IMPROVING INSPECTION PERFORMANCE

by

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INTRODUCTION and PROBLEM

Westinghouse Electric Corporation at Salina, Kansas manufactures fluorescent lamps. The company manufactures mainly two types of fluorescent lamps. One is a four foot long 40 Watt bulb, while the other is an eight foot slimline model.

Knowing the concern of the company over the outgoing quality and high amount of shrinkage due to inprocess rejection, it was decided to study the inspection procedure of the fluorescent tube ends (called mounts henceforth). The defective mounts, if not separated at the mount inspection station, go directly into the assembly of the final product. Thus an error made by an inspector results in a cost to the company, regardless of whether a defective item is shipped or a good item is classified as defective and scrapped.

Manufacturing Facilities at Westinghouse.

The Westinghouse lamp manufàcturing plant has Highly Automated Production manufacturing lines (HAP I and HAP II) for 40 Watt lamps producing about 2600 L/hr. For slimline lamps, two manufacturing lines (UNIT III and UNIT IV) produce about 1500 L/hr. Fig. 1 shows the detailed schematic sketch of the 40 Watt manufacturing line.

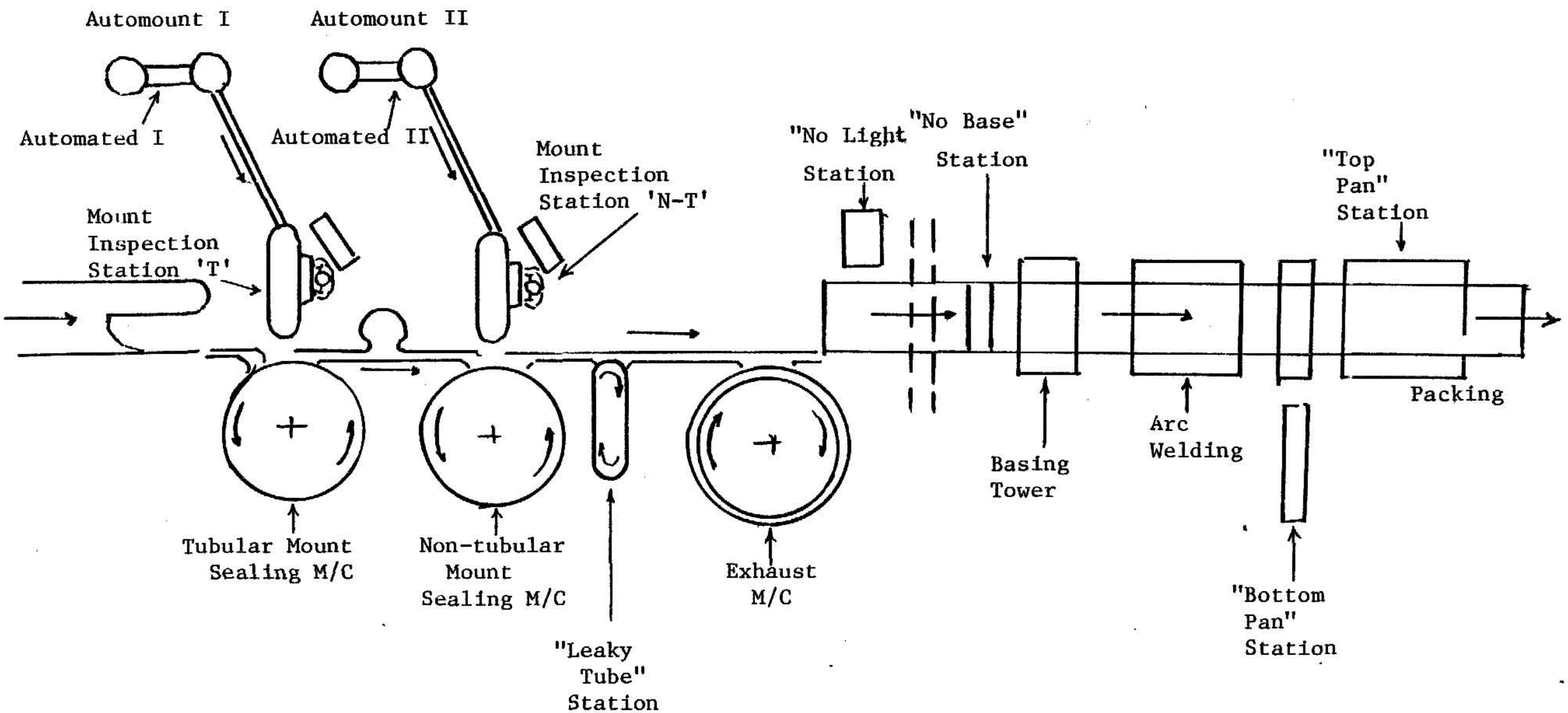

Fig. 1. 40 Watt Bulb Manufacturing Line(HAP I).

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The Important Inspection Stations on the 40 Watt Line.

There are seven automated inspection stations and three manual inspection stations per line.

A. Mount making machine or Automount (automated 1 & 2).

There are two automounts per manufacturing line. One produces tubular mounts and the other produces non-tubular mounts. The two lead wires and a filament are assembled with the glass flare. The assembled mount is checked automatically for the presence of lead wires and filament. If one of them is missing the mount is kicked off the line. The counter at this station measures the number of rejections.

B. Manual Inspection Station (manual 1 & 2).

At the mount inspection station, an inspector visually checks for various other major and minor defects. In addition, the inspector has to transfer the good mounts to the outgoing conveyor (called seal conveyor henceforth). This station is considered to be the most crucial from an efficiency improvement point of view.

At the time of this study, the number of inspectors working at this station is as follows:

40 Watt line

On HAP I, 4 groups/wk X 4 inspectors/grp.= 16 inspe./wk.

On HAP II,4 groups/wk X 4 inspectors/grp.= 16 inspe./wk.

Slimline

On UNIT III,2 groups/wk X 4 inspectors/grp.=8 inspe./wk.

On UNIT IV, 2 groups/wk X 4 inspectors/grp.=8 inspe./wk.

Total 48 inspe./wk.

C. Automated Leaky Tube Station.

This station is located after the sealing machines. See Fig. 1. There are 62 positions for holding the rejected tube at this station. Here the tube is inspected automatically for the following defects.

Defect	Control panel indicator
Leakage	Orange
No or misplaced lead wires at the non-tubular end	Blue
No or misplaced lead wires at the tubular end	Green

D. Automated No Light Station.

Here several spark coils are used to indicate the pressure level. The desired pressure level is achieved by proper combination of Mg vapour and the inert gas. If the lamp shows any one of the following three defects, it is automatically removed.

Indicator	Defect
Purple band	Leakage
Yellow star	Indicate less fill pressure than specified limits.
Dead	Broken, damaged etc.

E. Automated No Base Inspection Station.

Here two photocells detect the presence of a base (a base is the plastic cap on either end). If the bases are missing, the lamp is kicked out. An operator rechecks these lamps and after putting back the bases, replaces about 99% of the lamps onto the line.

F. Automated Bottom Pan Station.

At this station a known amount of current is passed to check the resistance of the mount. If the observed resistance is matched with the known resistance, the lamp is accepted; otherwise it is rejected. This is an important continuity test.

G. Automated Top Pan Station.

This is the last automatic inspection station. Here the lamp is lit up by an AC supply (lower limit of the household supply). The intensity of the light is compared with the known amount using photocells.

H. Final Manual Inspection/Packing Station.

The two operators at this station do packing and check the lamps for the following defects:

1. Etching.
2. Coating defects.
3. Base defects.

At every inspection station above, one can see that the quality of the mount is of paramount importance. If a faulty mount is used in making the lamp, either the lamp will fail immediately or will be passed undetected. If the lamp is passed undetected it can result in end discoloration, reduced luminescence or shortened life.

Thus it was decided to concentrate on improvement of inspection performance at the manual mount inspection station. To achieve this the following three areas were given special attention.

1. Inspector training and training aids.
2. Considerations to workplace design.
3. Inspection procedure.

METHOD

The present training activity at Westinghouse for the Automount machine and the mount inspection area constitutes watching the videotape and on-the-job training by a designated trainer. To make this training procedure more effective, many improvements should be incorporated. It was felt necessary to establish norms for defective mounts. These norms can be in the form of samples of good and defective mounts, exploded views and sketches of the defective mounts, or audio-visual presentation of good and bad mounts.

Ekstrand (1964) and Embrey (1979) have presented a comprehensive general approach to the development of an inspection training system. Using these guidelines a probable training system for Automount inspectors is suggested. The proposed training system can be the combination of the following points.

1. Definition of the training objectives.
   The ideal goal, an unrealistic one, can be detection of every defect. At Westinghouse the goal could be to miss as few defective mounts as possible. If the inspector rejects a small proportion of good mounts, these errors are not as important since the cost of a good mount is less than the cost of a bad lamp.

