ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR

Semiannual Progress Report No. 2

SHOCK ON ELECTRICAL COMPONENTS IN TRACK-LAYING AND WHEELED VEHICLES

July, 1954, to January, 1955

H. S. BULL

Project 2145

DETROIT ARSENAL, DEPARTMENT OF THE ARMY
CONTRACT NO. DA-20-089-ORD-36543
CENTER LINE, MICHIGAN

January, 1955

FOREWORD

This is the second semiannual progress report on a research program being carried on in the Department of Electrical Engineering, University of Michigan, under the supervision of the author.

Most of the work reported here represents the labor of Mr. Harris Olson, who has devoted his entire time to this research. In addition, the project has benefited from the expert counsel of Professor Jesse Ormondroyd of the Department of Engineering Mechanics and Professor David Ragone of the Department of Chemical and Metallurgical Engineering, and from the generous cooperation of the General Electric, Hudson, and Westinghouse lamp companies in making available much-needed test samples and in generously donating their engineering talent.

TABLE OF CONTENTS

OBJECT

The objects of this research project are:

1. To determine practicable means of increasing the operating life of incandescent lamps used on military vehicles, with particular reference to their resistance to vibration and mechanical shock.

2. To study the presently accepted method of impact-testing vehicular lamps and to determine practicable means of improving the tester and correlating the results obtained by the several testers now in service.

ABSTRACT

This is the second semiannual progress report, covering the period from July, 1954, to January, 1955, inclusive. The accomplishments may be summarized as follows:

1. The impact tester, known as the Arsenal incandescent lamp tester which has been temporarily installed in the project laboratory at the University of Michigan, was modified structurally in conformity with the recommendations of the previous progress report and has since been used to obtain mortality data on several types of vehicular lamps.

2. A duplicate of this tester, located at the Electric Auto-Lite Company, Cincinnati, Ohio, has been similarly modified and has since been used on routine lamp testing.

3. Comparative studies of mortality data obtained on these two machines for presumably identical groups of lamps have been undertaken and are still in progress.

4. Test samples of vehicular lamps having special design features have been supplied to the project by the cooperating lamp companies. Some of these lamps had totally recrystallized filaments; others had auxiliary coils slipped over the ends of the filament. These lamps were impact-tested and some were subjected to metallographic study.

CONCLUSION AND RECOMMENDATIONS

1. The results to date show that the structural modifications of the impact tester have definitely improved the reliability and consistency of its performance.

2. Mortality data thus far obtained on groups of presumably identical lamps tested on two presumably identical machines do not match as closely as desired, thus raising doubts as to the wisdom of long-continued efforts to improve the match by further modifications of the structure of the tester.

3. The possibility of improving lamp life by modifying the crystalline structure of the filament and/or modifying the physical features of the filament such as its method of support, its size and pitch, the use of slip coils, etc., looks promising enough to justify continued studies of all of these devices.

4. It is recommended that studies be initiated leading to a new and simplified design for an impact tester, and that the modified form of the tester now in use be considered as a temporary device to be retired as soon as a practicable new design can be developed and placed in service.

I. CONTINUED STUDIES OF LAMP IMPACT TESTER

A. COMPLETION OF RECOMMENDED STRUCTURAL CHANGES

On page 36 of the semiannual progress report on this project, dated July, 1954, there appears a list of five structural changes in the Arsenal impact tester, recommended after intensive study of its performance. These were:

1. Alter the drive pulleys to produce a cam speed of 700 rpm.
2. Employ 0.081-inch elastic hinges for the arm mounting.
3. Change the mounting of the lamp-holder plate to eliminate distortion of the upper anvils.
4. Standardize the weights of all the lamp-holder plates and the weight of the arm.
5. Determine the proper amount of spring loading to be added to the arm so that the peak acceleration will be maintained at or very close to 50 g.

Completion of these changes was one of the first items on the research program for the period covered by the present report.

The speed change was accomplished without difficulty and requires no further comment. The modification of the arm to accommodate the new elastic hinge was described in the July report, and the performance of this hinge has been very satisfactory in eliminating one of the major factors contributing to erratic tester performance.

A new method of attaching the lamp-holder plate to the arm (item 3, above) was devised which involved only minor changes in the existing structure. A strip was added to the bottom edge of the plate and a groove to accommodate it was milled in the upper surface of the upper anvils. It was held firmly in the groove by four lateral screws going through both sections. Subsequent operation indicated that this change in the means of plate attachment eliminated the bowing of the upper anvils previously observed, so that the same plate could be repeatedly locked in place for operation, removed, and then locked in place again without altering the observed peak acceleration values appreciably. However, a general stiffening of the front section of the arm resulted which raised the average peak acceleration considerably above the value of 50 g considered to be a desirable maximum for lamp testing.

