
<td>3.21</td>
<td>2.65</td>
<td>2.02</td>
</tr>
</tbody>
</table>
False ceiling using 4 - 40 watt 110 volt tungstens; and 4 - 100 watt 110 volt tungstens. Voltage held constant at 110 v.

<table>
<thead>
<tr>
<th>Position</th>
<th>Foot candles with 40 watt tungstens</th>
<th>Foot candles with 100 watt tungstens</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.32</td>
<td>4.55</td>
</tr>
<tr>
<td>2</td>
<td>1.80</td>
<td>5.80</td>
</tr>
<tr>
<td>3</td>
<td>1.52</td>
<td>4.60</td>
</tr>
<tr>
<td>4</td>
<td>1.03</td>
<td>3.20</td>
</tr>
<tr>
<td>5</td>
<td>1.28</td>
<td>4.60</td>
</tr>
<tr>
<td>6</td>
<td>1.80</td>
<td>4.35</td>
</tr>
<tr>
<td>7</td>
<td>1.30</td>
<td>3.10</td>
</tr>
<tr>
<td>8</td>
<td>1.46</td>
<td>3.00</td>
</tr>
<tr>
<td>9</td>
<td>1.90</td>
<td>5.00</td>
</tr>
<tr>
<td>10</td>
<td>1.45</td>
<td>4.80</td>
</tr>
<tr>
<td>11</td>
<td>1.18</td>
<td>3.18</td>
</tr>
<tr>
<td>12</td>
<td>1.67</td>
<td>4.50</td>
</tr>
<tr>
<td>13</td>
<td>1.62</td>
<td>6.10</td>
</tr>
<tr>
<td>14</td>
<td>1.50</td>
<td>4.18</td>
</tr>
<tr>
<td>Average</td>
<td>1.49</td>
<td>4.35</td>
</tr>
</tbody>
</table>
The effect of voltage variation on the 60 watt lamps was as follows:

<table>
<thead>
<tr>
<th>Percent of normal voltage</th>
<th>Percent of normal intens.</th>
</tr>
</thead>
<tbody>
<tr>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>95.5</td>
<td>82.5</td>
</tr>
<tr>
<td>89.0</td>
<td>63.0</td>
</tr>
</tbody>
</table>

Since the tungsten lamp has a positive temperature coefficient, the decrease in candle power for a given decrease in voltage is much less than for a carbon filament lamp, which has a negative coefficient. The decrease of intensity as shown by the test compare very closely with the decrease of candle power of tungsten lamps as given by Hutchinson's "High Efficiency Electrical Illuminants and Illuminations."

After testing with the false ceiling, the upper deck of the car was covered with the same kind of cardboard used for the false ceiling. The fixtures were wired for parallel operation on a 115 volt circuit with a rheostat in series for maintaining the rated voltage of the lamps. As in previous tests, 40, 60 and 100 watt tungstens were used. The results of the test are given below, the average intensities being as follows:

- 4- 40 watt tungstens 1.33 foot candles
- 4- 60 " " 1.88 " "
- 4-100 " " 3.53 " "

For the last test the card board was removed, using the regular maple colored veneer ceiling for the reflecting surface. The average intensity given by the 100 watt lamps was found to be the same as when 40 watt lamps were used with the cardboard covered ceiling, but the general illumination
Upper deck of car covered with cardboard. Tests made with 40, 60 and 100 watt lamps, on rated voltage and with the regular maple colored ceiling.

![Diagram of foot candles intensity](image)

<table>
<thead>
<tr>
<th>Position</th>
<th>40 watt 110 volts</th>
<th>60 watt 112 volts</th>
<th>100 watt 110 volts</th>
<th>100 watt Veneered Ceiling</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.28</td>
<td>1.50</td>
<td>3.50</td>
<td>1.30</td>
</tr>
<tr>
<td>2</td>
<td>1.43</td>
<td>2.07</td>
<td>4.20</td>
<td>1.55</td>
</tr>
<tr>
<td>3</td>
<td>1.18</td>
<td>1.72</td>
<td>3.07</td>
<td>1.15</td>
</tr>
<tr>
<td>4</td>
<td>1.15</td>
<td>1.70</td>
<td>3.20</td>
<td>1.18</td>
</tr>
<tr>
<td>5</td>
<td>1.41</td>
<td>1.93</td>
<td>3.70</td>
<td>1.36</td>
</tr>
<tr>
<td>6</td>
<td>1.40</td>
<td>1.83</td>
<td>3.11</td>
<td>1.26</td>
</tr>
<tr>
<td>7</td>
<td>1.24</td>
<td>1.73</td>
<td>3.21</td>
<td>1.22</td>
</tr>
<tr>
<td>8</td>
<td>1.67</td>
<td>2.08</td>
<td>4.00</td>
<td>1.50</td>
</tr>
<tr>
<td>9</td>
<td>1.47</td>
<td>2.02</td>
<td>3.83</td>
<td>1.39</td>
</tr>
<tr>
<td>10</td>
<td>1.10</td>
<td>1.60</td>
<td>3.24</td>
<td>1.29</td>
</tr>
<tr>
<td>11</td>
<td>1.45</td>
<td>2.18</td>
<td>4.08</td>
<td>1.50</td>
</tr>
<tr>
<td>12</td>
<td>1.53</td>
<td>2.20</td>
<td>4.20</td>
<td>1.52</td>
</tr>
<tr>
<td>13</td>
<td>1.08</td>
<td>1.60</td>
<td>2.81</td>
<td>1.13</td>
</tr>
<tr>
<td>Average</td>
<td>1.33</td>
<td>1.88</td>
<td>3.55</td>
<td>1.33</td>
</tr>
</tbody>
</table>
in the latter case was more pleasing due to the absence of glare on the ceiling.