2. Specification of training criteria.

   Probability of correct defect detection and also probability of rejecting good mounts needs to be specified.

3. Derivation of training contents.

   It mainly involves breaking the inspection task into its elements. This allows close investigation of the work cycle and helps to establish the most economical hand motion pattern for the task. Thus a MTM analysis of the existing method and improved method was done. See Appendix B.

   The mount inspection job, if observed closely, is done in three different work cycles. They are as follows:

   a. Transfer and inspection of mounts from input conveyor to seal conveyor.
   b. Transfer and inspection of mounts from input conveyor to trays.
   c. Transfer of mounts from trays to the seal conveyor.

4. Design of training method and material.

   The mount transfer and inspection job, as it implies, constitutes transfer of mounts from the input conveyor to the seal conveyor and visual inspection of the mounts at the same time. During the visual inspection, inspectors are expected to look for at least one of the several possible defects mentioned in Appendix A. This requires a high degree of judgement and decision making on the part of the inspectors. In addition, it increases the complexity of the inspection task.

The findings of Harris (1966) shows that inspection performance can be improved by developing procedures and aids which reduce the effect of complexity. Thus to improve inspection performance it is necessary to provide inspectors with meaningful and usable quality standards, which ultimately help the inspector for a judgment of whether or not the characteristic conforms to the given standards.

The above discussion shows that the present training system for Automount operation needs specific improvements. Various possibilities including an audio-visual presentation (slide-booklet method) and on the job training were considered. After judging the effectiveness and applicability of each method, we decided to develop the following three training aids.

A. Pictorial explanation of the motion pattern accepted and used during the MTM analysis of the job.

Using an experienced operator, pictures were taken of the desired orientation and positions of hands (LH and RH) during the transfer and inspection of mounts. A suitable written explanation supplemented each picture. See Appendix C. A set of such motion pattern pictures should be placed near every inspection station. This will help the operators and the designated trainers to compare and improve their motions.

B. Preparation of a booklet specifying defect definitions.

This booklet contained the exploded views and sketches of the defective mounts. Every defective mount was classified under three headings.

1. Critical defect

   Defects difficult to detect. May not cause immediate failure of the lamp.

2. Major defect

   Defects somewhat difficult to detect. May or may not cause immediate failure of the lamp.

3. Minor defect

   Defect less difficult to detect. The lamp may be rejected in the further operations.

In addition, every sketch was supplemented with a short explanation and consequences of the defects on the final quality. See Appendix D.

C. Representation of defective mounts on display board.

Samples of the defective mounts were collected and were arranged on a display board. The arrangement was done according to critical, major and minor defects. Each mount was labeled with the appropriate color label, such as:

Defect	Color of the label
Critical	Red
Major	Orange
Minor	Yellow

This will help the designated trainer to demonstrate and emphasize the defects to the inspectors while training. This display can become a permanent feature of the training aids at Westinghouse.

5. The Training Program.

The whole training program should be considered from the following three viewpoints.

1. The attitude of the inspector to the work.
2. Job knowledge.
3. Possession of the specific skills required to perform the task.

As there are 48 different inspectors involved in this task and their quality of work directly affects the quality of the outgoing product, the company policy should be directed towards emphasizing the importance of the job of mount inspection. Every inspector has to learn the basic procedures required to carry out the task. As this job needs a high degree of subjective judgement of quality standards, the training and retraining techniques must be used extensively.

Metods Improvement

The existing method and the hand motions during the following two work cycles were studied. A new systematic method was suggested.

Work cycle 1.

Transfer and inspection of mounts from input conveyor to tray.
The inspector fills the tray whenever she has excess mounts, otherwise she loads the seal conveyor. This shows that the tray remains on the support board for most of the time. In addition, it was observed that during these work cycles the left hand is at LH bottom corner of the tray.

The new method, in which the operator fills the tray from RH top corner to the LH bottom corner, gives free access for left hand movements and reduces the

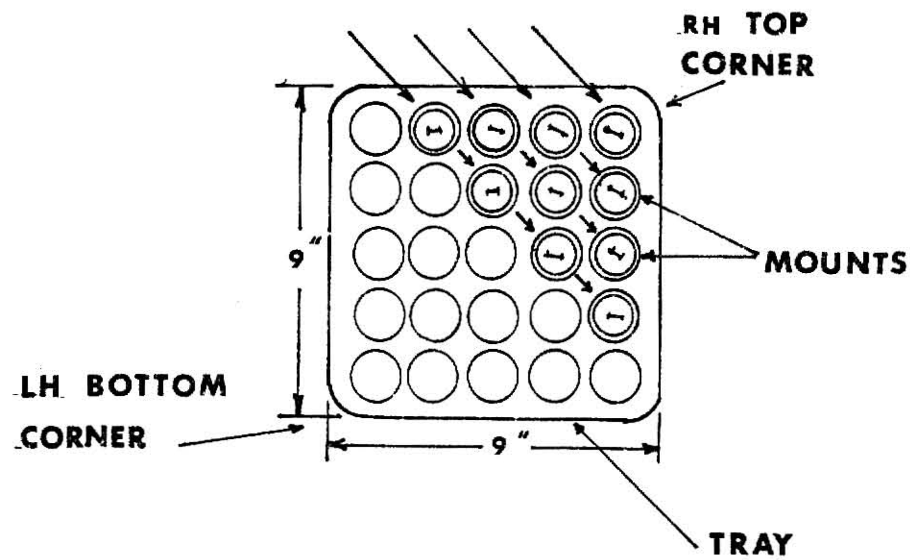

FIG. 2 IMPROVED METHOD OF LOADING THE TRAY

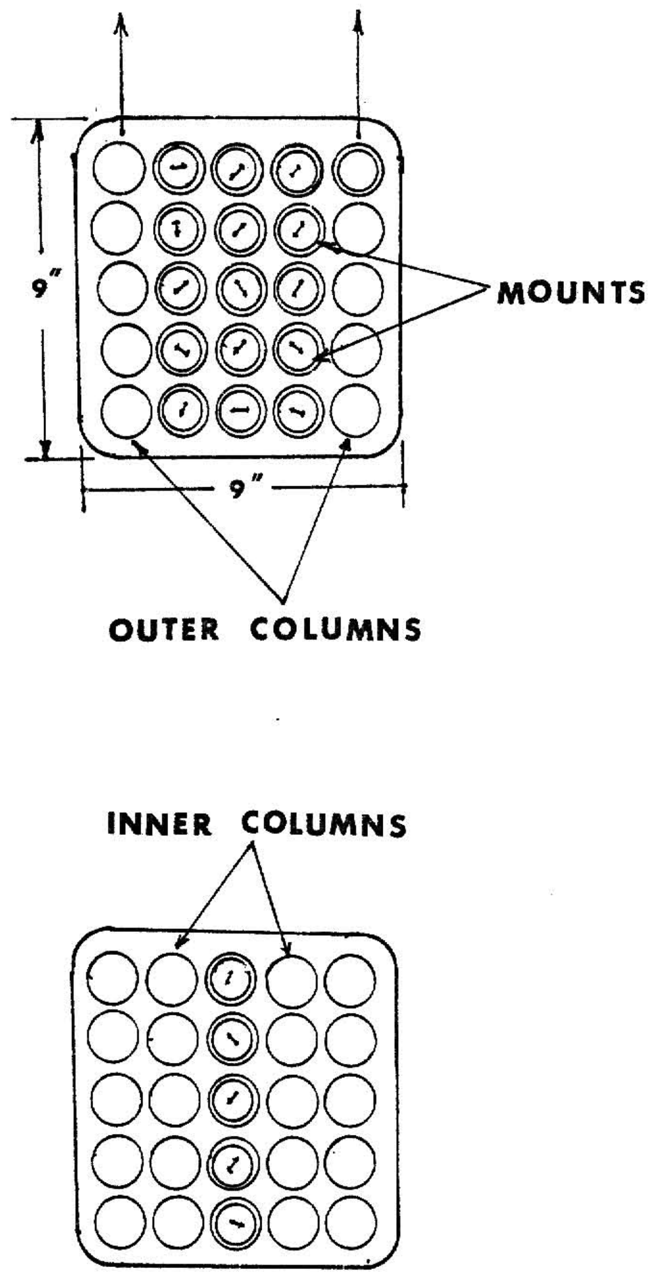

FIG. 3 IMPROVED METHOD OF UNLOADING THE TRAY

accidental damages of the mounts. See Fig. 2.

Work cycle 2.

Transfer of mounts from the tray to the seal conveyor. The improved method suggests that the inspector should start unloading mounts from the two outer columns of the tray. See Fig. 3. The motions of the hands should be symmetrical and should be made simultaneously. This will improve the efficiency and will reduce the mount damage. For more details see Appendix C.