The following table gives the results of three trials with the 2416 lamp-holder plate in which the plate was fastened in place, tested, removed, and then secured in place again. In evaluating these results, it should be noted that no special care was used in mounting the plate.

Assembly Trial	Average Peak Acceleration, g	Range	Deviation from Average, %
1	73.1	71.1 - 75.0	2.7
2	68.1	67.1 - 69.1	1.5
3	66.5	65.6 - 67.5	1.5
Average	69.2		5.6

Upon reconsideration of the problem of standardizing the weight of the lamp-holder plates and the weight of the entire arm (item 4) it was decided to postpone making a definite decision until more information became available on the comparative performance of several testers of the same design.

It no longer appears necessary or desirable to design a system of spring loading for the arm (item 5) for the purpose of increasing the average peak acceleration, since the new method of attaching the lamp-holder plate stiffened the plate-holding yoke so much that the peak acceleration became higher than the 50 g desired.

B. FURTHER STUDIES OF TESTER PERFORMANCE WITH THE NEW PLATE MOUNTING

A group of type 2416 lamps was given a life test on the impact tester with the new plate mount and at the higher acceleration. The results indicated that:

1. most of the coiled coils sagged,
2. many of the sagged filaments failed by shorting out one or more of the secondary coils, and
3. only one of the seventeen tested showed evidence of fatigue failure.

This test confirmed the conclusion drawn from previous single lamp tests that peak accelerations above 50 g are too severe for use in routine testing because they do not permit normal fatigue failure to be observed. Accordingly, consideration was given to practicable means of reducing the peak acceleration.

The addition of mass to the lamp-holder plate was tried first, since if it proved to be a reliable and controllable method of reducing acceleration, it might also serve as a means of standardizing plate weights. The data in the following table indicate that a reduction in acceleration might be secured in this way but with an undesired increase in the spread of peak values. It was also noted that slight changes in weight position and method of attachment caused considerable variation in observed results.

Weight Added, lb	Force to Open Anvils 0.002"	Range of Peak Acceleration, g
0	17	62.4 - 64.8
3-3/8	19	48.6 - 58.7
6-5/8	22	48.6 - 58.7
9-5/8	23	36.4 - 48.6

This method of reducing peak acceleration was accordingly abandoned.

The next method to be tried involved lowering the center of the cam so that the amount of lift of the upper anvils might be reduced. The thickness of the bearing blocks was reduced by milling a moderate amount off the bottom surface. The amount of drop for a particular test could then be adjusted by the use of shims of the desired thickness under the bearing blocks. A series of tests was then arranged in which the peak acceleration was observed for anvil drops ranging from 0.035 inch to 0.058 inch. The corresponding range of peak acceleration was 48 to 68 g in an almost linear pattern. A drop of 0.041 inch was finally selected as being capable of producing fairly consistent peak accelerations of 50 g under normal operating conditions with the new plate mounting.

A fairly reliable indication of the improved performance of the Arsenal tester, with the structural changes which have been described, can be obtained by referring to the lamp mortality curves of Fig. 1. Four groups of type 1251 lamps were tested at 28 volts, employing the customary 25-minute-on—5-minute-off operating cycle and an average peak acceleration of 50 g. It will