The average illumination with the false ceiling was greater in each case than with the regular ceiling covered, with cardboard. This difference is not due entirely to the difference in height of the two ceilings. Since the area illuminated was the same for both types of ceiling, the same intensity could be obtained by the use of a different type of reflector with the false ceiling if it were placed at a different distance below the reflecting surface.

From the results of the test it is seen that the illumination is fairly uniform in all cases. The original lighting system of the large compartment of the car consists of 14-16 candle power carbon lamps arranged in rows of seven each on each side of the car. The advantage of the indirect system is seen at once when the two methods can be seen in alternate operation.

Referring to the drawings; Plate 3 shows the designed distribution of light for the cross section of the test car; Plates 4 and 5 the longitudinal sections of the large and the small compartments, and Plate 6 the cross section with the false ceiling. The colored curves on Plate 4 shows the actual distribution for the given section, as found by the test. These curves show that the illumination is practically uniform throughout the car.

By the indirect system a more uniform distribution is obtained; no direct rays meet the eye; fewer units are required because of the wider area illuminated per unit; and wiring is
simplified because of the fewer units. That a much larger area is thus covered by a single light source may be shown by the optical principal of images, considering the reflecting surface as a mirror, and the source of light coming directly from the image position of the true light. Then the rays coming from such a light will coincide with rays for the indirect system. A numerical example, with the figure below, will serve better to show the increased area illuminated by the indirect system.

Consider a flat ceiling 15 feet high, with a distributing reflector E100 placed 2 feet below the ceiling. For the direct lighting assume that the same reflector is used, inverted, at the same point, that is, two feet below the ceiling, and that in each case the area illuminated is a circle. By the direct method with reflector E100 at A, the diameter of the circle
illuminated is mn, and the total area illuminated is 373 sq. ft. With the indirect system the reflector being at A, or considering the light as coming directly from its image at D, the diameter of the circle illuminated is HK and the area is 640 sq. ft or an increase of 267 sq. ft. (71.5%), over the direct system. If the light is considered as coming from the image in this way the intensity of light on any plane will be much less, but the greater area lighted more than compensates for this.

The results of the test were very satisfactory, and show without a doubt, that the indirect system of lighting can be applied to cars with success. Dining car and coach lighting would be similar to that of the test car. The arrangement of lighting for sleeping cars would necessarily have to be different. Most cars are long enough for the use of three fixtures. In this case the wiring can be so arranged that the end lights may be turned out, leaving the center light for the general illumination after the berths are made up.

The test as made illustrates better the lighting of steam railway cars by a constant voltage than the ordinary electric cars where the voltage varies so rapidly. The voltage on steam car systems is practically constant, especially where storage batteries are used. Although it is not absolutely necessary for the voltage to constant it is desirable, as shown by the tests.

The results of the tests were much better than was expected, and it is the opinion of the writers that this system of car lighting can be used with success in most cases.
Plate 1.
Design of Illumination.

I.T.S Cor No. 517
3. E-451 Fixtures
E100 Reflectors
Scale 1"
Distribution of light parallel to section of
ITE Co. No. 791
Type 2 on pattern 1
Scale 1/10"
Plate 3.
U. of I. Test Car.
Type E100 Reflector
Scale: 1" = 18 ft.

Center of Curvature = 8' radius.

7'6½"
Plate S
Longitudinal Section of Small Compartment U. of I. Test Car
Type E-100 Reflectors Scale = 1" = 1'
Plate 6.
U. of I. Test Car
with false ceiling.
Scale = 1" = 1'

Center of Curvature of Ceiling.
9'-6" Radius.