Workplace Design

Comments on the existing design. See Figs. 4, 5 and 6.

1. The support board (20" X 10").

   This acts as a work area for the inspector. The board is about 5" below the seal conveyor, in line with the main beam structure, attached to it by two 4" wide brackets. This leaves a 4" wide gap between the seal conveyor and this board. At present this gap is covered by a brown cardboard.

2. The Chair.

   Almost every inspector slides the chair below the support board (probably to get as close to the conveyor as possible). The gap between the support board and the chair seat is $34" - 28\frac{1}{2}" = 5\frac{1}{2}"$, sufficient to accomodate the thighs. It also was

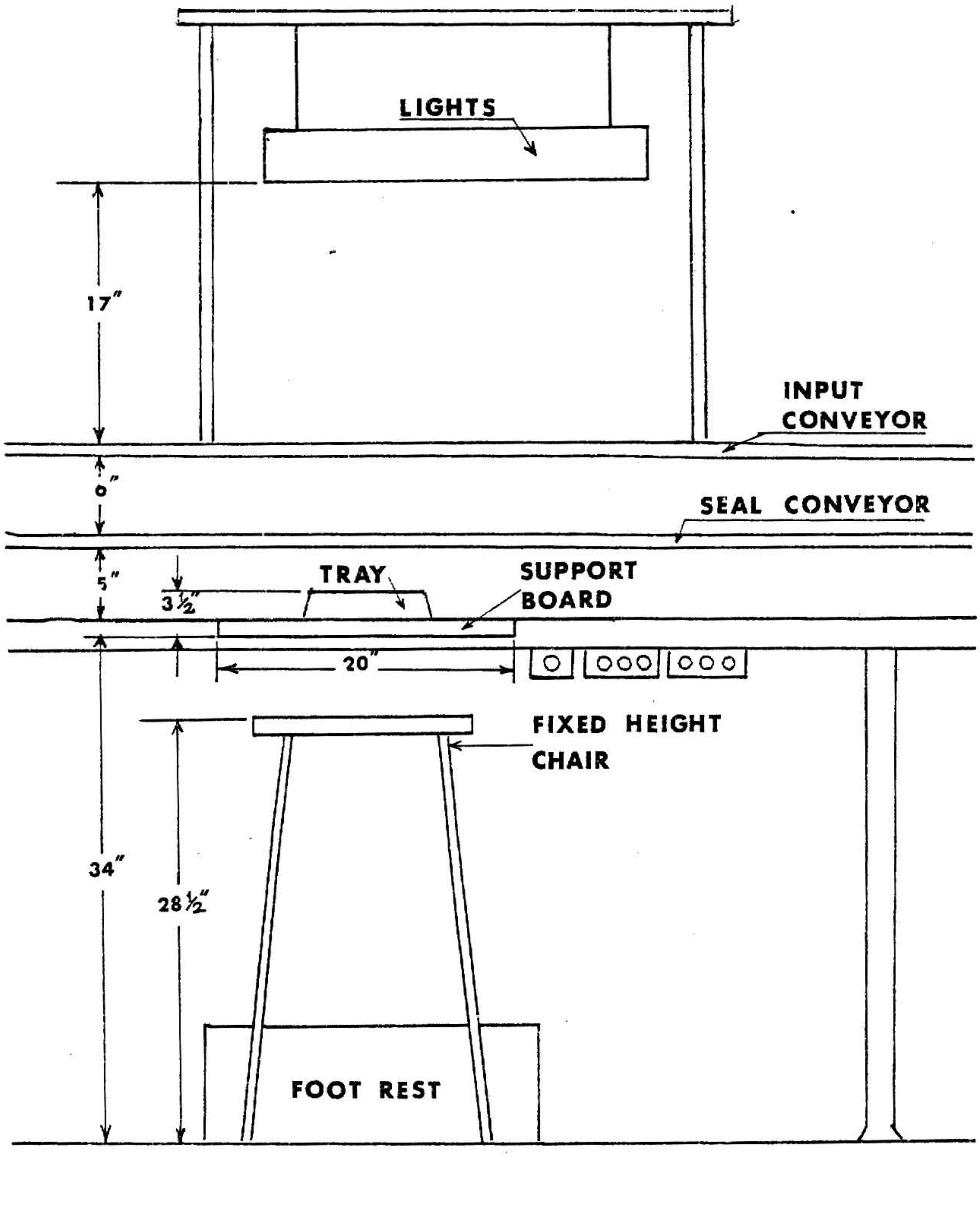

FIG. 4 THE MOUNT INSPECTION STATION AT PRESENT

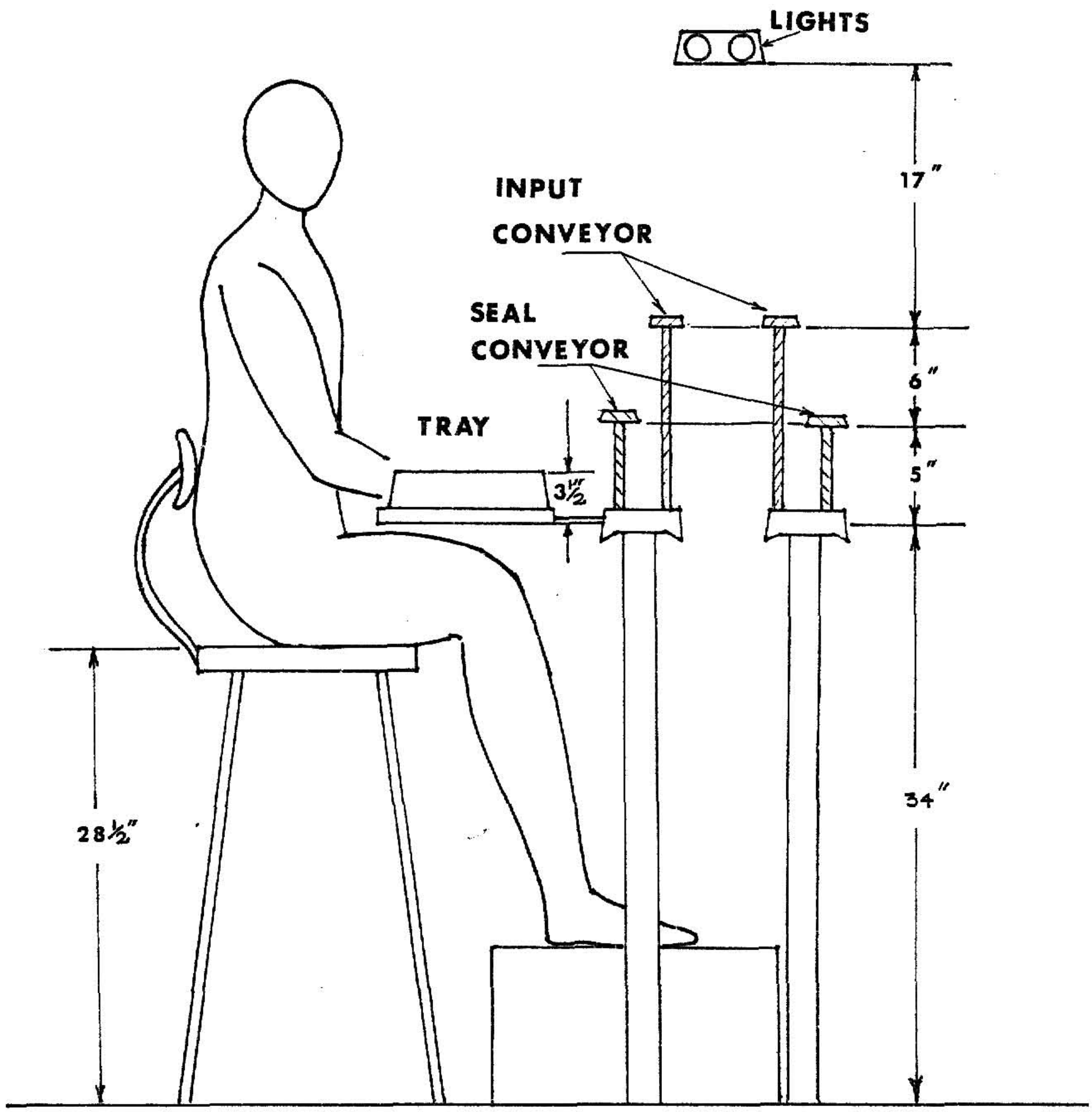

FIG. 5 THE WORKPLACE LAYOUT

(SIDE VIEW)