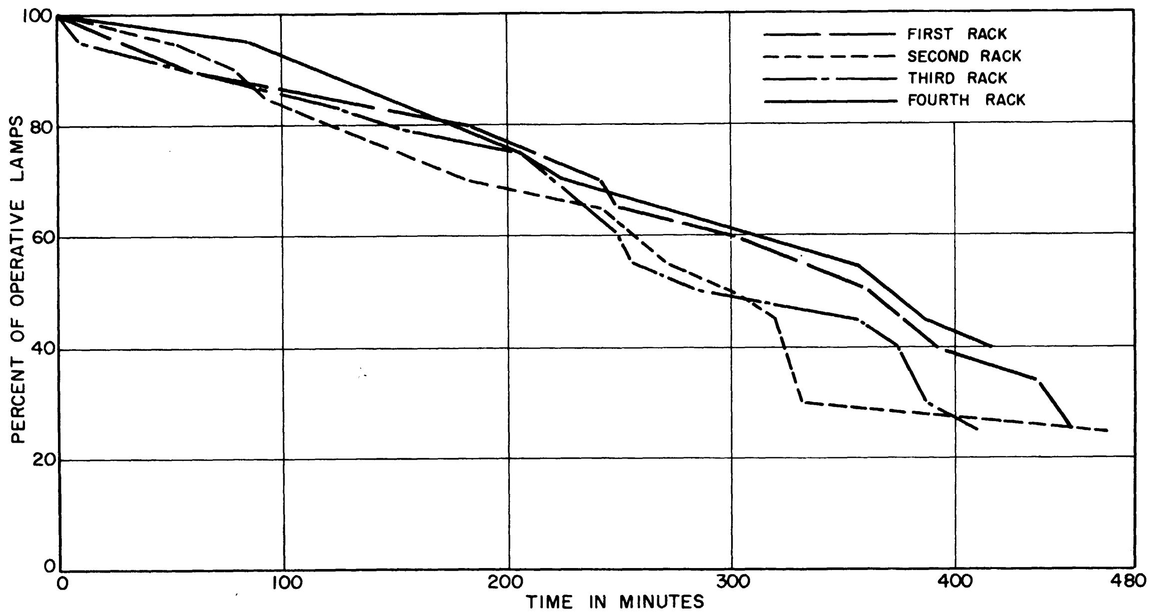


Fig. 1. Mortality Curves of Four Racks of Lamps Operated on the Arsenal Impact Tester.

be noted that only during the final part of the test did the curves separate by more than 10 percent.

The operating experience thus far obtained with the modified Arsenal tester indicates that fairly consistent results may be expected if certain critical parts are kept clean and free from excess grease and oil. Frequent cleaning of the cam, the anvil surfaces, and the groove retaining the lamp-holder plate is essential. A true fit must be maintained between the plate and the retaining walls of the groove to minimize the danger of distortion of the anvil contact surfaces. So long as the machine produces a steady rhythmic sound its average peak acceleration may safely be assumed to be constant.

C. CONVERSION OF ELECTRIC AUTO-LITE TESTER

The Electric Auto-Lite Company, through its representative on the SAE lighting subcommittee, volunteeered to make its impact tester available to the project so that it might be modified to conform to the changes just completed on the Arsenal tester. This seemed to be a logical step in that it would permit a series of parallel tests to be carried on simultaneously on both machines for the purpose of indicating the amount of correlation to be expected in their performance. Accordingly, the Auto-Lite tester was removed from its base and shipped to the University of Michigan on August 30, 1954. Figure 2 shows the tester as received.

Careful inspection of the machine revealed the following features needing attention:

1. The cam speed was 915 rpm.
2. The anvil surfaces were rough and deformed, making contact on only one side.
3. The anvil drop was 0.115 inch.
4. The cam started lifting the upper anvil about 100 degrees ahead of the normal position.
5. The amount of upward force needed to separate the anvils 0.002 inch was 6.5 pounds with a 5-pound lamp-holder plate on the arm, and 4 pounds without the plate.
6. Several welded joints in the arm frame were fractured.

Preparations were made for several tests on the machine as received. A Statham A5A accelerometer was mounted on the frame and a number of oscillograms were taken with the cam operating at 915 rpm. Two typical recordings are shown in Fig. 3, in which the very irregular performance pattern can be clearly observed. The average peak acceleration was 44 g, with a high of 53 and a low of 27. The cam speed was then reduced to 700 rpm, resulting in an average peak acceleration of 56 g, and a much narrower spread of peak values, 4.3 g. Substitution of the "S" cam (a special cam designed for the Arsenal tester having a spiral contour and 0.0625-inch lift) gave an average peak acceleration of 41 g.

After the completion of these tests, work was begun on the conversion of the Auto-Lite tester to conform to the structural changes in the Arsenal tester.

1. Pulleys were substituted to produce a cam speed of 700 rpm.
2. The structural changes necessary to accommodate the new elastic hinge were completed.
3. The lamp-holder plate mounting was converted to the new design.
4. A new cam was installed having the same general shape as the cam in the Arsenal machine.
5. The centers of the bearing blocks were lowered by 0.030 inch.
6. The anvil surfaces were reground.
7. The frame cracks were rewelded.

After these changes were completed the machine was assembled and mounted temporarily on the Arsenal tester base. The initial anvil drop was

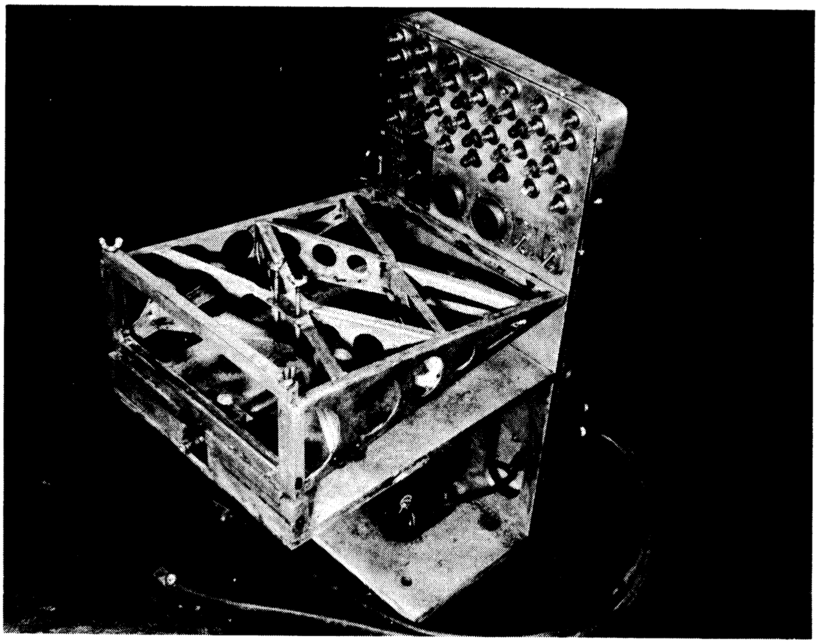
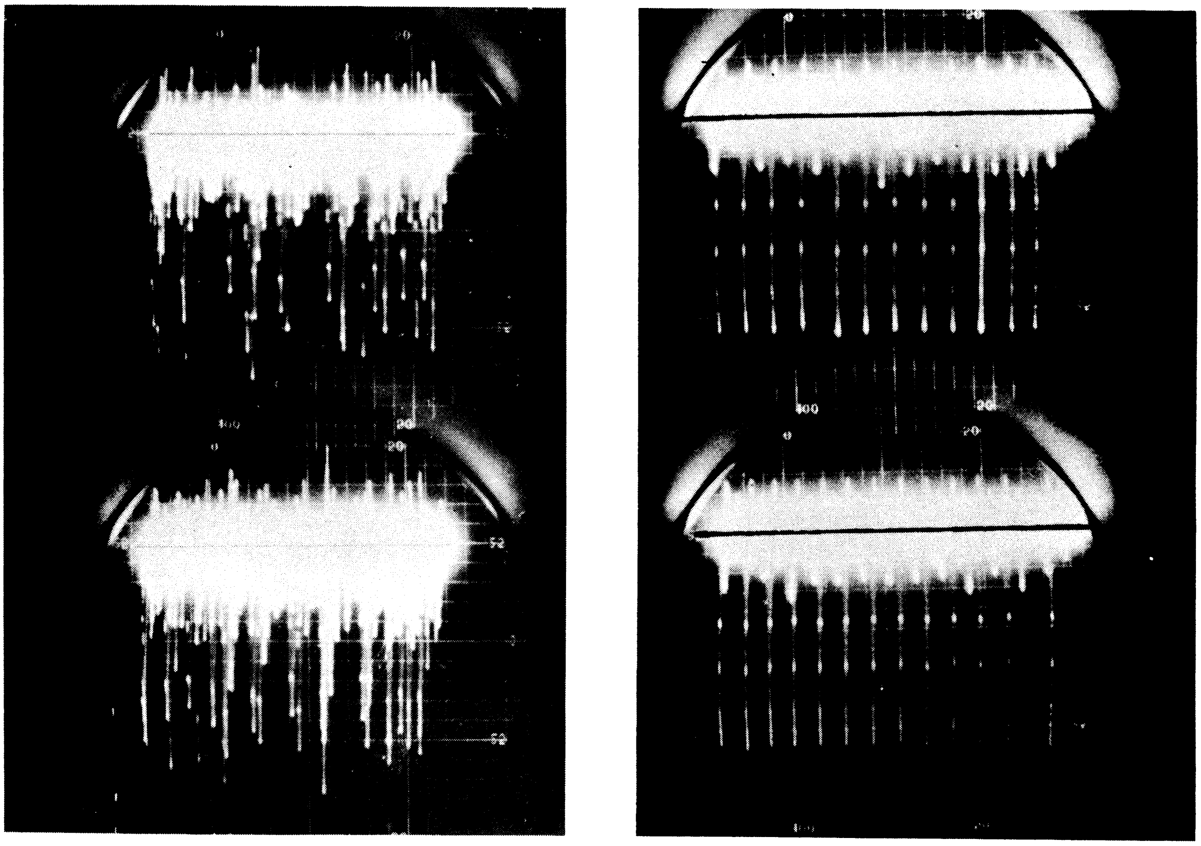


Fig. 2. Auto-Lite Impact Tester.



A B

Fig. 3. A, Acceleration Pattern of Tester as Received; B, Acceleration Pattern after Modification.

0.066 inch, producing a peak acceleration of 66 g. This was reduced to 50 g by reducing the drop to 0.030 inch.

The impact tester was then transported to the Electric Auto-Lite plant and assembled on its own base. Initial test runs showed erratic performance which was finally traced to anvil distortion caused by tightening the two side brackets clamped on the lamp-holder plate. When these brackets were removed consistent acceleration values were observed and the machine appeared to be in satisfactory working order.