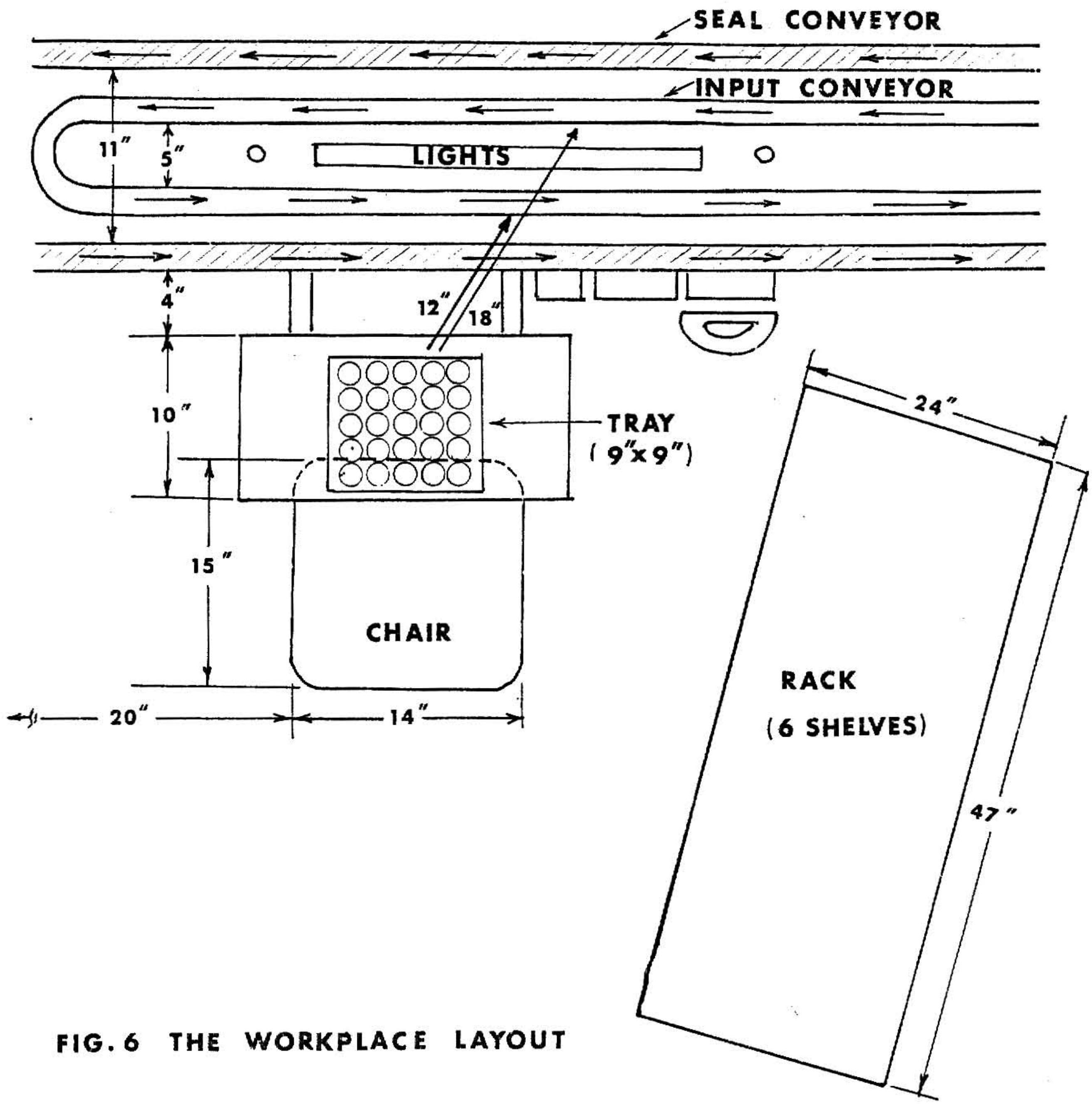

FIG. 6 THE WORKPLACE LAYOUT

(TOP VIEW)

observed that the lower portion of the inspector's stomach was touching the edges of the board in most of the cases. The present chair has a hard wooden seat, a metallic back and no height adjustments or rotational movements.

3. Design and position of the rack.

   The present rack, which is used as a buffer storage for the mounts, has the following dimensions.

   width - 47½"
   depth - 24"
   height - 60"

   It has six shelves. The three sides, except the front, are closed. The rack is movable. At present the empty trays and the loaded trays are stored in the same rack.

Proposed Improvements In the Workplace Design.

1. Direction of the input conveyor.

   It is possible to change the direction of the movement of the input conveyor. This will reduce the distance from 18" to 12" for every reach and move elements of the work cycle. The position of the conveyor fixture, due to the present direction of movement, is as shown in Fig. 7. This position necessitates a "clear" motion to remove the mount from the fixture.

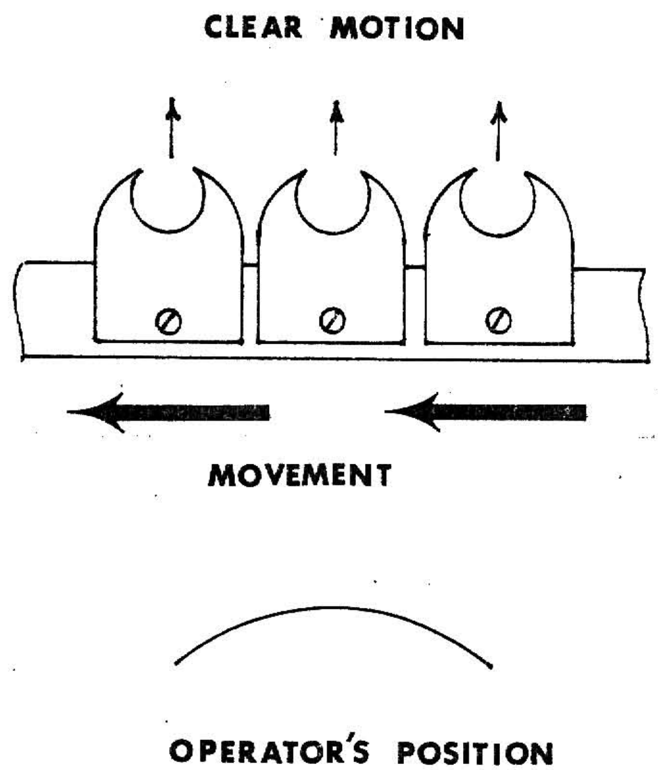

FIG. 7 THE PRESENT CONVEYOR FIXTURE POSITION

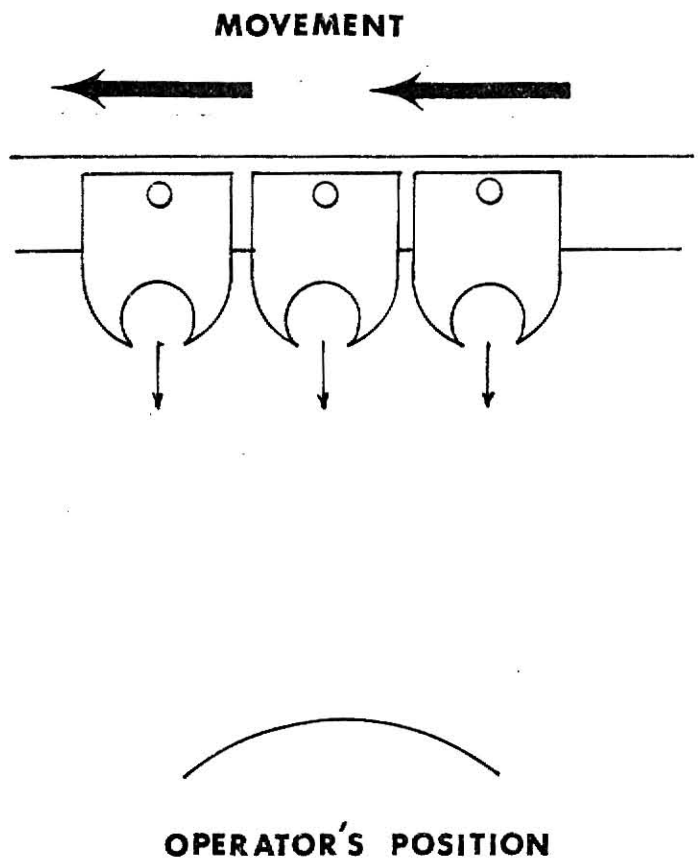

FIG. 8 THE CONVEYOR FIXTURE POSITION AFTER REVERSING THE DIRECTION

After reversing the direction of the conveyor, the position of the fixture will be as shown in Fig. 8. As an immediate effect, the inspector can pick up the mounts more conveniently, without a clear motion. This will save almost 3 elements of MTM per cycle in addition to the reduction in reach and move distances.

2. The support board.

This can be brought closer to the main beam structure by 2". A further modification can be made by elevating the board, so as to bring the tray to almost the same level as the seal conveyor. It was observed that the support board and the tray are used as an arm rest during transfer and inspection from input conveyor to the seal conveyor, and also from the input conveyor to the tray. By elevating the support board, we are trying to bring the position of the hand to almost the same level as the seal conveyor. These two improvements can reduce the hand motions by 2" in the vertical direction and about 2" in the horizontal direction.

At present the support board is 20" X 10" in size, which accomodates two trays at a time. The observations show that keeping two trays on this board creates a hindrance in free hand motions. In addition, chances of damaging the mounts are greater. Thus it was suggested to reduce the size of the support board to 12" X 9". An allowance of 3" in the horizontal direction should be provided, so that each inspector can locate the position of the tray as she desires.

3. Position of the overhead lights.
At present the lights are located off center. See Fig. 4. It was observed that the lights can be centered by moving the fixture 6" to the left side.

4. The improved chair.
A more comfortable chair, adjustable in height and with movable seat, was tried. As an effect of elevating the support board, the chair height was raised. In this position the inspector worked with her elbows and forearms in a straight line, which is ergonomically less fatiguing. In elevated sitting posture it also was easier to stand and sit. See Appendix E for the new chair.

5. Redesign of the rack.
At present the empty trays and the loaded trays are stored in the same rack. It was observed that the design of the tray permits nesting (empty trays can fit into each other). Thus these empty trays can be stored separately, preferably in a spring

loaded trolley, on the left hand side of the inspector. For this purpose Industrial Lowerator (self-leveling work dispenser) can be used. This will keep the empty trays at the desired working height for all of the time. See Fig. 9.

Following are some of the immediate advantages of implementing this suggestion:

a. Use of self-leveling work dispenser will provide a permanent location near the work station for these empty trays and will stop unnecessary handling.

b. The storage capacity of the rack will be increased as the empty trays are no longer stacked on the racks.

c. Providing self-leveling work dispenser on the left hand side of the inspector will improve the balanced hand motions.

d. Self-leveling work dispenser will help to reduce fatigue.

The present rack has six shelves. One shelf can hold ten trays. Thus the present capacity of the full loaded rack is 60 trays or 1500 mounts. A modified rack with seven shelves was tried and it was observed that it works equally as well. This will increase the storage capacity to 70

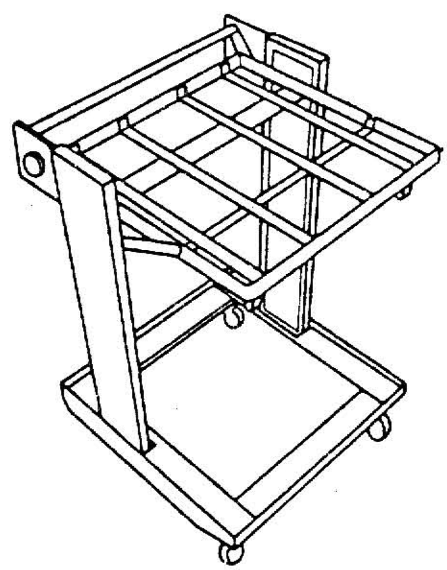

Fig. 9 Self leveling tray dispenser.

trays or 1750 mounts per rack. This is 17% more storage capacity.

EXPERIMENTAL DESIGN

In order to improve the inspection performance, it was felt necessary to measure the inspection efficiency under existing conditions. Considering the time available and the cost of measuring the inspection performance, it was decided to take a preliminary survey of the defective mounts separated by the inspectors and the rejections at the bottom pan.

On Jan. 15, 1980 starting at 6 am and continuing for 12 hrs. all the defects (200) from the Bottom Pan Station on HAP I were saved. In addition, some of the defective mounts (800) separated by the inspectors also were saved.

The mounts from the defective bulbs were obtained by cutting off the tube and then the defects in the mounts were examined. The defective mounts separated by the inspectors also were categorised into the various groups. See Appendix F.

Some of the defective mounts separated at the mount inspection station were passed through the manufacturing line. As the known defective bulbs proceeded, they were eventually marked for the known defect. The bulbs were picked up at the various mount inspection stations, mentioned at the beginning or were manually removed after passing the Top Pan Station. This experiment helped to find the exact function of each inspection station. In addition, it helped to categorize the defects into critical, major and minor. See Appendix G for the results.

Training Package

To test the effectiveness of the training package, a specially designed Inspection Training Test was carried out.

Task

A total of 500 mounts including 10% defectives were collected. All the 500 mounts were numbered. The known defectives were noted and were mixed randomly. All the mounts were loaded on the trays. See Appendix I for the list of known defects.

The actual inspection test was carried out in the laboratory. The inspectors were shown the experimental set up and were given a brief verbal explanation of the procedure. In addition, the written instructions about the experiment were given to the inspectors. See Appendix H.

The procedure involved picking up a tray and observing it for 15 sec. If a defective mount is located, then call out the number on the defective mount and the name of the defect. The findings were recorded on a tape recorder.

After the above test the inspector underwent a training session by Mary of QES dept. The training aids specified in Appendix C and D and the 'Mount Defects Display Board' were used while training.

A copy of the Training Manual was given to the inspector after this. Immediately after training, the inspector was asked to inspect the same set of mounts, in exactly the same way. It was expected that the inspectors would study the copy of Training Manual and would actually apply the instructions on the job. The last phase of experiment consisted of asking the inspector to inspect the same mounts, two weeks later. This tested the retention and the effectiveness of the training procedure.

Subjects

Four women inspectors from the manual mount inspection station, HAP II of the Westinghouse plant at Salina, Kansas were volunteered to be subjects. All four inspectors had worked on this job for 5 to 7 years. The average age was approximately twenty-nine years with a range from 24 to 35 years.

RESULTS

MTM Analysis

The main aim of the MTM analysis here was to study the job of mount transfer and inspection closely, to its smallest element. This study helped to establish the most economical motions of the hand. In addition, the study generated various questions about the procedure and the workplace layout. The efforts to answer these questions in turn helped in modifying the hand motions and the workplace layout.

MTM analysis of the existing method and the improved method resulted in either dropping or removing the following task elements. See Appendix B.

1. The distance for 'reach' and 'move' motions is reduced by bringing the picking point closer. This was achieved by reversing the direction of the conveyor.
2. As the inspectors are picking up from the input conveyor closer to them and as the conveyor fixture is 'open' on their side, the 'clear conveyor' element is removed.
3. Including the above changes and the other workstation improvements the savings are 0.177sec./mount. (This conclusion is based on the assumption that 80% of the time inspectors are transfering the

mounts from the input conveyor to the seal conveyor and for the rest of the time, they transfer from the input conveyor to the tray.

Savings while transfering from the input conveyor to the seal conveyor ... 5.94 TMU/mount

Savings while transfering from the input conveyor to the tray .... 3.58 TMU/mount

Thus savings per mount are

(5.94 X 0.8)+(3.58 X 0.2) X 0.036 sec./TMU

= 0.196 sec./mount.)

Methods Improvements

Use of self-leveling work dispensers provided a permanent location for the empty trays and allowed the present rack to store the loaded trays.

Improvements in the rack design resulted in about 17% more storage capacity.

The Training Package

To measure how well the inspectors were doing before and after the inspection training, an Inspection Training Test was run. The data gathered during the experiment was analyzed so as to establish levels of inspector performance. For the analysis the data was classified under four headings as shown in Table 1.

Table 1. Inspectors Decision Matrix.

		Mount		
		Defective	Good	Total
Decision	Accept	Miss	Correct Accept	Total Accepts
	Reject	Hit	False Alarms	Total Rejects
	Totals	Total Defects	Total Good	Total

Though there are large number of criteria available for measuring inspection performance, only three were selected. These three criteria necessarily fit very well into the present situation.

1. Hit Rate

$$A_1 = \frac{\text{Hits}}{\text{Total defects}}$$

2. Efficiency in improving the product.

$$E = \frac{(\%\ \text{OK after inspection}) - (\%\ \text{OK before inspection})}{(\%\ \text{possible improvement})}$$

$$= \frac{\dfrac{\text{correct accepts}}{\text{total accepts}} - \dfrac{\text{total good}}{\text{total}}}{1 - \dfrac{\text{total good}}{\text{total}}}$$

3. % Errors made

$$\%\ \text{Errors} = \frac{\text{misses} + \text{false alarms}}{\text{total}}$$

The results of the various calculations are summarized in Tables 2 and 3.

The results of the Inspection Training Test clearly showed the need for training and retraining of the inspectors. After using the training aids, we observed that, in the 2nd test, the Hit Rate was improved by 32.5% and efficiency was increased by 47.4%, while the % Errors were dropped by 11.85%. In addition, the results of the third test showed that the inspection performance was consistant even after two weeks. Refer to Table 3. Note that these improvements were for inspectors with

5 to 7 years of experience.Please refer to Appendix K for the detailed calculations.