D. COMPARATIVE PERFORMANCE OF ARSENAL AND AUTO-LITE TESTERS

Since the structural features and average peak acceleration of the two testers had been made as nearly alike as possible, it was anticipated that they should yield very similar mortality data on routine testing of similar groups of incandescent lamps. The machines did differ in the anvil drop distance (to produce equal accelerations) and in the force required to separate the anvils, these items being 0.041 inch and 16 pounds, respectively, for the Arsenal machine, and 0.030 inch and 21 pounds for the Auto-Lite machine. These differences did not change the energy delivered on impact by a large amount as will be observed in the following.

$$\text{Force} \times \text{moment arm} \times \text{angle} + \text{weight} \times \text{drop} = \text{energy}.$$

$$\text{Arsenal:} \quad 16 \times 16.75 \times \frac{.041}{16.75} + 15 \times 0.041 = 1.27 \quad .$$

$$\text{Auto-Lite:} \quad 21 \times 16.75 \times \frac{.030}{16.75} + 15 \times 0.030 = 1.08 \quad .$$

Preparations were then made to obtain data for mortality curves on several groups of type 1251 lamps taken from the same batch as the groups tested on the Arsenal machine (see Fig. 1). During the test of the first group the Auto-Lite machine developed an erratic behavior which was traced to a defective hinge. When this condition was remedied testing was resumed and five groups of twenty lamps each were tested. The mortality curves for these five groups are shown in Fig. 4.

On comparing these with the curves of Fig. 1, it will be evident that the tests on the Auto-Lite machine showed considerably more spread, for reasons which are not yet understood. It is also evident that the Auto-Lite tester subjects the lamps to higher stresses, as the average slope of the mortality curves is steeper. Further study of this tester is being undertaken.

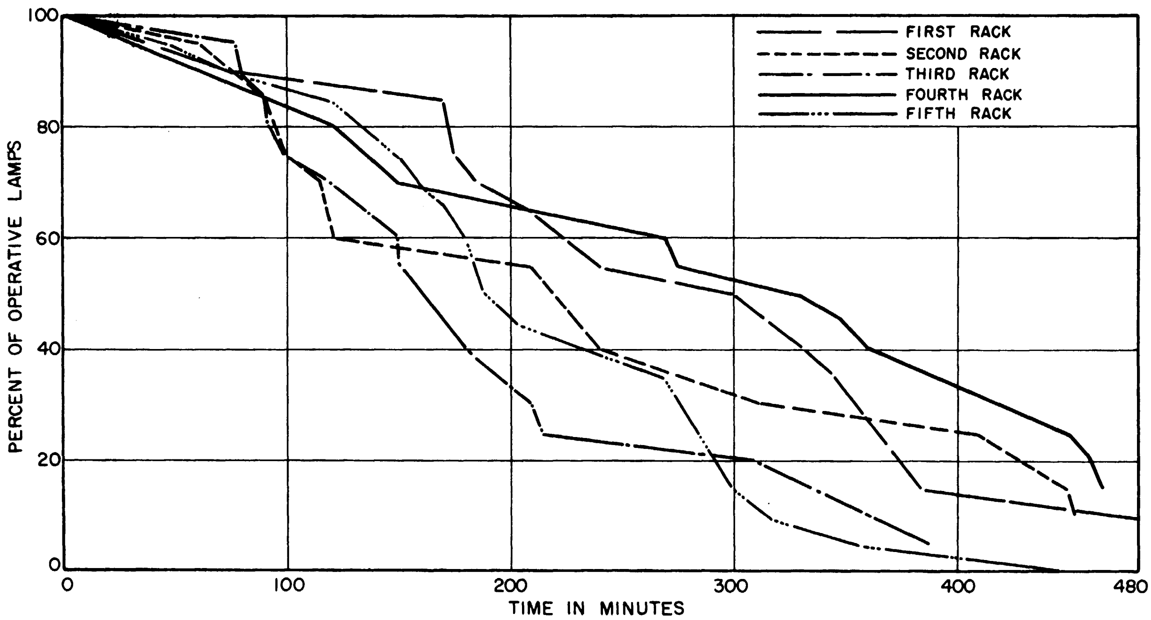


Fig. 4. Mortality Curves of Five Racks of Lamps Operated on the Auto-Lite Impact Tester.

II. EFFORTS TO IMPROVE SERVICE-DRIVE LAMPS

A. STUDY OF TYPICAL FAILURES

It was hoped that a considerable number of service-drive lamps, showing premature filament failure while in use on military vehicles, could be made available to the project for study so that the nature of the failure might be determined and compared with the failures secured in laboratory tests.

A good start in this direction has been made through the efforts of Mr. Robert Zuege of the Detroit Arsenal, who arranged for a group of lamps to be shipped to the project from Fort Bragg, North Carolina. Sixteen of these lamps had one filament failure and seven of the sixteen had lost both filaments.

The most common type of failure observed in this group was a short circuit between two or more turns of the secondary or coiled coil. No consistent pattern could be observed as to the exact location of the short. Five filaments apparently failed from fatigue and in several cases a cold failure apparently occurred, followed by severe arcing.