The various methods improvements such as location of light, new chair, reversed conveyor direction, level and size of the support board, etc. will improve the quality and performance of the inspection. They also will provide more comfort and convenience to the inspector.

Table 2. Summary of Inspection Training Test Results. Also see Table 3.

	Subject 1			Subject 2			Subject 3			Subject 4		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Hit Rate	36%	50%	46%	50%	62%	66%	30%	50%	66%	44%	50%	48%
Efficiency*	33%	47%	43%	47%	59%	63%	34%	47%	45%	37%	46%	44%
% Errors	7%	5.4%	5.4%	5.8%	5.4%	5.6%	7.8%	6%	6.2%	6.4%	7%	6.8%

* The percentages are rounded to the nearest integer.

Table 3. Average Improvements After the Inspection Training Test and After Two Weeks.

	Avg. of Test 1	Avg. of Test 2	% Improvement in Test 2	Avg. of Test 3	% Improvement in Test 3
Hit Rate	40.00%	53.00%	32.50%	56.50%	41.25%
Efficiency	33.75%	49.75%	47.40%	48.75%	44.44%
% Errors	6.75%	5.95%	11.85%	6.00%	11.11%

DISCUSSION

Every effort has been made throughout this study to improve the productivity of the mount inspection station by suggesting new techniques of hand motion, changes in the workplace layout and by providing training aids.

The inspection performance was measured using three major criteria. It is very important to discuss why these criteria are applicable in this particular situation.

1. $$\text{Hit Rate} = \frac{\text{Hits}}{\text{Total defects}}$$

   Reasons to use this criterion:

   a. This criterion measures what inspectors normally see as their function. The inspectors main job is to detect the defective mounts.

   b. This criterion gives more importance to the 'Hits' than the 'False Alarms'.

2. Efficiency in improving the product.

   $$E = \frac{(\%\ \text{OK after inspection})-(\%\ \text{OK before inspection})}{(\%\ \text{possible improvements})}$$

   Reasons to use this criterion:

   a. This criterion measures the efficiency of the inspector as defined by the amount by which the quality of the batch is improved by passing through their hands.

b. The cost structure of the mounts shows that it is more expensive to accept a defective mount than to reject a good mount. The above criterion complies with this goal by giving more weight to 'Misses' than to the 'False Alarms'.

3. $\% \text{ Errors} = \dfrac{\text{Hits + False Alarms}}{\text{Total}}$

Reason to use this criterion:

a. This criterion measures the total mistakes done, and hence helps to compare performance after a training session.

Installing the Suggestions

Installing and implementing various suggestions made during this study is a very crucial and difficult stage. It was felt that, to follow up this study and to maintain a close contact with the progress of the job, Westinghouse management should assign an Industrial Engineer at least for a few hours in a week. The following points should be given immediate attention.

1. Reversing the direction of the input conveyor in HAP I and HAP II.

2. A professional photographer should be assigned to take pictures of the hand motions pattern during transfer and inspection of the mounts. The pictures shown in the Appendix C should be used as a guideline.
3. Using the above pictures, a booklet of correct hand motions should be prepared. The copies of this booklet should be given to every mount inspection workstation along with the manual of the defect definitions.
4. The suggested changes in the workplace layout and in the storage system should be given a thoughtful consideration and should be installed as soon as possible on every work station.
5. The training aids have been proven satisfactory in an actual test. These training aids should be used more often and on everybody so as to develop the habit of doing the transfer and inspection job in the correct way.
6. The communication between the quality control staff (QES) and the line inspectors should be improved. They now seem to operate independently. The line inspectors seem to be considered as "production" rather than "quality" personnel.

Appendix I shows the list of 50 defective mounts in the sample of 500 mounts. The defects detected by each subject during the three tests are marked against the list of the known defects. This table gives an idea how the subjects performed during the Inspection Training Test. In addition, it shows the defects which the subjects could not detect.

Appendix J categorizes these defects under critical, major and minor headings. Also it gives how many of each kind were present in the sample.

The defects such as "insufficient dumet in press", "scissor clamp" or "emission too close to clamp" were almost left undetected. It is necessary that, while using the training aids next time, greater emphasis should be given to these defects.

Benefits From the Study

The aim of improving inspection performance at the mount inspection station is tackled by suggesting improved methods, modifying the workplace layout and by providing the new training aids for the Westinghouse inspectors.

It is very important at this stage to present the results in terms of increased productivity and the savings in dollars.

The MTM Analysis

Refering to the results section we noticed that, the improved techniques of hand motions and the new work-place layout, if installed, will save 0.196 sec./mount. Assuming the inspectors inspect and transfer 3000 mounts/hr. the savings are 9.83 min./3000 mounts, or in other words the job of inspecting and transfering 3000 mounts can be done in 50.16 minutes.

Thus the two immediate benefits are:

1. Inspectors can use this additional time for inspection and can improve the quality of the final product.
2. Management can use this additional time to raise the production rate. With this improvement inspector can transfer and inspect $\frac{60}{50.16} \times 3000 = 3588$ mounts. This is a 19% increase in the productivity.

The Training Program

In the results section we have noted the improvements in the inspection performance due to the inspector's training.

Using the following assumptions, which are close to the real situations, we can emphasize the importance of the training program, in terms of dollars saved per year.

1. Assume 2.0% of the incoming mounts are defective.
2. Assume that the inspector misses 20% of the defective mounts, or in the other words she detects 80% of the defective mounts. (The laboratory test showed that the inspectors could detect only 40% of the defective mounts or they missed 60% of the defective mounts before undergoing the training. Refer to Table 3. Thus our assumption is within the reality.)
3. Assume that the cost of a rejected lamp is one dollar. This includes the material cost and the overheads.

Calculations for HAP I and HAP II:

Production rate on HAP I and HAP II is 2600 L/hr. Therefore the mounts(tubular and non-tubular) inspected and put into the line = 2600 x 2 = 5200 mounts/hr. For 12 hrs./shift, we get 5200 x 12 = 62,400 mounts/shift/line. With 2% defect rate, 62,400 x .02 = 1248 bad mounts/shift./Li.

If the inspector fails to detect 20% of the bad mounts, then 1248 x .2 = 250 mounts/shift are passed undetected. And at one dollar/lamp rejection cost, $250 is lost per shift on one line. Thus for HAP I and HAP II, 250 x 2 = $500/shift is the loss.

Now with 32.5% improvement in the detection rate after training, we get 500 x .325 = $162.5/shift savings for two lines.

Then for 12 shifts a week and 50 weeks a year we have 162.5 x 12 x 50 = $97,500/yr. savings on HAP I and HAP II.

Calculations for UNIT III and UNIT IV:

Production rate on UNIT III and UNIT IV is 1500 L/hr. Therefore the mounts(tubular and non-tubular) inspected and put into the line = 1500 x 2 = 3000 mounts/hr. Then for 8 hrs./shift, we get 3000 x 8 = 24,000 mounts/shift/line. With 2% defect rate, 24,000 x .02 = 480 bad mounts/shift.

If the inspector fails to detect 20% of the bad mounts, then 480 x .2 = 96 mounts/shift are passed undetected. And at one dollar/lamp rejection cost, $96 is lost per shift on one line. Thus for UNIT III and UNIT IV, 96 x 2 = $192/shift is the loss.

Now with 32.5% improvement in the detection rate after training, we get 192 x .325 = $62.4/shift savings for the two lines.

Then for 10 shifts a week and 50 weeks a year we get 62.4 x 10 x 50 = $31,200/yr. on UNIT III and UNIT IV.

The above results show that the company can save $97,400 + $31,200 = $128,700 per year.

The Cost of Installing the Training Program

There are 16 pictures in the Training Manual. A professional photographer may charge $100 for 16 pictures. We need 8 copies of each picture, ie. 128 prints, or at one dollar/print it is $128. Assuming the cost of assembling these pictures into a booklet is $10/booklet, we require $80 for 8 booklets. Therefore the total cost of 8 booklets is $100 + $128 + $80 = $308, say $400.

Then we need one hour of each inspector to undergo the training session. Therefore for 48 inspector hours, 48 x 6 = $288, say $300.

Thus the total cost of installing the training program is $400 + $300 = $700.

The benefits generated from these implementations are tremendous.