The same sort of filament failures occur under controlled laboratory test conditions. In general, failure by shorting between turns occurs when the secondary coil pitch becomes nonuniform, either because of some defect in the lamp assembly at the factory or because the acceleration produced by the impact tester becomes large enough to cause distortion of the filament structure.

Metallographic examination of filaments with fatigue failure shows that the point of fracture is nearly always in the recrystallized, fine-grained structure, which is one or two primary turns from the leg insert.

B. POSSIBLE STRUCTURAL CHANGES

In the July, 1954, progress report it was noted that the points of maximum flexure in the filament of the type 2416 lamp occur where the crystalline structure is inherently the weakest. The problem of improving the resistance of the filament to vibration and shock can be approached from at least two angles.

1. Devise a means of changing the method of filament mounting or changing the crystalline structure so that the points of maximum flexure occur where the filament is metallurgically stronger.

2. Reduce the severity of flexure by shock mounting the filament or by the use of a larger diameter and more rugged filament wire (operating at a lower efficiency and higher wattage).

C. PERFORMANCE OF TOTALLY RECRYSTALLIZED FILAMENTS

From a metallurgical standpoint a filament which has been fired at about 2200°C before mounting would be very desirable since firing at this temperature would produce a large-grain structure which should be stronger under repeated bending stresses. There are certain practical difficulties, however, which would have to be overcome before this process could be applied to routine lamp production. Foremost among these are the added cost of heat treatment and the added difficulty of mounting the treated filaments because they are quite brittle.

Several type 2416 lamps having totally recrystallized filaments were assembled by one of the lamp companies and shipped to the project for testing purposes. These were similar in size and design to regular production lamps except for the omission of the minor filament. They were mounted on the Arsenal impact tester and given the normal testing cycle. The following table shows the results.

Lamp No.	Operating Voltage	Life, min	Remarks
459	28	59	Failed hot; fatigue; filament dropped out
461	27.5	180	Failed as power turned on; broke one side only; hung in place till end of test
462	27.5	255	Failed hot; broke one side only; hung in place till end of test
463	27.5	217	Failed hot; fatigue; filament dropped out

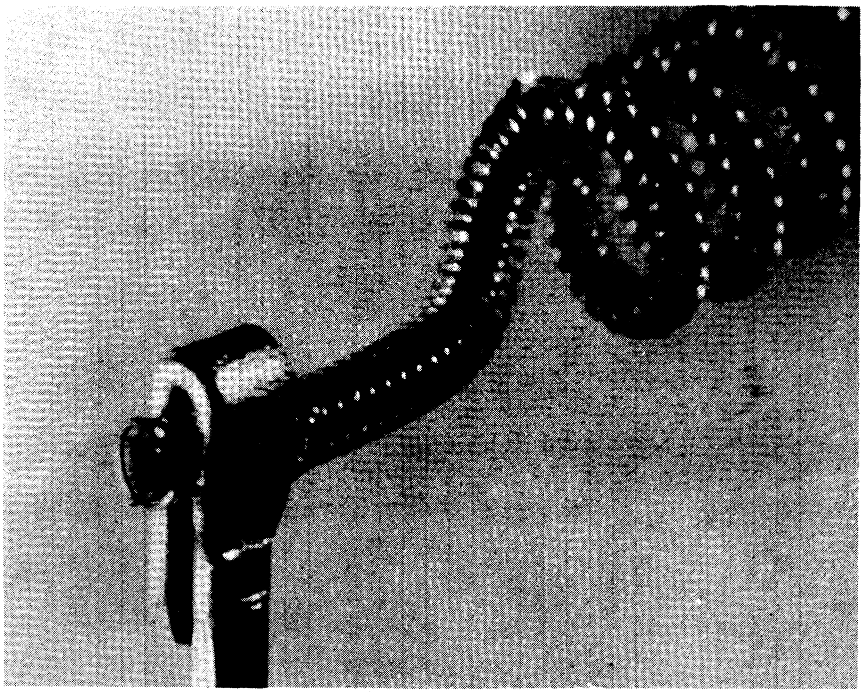
These lamps failed much sooner than was expected, and on the basis of the performance of these few samples the practicability of improving lamp life by the use of totally recrystallized filaments seems remote but further experimentation is being undertaken.