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APPENDICES

APPENDIX A

CLASSIFICATION OF DEFECTS (MOUNTING)

CLASS I

101 - High air line
102 - Exposed inner knot
103 - Broken or cracked glass
104 - Wrong coil
105 - No blow hole
106 - Coil out of clamp
107 - Bubbled dumet
108 - Red dumet
109 - Multiple coils or wires
110 - Misplaced wire
111 - Oil or grease
112 - Damaged coils
113 - No coil
114 - Burned dumet
115 - Wire or glass adhered to mount
116 - Coil broken

CLASS 2

201 - Emission on wires
202 - Emission length
203 - Scissor clamp
204 - Off center flare
*205 - Crooked or Off-center tube
*206 - Poor dumet seal
*207 - Coil out of clamp pocket
*208 - Coil loose in clamp

CLASS 3

301 - Emission coverage poor
302 - Blow hole small
303 - Blow hole shape poor
304 - Coil off center
305 - Ridged flare
306 - Out of round flare
*307 - Burned dumet
309 - Foreign material on mount

CLASS 4 (SPECIAL TEST)

401 - Clamp thickness wrong
402 - Clamp spacing before stretch wrong
403 - Clamp spacing after stretch wrong
404 - Hook depth wrong

405 - Emission weight wrong
406 - Strain excessive
407 - Flat thickness wrong
408 - Re-entrant angle poor

MOUNTING Q.E.S. INSPECTION CRITERIA

DEFECT IDENTIFICATION

DEFECT #101 - HIGH AIR LINE

A line of air extending all the way through the press along a dumet wire.

DEFECT #102 - EXPOSED INNER KNOT

An outer lead weld knot partially or completely outside of glass.

DEFECT #103 - BROKEN OR CRACKED GLASS

Any broken, cracked or chipped glass in the press, flare or exhaust tube. Half moon chips on the flare edge are not criticizable.

DEFECT #104 - WRONG COILS

Any coil other than specified.

DEFECT #105 - NO BLOW HOLE

No blow hole on tubular mounts.

DEFECT #106 - COIL OUT OF CLAMP

Criticize any coil completely out of the clamp.

DEFECT #107 - BUBBLED DUMET

A continuously connected line of bubbles along the entire length of a sealed dumet section.

DEFECT #108 - RED DUMET

A dark red or purple line along the entire length of a sealed dumet section. Refer to standard.

*DEFECT #109 - MULTIPLE COILS OR WIRES

More than one coil or two wires on the mount

DEFECT #110 - MISPLACED WIRE

A wire obviously out of position in the press.

DEFECT #111 - OIL OR GREASE ON MOUNT

Any oily or greasy substance on flare, press, wires or coil.

DEFECT #112 - DAMAGED COILS

Any obviously distorted or skeleton coils.

DEFECT #113 - NO COIL

The absence of a coil.

*DEFECT #114 - BURNED DUMET

Dumet burned along its entire length.

DEFECT #115 - WIRE OR GLASS ADHERED TO MOUNT

Criticize a mount with any extranious metal or glass adhering to any part of it's glass surface.

DEFECT #116 - COIL BROKEN

Criticize any coil with a broken primary winding.

DEFECT #201 - EMISSION ON WIRES

Any emission on the clamp or outer lead wire.

DEFECT #202 - EMISSION LENGTH

Any coated coil which falls outside the following limits: 1 to 2 mm from clamp - 40 Watt.

$\frac{1}{2}$ to $1\frac{1}{2}$ mm - Slimline

DEFECT # 203 - SCISSOR CLAMP

Any clamp scissored more than $\frac{1}{2}$ the width of the flattened wire.

DEFECT #204 - OFF CENTER FLARE

The flare is out of alignment with the exhaust tube and wires. Limit to be established.

*DEFECT # 205 - CROOKED OR OFF-CENTER TUBE

The flare and wires are in alignment. The exhaust tube is out of alignment. Limit to be established.

*DEFECT #206 - POOR DUMET SEAL

Criticize any mount with less than 2 mm good dumet seal. Good dumet is that which is not burned, excessively red, bubbled or otherwise defective.

DEFECT #207 - COIL OUT OF CLAMP POCKET

Any coil secured past the center point of clamp.

DEFECT #301 - EMISSION COVERAGE POOR

A gap in emission coverage of more than 1 sq. mm. Refer to defect #405.

DEFECT #302 - BLOW HOLE SMALL

Limit: ½ the inside diameter of the exhaust tube. Note: see defect #105.

DEFECT #303 - BLOW HOLE SHAPE POOR

Limit to be established.

DEFECT #304 - COIL OFF CENTER

Criticise any coil end which does not extend beyond the clamp.

DEFECT #305 - RIDGED FLARE

Criticize any obvious ridges which may prevent sealing.

*DEFECT # 306 - OUT OF ROUND FLARE

Criticise any flare which is out of round more than 1.0 mm.

*DEFECT #307 - BURNED DUMET

A dark or brown spot on the dumet caused by overheating. Criticise any in excess of 1.5 mm in length. Refer to defect 114 and 206.

DEFECT #309 - FOREIGN MATERIAL ON MOUNT

Criticize any foreign substance on any part of a mount . Disregard the white film which is sometimes on the flare as a result of SO_2.
Note: See defect #111 when oil or grease is present.

*DEFECT #401 - CLAMP THICKNESS WRONG

Criticise any clamp thickness outside of specification.

DEFECT #402- CLAMP SPACING BEFORE STRETCH WRONG

Criticise any mount outside of specification.

DEFECT #403 - CLAMP SPACING AFTER STRETCH WRONG

Criticise any mount outside of specification.

DEFECT #404 - HOOK DEPTH WRONG

Criticise any mount outside of specification.

DEFECT #405 - EMISSION WEIGHT WRONG

Criticise emission weight outside of specification.

DEFECT #406 - STRAIN EXCESSIVE

~~Limits to be established.~~

CRITICISE ANY STRAIN IN EXCESS OF THAT SHOWN IN PICTURES AT POLARISCOPE.

DEFECT #407 - FLAT THICKNESS WRONG

Criticise any flat thickness outside of specification.

*DEFECT #408 - RE-ENTRANT ANGLE POOR

Criticise a sharp re-entrant angle between the exhaust tube and stem press, or wire touching side of flare just below entry into the stem press.

APPENDIX B

MTM Analysis

ILLEGIBLE DOCUMENT

THE FOLLOWING DOCUMENT(S) IS OF POOR LEGIBILITY IN THE ORIGINAL

THIS IS THE BEST COPY AVAILABLE

MTM

MTM ASSOCIATION FOR STANDARDS AND RESEARCH
9-10 Saddle River Road
Fair Lawn, N.J. 07410

INPUT CONVEYOR TO SEAL CONVEYOR

(EXISTING)

Sheet ____ of ____
SYSTEM: MTM-
STUDY NO. ________
DATE: ________
ANALYST: ________

LEFT HAND DESCRIPTION	F	LH MOTION	TMU	RH MOTION	F	RIGHT HAND DESCRIPTION
Reach to input conveyor	1	R 15 D	18.4			
Grasp two mounts	1	G1C3	10.5			
clear conveyor fixture	1	M2 B	4.6			
Grasp two mounts	1	G1C3	10.8			
clear conveyor fixture	1	M2 B	4.6			
Grasp two mounts	1	G1C3	10.8			
clear conveyor fixture	1	M2 B	4.6			
Move near to seal	1	M 18 B	17.0	EF	1	Eye focus
conveyor — Turn 180° —				ET	1	Eye time
inspect during the move					1	Drift near [illegible]
			33.6	G3	6	Grasp one mount
			70.5	M8 C	6	Move to seal conveyor
			54.6	SS	6	Position
			12.0	RL1	6	Release
			37.5	R 8A	5	Reach for next mount
			8.0	R 6 E	1	Return hand to work area
			300.1			
per mount			50.0			

MTMA 1006

MTM ®

MTM ASSOCIATION FOR STANDARDS AND RESEARCH
9-10 Saddle River Road
Fair Lawn, N.J. 07410

INPUT CONVEYOR TO SEAL CONVEYOR

(IMPROVED)

Sheet ___ of ___
SYSTEM: MTM-
STUDY NO. ________
DATE: ________
ANALYST: ________

LEFT HAND DESCRIPTION	F	LH MOTION	TMU	RH MOTION	F	RIGHT HAND DESCRIPTION
Reach to input conveyor	1	R12D	14.2			
Grasp two mounts	3	G1C3	32.4			
Move to seal conveyor	1	M12B	13.4	EF	1	Eye Focus
– turn 180° – inspect				ET	1	Eye Time
during the move					1	Drift near L.H.
			33.6	G3	6	Grasp one mount
			61.8	M6C	6	Move to seal conveyor
			54.6	SS	6	Position
			12.0	RL1	6	Release
			35.0	R6A	5	Reach for next mount
			7.4	R5E	1	Return hand to work area
			264.4			
per mount.			44.06			

MTMA 1006

MTM ASSOCIATION
FOR STANDARDS
AND RESEARCH
9-10 Saddle River Road
Fair Lawn, N.J. 07410