D. USE OF AUXILIARY COILS ENCLOSING ENDS OF PRIMARY COIL

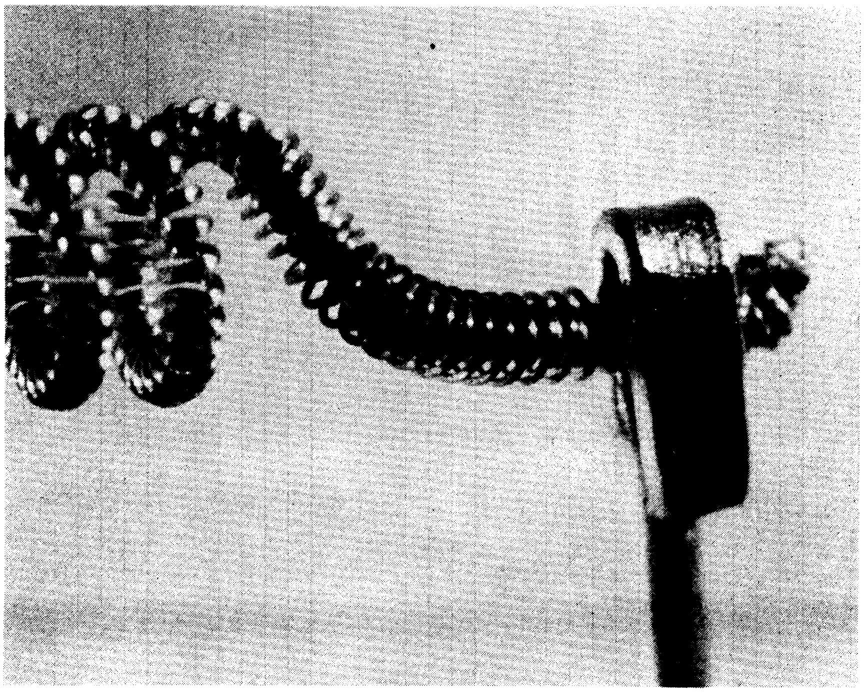
In the July, 1954, progress report it was suggested that the possibility of using slip coils covering the first few turns beyond the leg insert should be investigated. It was hoped that these slip coils would divert enough current from the main filament structure to lower the temperature of the ends of the filament, where maximum flexure occurs, enough to retain the cold-worked crystalline structure.

In response to our request two lamp companies provided the project with some lamps in which slip coils had been included. The first group submitted for test consisted of 50-watt, coiled coil-filaments similar to type 2416 with an RP11 bulb and a single contact bayonet base. Figure 5 shows the filament and slip-coil assembly for typical lamps of this group.

Four different wire sizes were used for the auxiliary coils enclosing the ends of the filaments of this group; some lamps without auxiliary coils were included as controls. See the following table for data on the auxiliary-coil dimensions and average life when mounted on the impact tester.



A



B

Fig. 5. Auxiliary Coils: A, 7 mg/200 mm; B, 11 mg/200 mm.

Auxiliary Coil	Weight, mg/200 mm	Diameter, mil	Average Life, min
(a)	20	3.19	864
(b)	11	2.465	750
(c)	7	1.889	565
(d)	4	1.427	590
(e)	No slip coils		644

It was quickly determined that operation of these lamps at 28 volts brought the temperature of the central part of the filament above normal because of the shorting effect of the slip coils, and it was necessary to reduce the voltage to 22 to obtain nearly normal filament temperature during these impact tests.

The data indicate that filaments with the heavier slip coils had a longer life than those with lighter coils or with no slip coils. Nearly all of these lamps had their secondary coils somewhat compressed and distorted. The average barrel length was about 50 mils shorter than in regular production lamps of the same type. Most of the failures on the test were due to shorting between turns rather than fatigue, and our limited experience indicates that this type of failure is expected to predominate if the coiled coils have a nonuniform pitch.

In the second group of lamps the auxiliary coils were screwed over the ends of the primary coil for distances ranging from three to seven turns beyond the weld point. No leg inserts were used (see Fig. 6).

When this group of lamps was tested on the impact machine in the same manner as the first group a much longer average life was observed. Every failure was a fatigue failure; no failures due to shorted turns were observed. The lamps all showed early blackening, however, due to improper degassing. A similar group, more carefully evacuated, will be supplied by the manufacturer for further testing.

E. EXPERIMENTS WITH SHOCK MOUNTING

Several attempts were made to secure a form of shock mounting by attaching the filament between the ends of strips of flat tungsten ribbon. Filaments so mounted showed vibration at a resonant frequency close to the value obtained for a filament of standard construction, but with a smaller

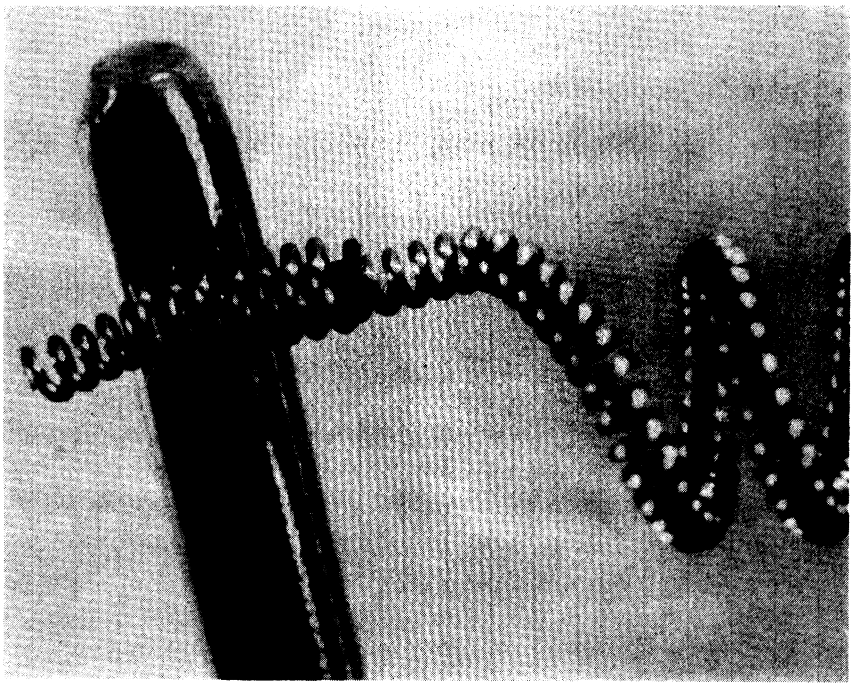


Fig. 6. Filament with Slip Coil

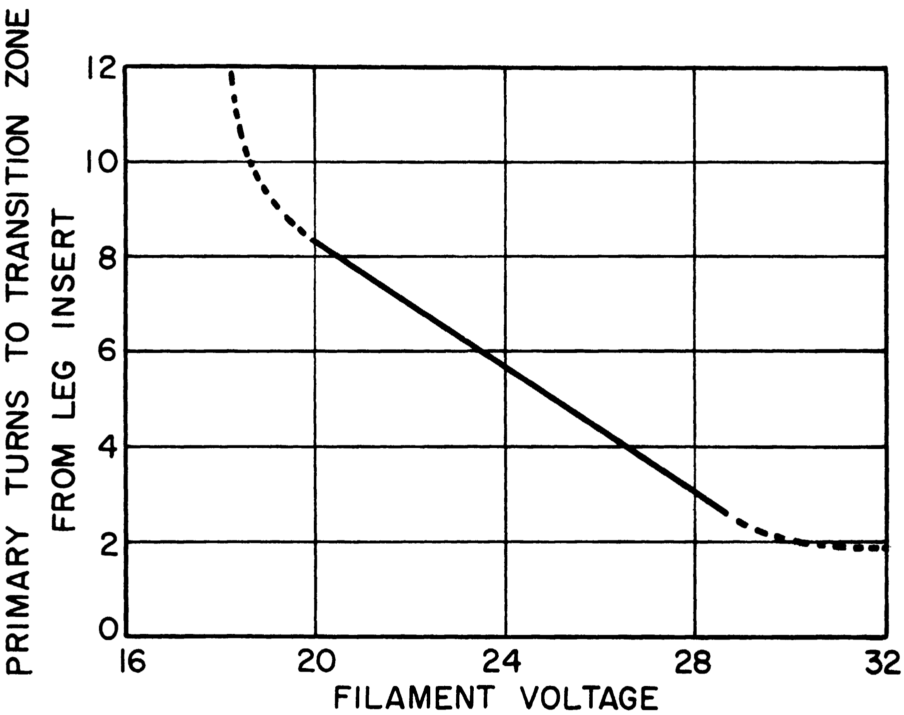


Fig. 7

amplitude. This in itself was advantageous. There was, however, a low-frequency vibration of the entire mount showing considerable amplitude, which of course was undesirable. It seems desirable to explore this possibility further.

F. EXPERIMENTS WITH LOW-EFFICIENCY FILAMENTS

A group of 50-watt lamps with coiled-coil filaments that had never been burned was flashed at various voltages ranging from 28 volts down to 20 volts. The filaments were then mounted, polished, and subjected to metallographic examination. The results are plotted in Fig. 7. It will be noted that there is quite a consistent relationship between operating voltage and the location of the transition zone marking the boundary between cold-worked structure and coarse-grained structure. As the voltage is lowered the transition zone moves farther away from the leg insert.

A group of type 2416 lamps with filaments that had never been burned was selected for impact tests. Arrangements were made to operate one third of the group on 28 volts and the remainder at 22 volts. They were placed on a stationary lamp-holder plate and burned at these voltages for 25 minutes. Then they were vibrated on the impact tester with the usual "on and off" operating cycle. Surprisingly, the number of failures in the set operating at subnormal voltage was appreciably greater than the failures at normal voltage. Nearly all of the failures in the subnormal voltage group were due to sagging and shorting. It is doubtful whether any valid conclusions can be drawn from this test because of the small number of lamps involved, but this phenomenon should be investigated more thoroughly.