INPUT CONVEYOR TO THE TRAY

(EXISTING)

Sheet ____ of ____
SYSTEM: MTM-
STUDY NO. ____
DATE: ____
ANALYST: ____

LEFT HAND DESCRIPTION	F	LH MOTION	TMU	RH MOTION	F	RIGHT HAND DESCRIPTION
Reach to input conveyor	1	R15D	18.4			
Grasp two mounts	1	G1C3	10.8			
Clear conveyor fixture	1	M2B	4.6			
Grasp two mounts	1	G1C3	10.8			
Clear conveyor fixture	1	M2B	4.6			
Grasp two mounts	1	G1C3	10.8			
Clear conveyor fixture	1	M2B	4.6			
Move to the L.H. bottom	1	M18B	17.0	EF	1	Eye focus
corner of the tray —				ET	1	Eye time
—Turn 180° — inspect					1	Drift near L.H.
during move.						
			33.6	G3	6	Grasp one mount
			48.0	M4C	6	Move to the proper hole on
						the tray.
			33.6	S	6	Position
			12.0	RL1	6	Release
			30.5	R4A	5	Reach for next mount
			3.8	R2E	1	Return hand to workarea
			243.1			
per mount			40.5			

MTM ASSOCIATION FOR STANDARDS AND RESEARCH
9-10 Saddle River Road
Fair Lawn, N.J. 07410

INPUT CONVEYOR TO THE TRAY

(IMPROVED)

Sheet ____ of ____
SYSTEM: MTM-
STUDY NO. ____
DATE: ____
ANALYST: ____

LEFT HAND DESCRIPTION	F	LH MOTION	TMU	RH MOTION	F	RIGHT HAND DESCRIPTION
Reach to input conveyor	1	R12D	14.2			
Grasp two mounts	2	G1C3	32.4			
Move to seal conveyor–	1	M12B	13.4	EF	1	Eye Focus
– turn 180° – inspect				ET	1	Eye Time
during the move					[illegible]	Drift near L.H.
			33.6	G3	6	Grasp one mount
			48.0	M4C	6	move to the proper
						hole on the tray
			33.6	S	6	Position
			12.0	RL1	6	release
			30.5	R4A	5	Reach for next mount
			3.8	R2E	1	Return hand to workarea
			221.5			
per mount			36.92			

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Fair Lawn, N.J. 07410

TRAY TO SEAL CONVEYOR

(EXISTING)

Sheet ____ of ____
SYSTEM: MTM-
STUDY NO. ____
DATE: ____
ANALYST: ____

LEFT HAND DESCRIPTION	F	LH MOTION	TMU	RH MOTION	F	RIGHT HAND DESCRIPTION
To left side of the tray	1	R4E	6.2	R4E	1	To Right side of the tray
Grasp the mount	3	G1C2	25.1	G1C2	3	Grasp the mount
Clear the hole	3	M2B	13.8	M2B	3	clear the hole
Move to the seal conv.	3	M8C	35.4	M8C	3	Move to the seal conv.
Position	3	SS	27.3	SS	3	Position
Release	3	RL1	6.0	RL1	3	Release
Reach for the next mount	2	R8A	15.5	R8A	2	Reach for the next mount
			131.2			
Per mount			21.56			

MTM

MTM ASSOCIATION FOR STANDARDS AND RESEARCH
9-10 Saddle River Road
Fair Lawn, N.J. 07410

TRAY TO SEAL CONVEYOR

(IMPROVED)

Sheet ____ of ____
SYSTEM: MTM-
STUDY NO. ______
DATE: ______
ANALYST: ______

LEFT HAND DESCRIPTION	F	LH MOTION	TMU	RH MOTION	F	RIGHT HAND DESCRIPTION
To left side of tray	1	R4E	6.8	R4E	1	To Right side of tray
Grasp the mount	3	G1C2	26.1	G1C2	3	Grasp the mount
clear the hole	3	M2B	13.8	M2B	3	clear the hole
Move to seal conveyor	3	M8C	35.4	M8C	3	Move to seal conveyor
Position	3	SS	27.3	SS	3	Position
Release	3	RL1	6.0	RL1	3	Release
Reach for the next mou.	2	R8A	15.8	R8A	2	Reach for the next mount
			131.2			
Per mount			21.86			

In this case a more systematic method is suggested.

MTMA 1006

APPENDIX C

This book is intended to help you to understand and learn the transfer and inspection operation at the manual mount inspection station.

The following rules explain how this training manual should be used by you.

1. This book will be always available near your work station. You are free to refer to this any time you desire.
2. You also are required to see the 'Mount Defects Display Board'. The actual defective mounts are displayed on this along with the proper explanation.
3. A designated trainer must be assigned to help you learn your job. She must explain each item listed in the book, and when appropriate show you how to do the operation. She should then let you try it yourself and help you if necessary.
4. The book contains a list of things you need to know to learn your job and the designated trainer will explain each of them to you. At the end of your training your supervisor will ask you if everything was explained to you.
5. It is not necessary for the designated trainer to explain to you the things you already know.

If you know how to do the part of the job, tell your teacher to skip that part of the training and go on to something you do need help with.

6. This book should be used on the manufacturing floor at the job. It is not supposed to be used in an office.

TRAINING PROGRAM

LAMP GROUP OPERATOR - MOUNT INSPECTION STATION

OBJECTIVE: To learn how to inspect and transfer mounts from one conveyor to the other. Also to learn the exact hand motions during these operations.

TEACHER: Pictures of hand motion pattern during transfer and inspection.
Help of designated trainer.

EXPLANATION: The following pictures will explain to you the hand motions you should follow in order to achieve maximum efficiency. In addition, these movements will help you to reduce strain and fatigue.

There are three major work cycles you will be doing:

1. Transfer and inspection of mounts from input conveyor to the seal conveyor.
2. Transfer and inspection of mounts from input conveyor to trays.
3. Transfer of mounts from trays to the seal conveyor.

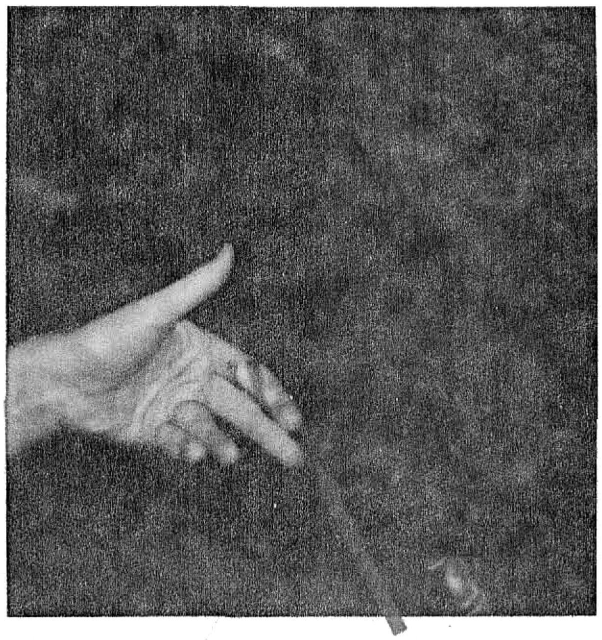
Refer to the pictures for mastering the movements and consult the teacher for further help.

THIS BOOK CONTAINS NUMEROUS PICTURES THAT ARE ATTACHED TO DOCUMENTS CROOKED.

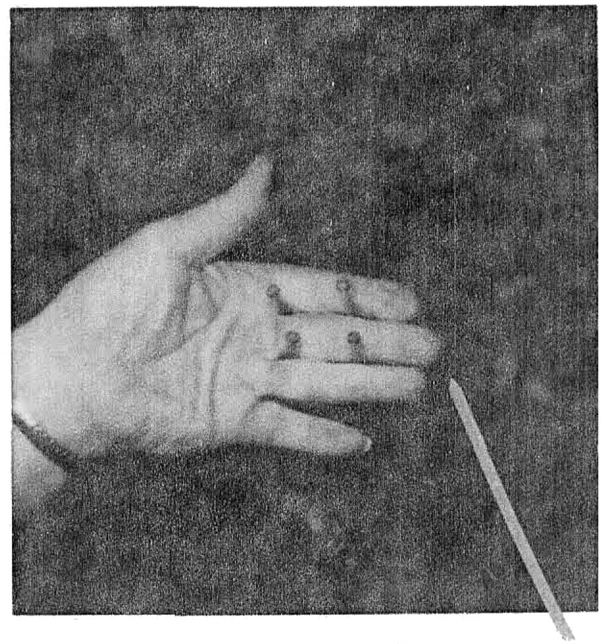
THIS IS AS RECEIVED FROM CUSTOMER.

FOLLOW THESE HAND MOTIONS

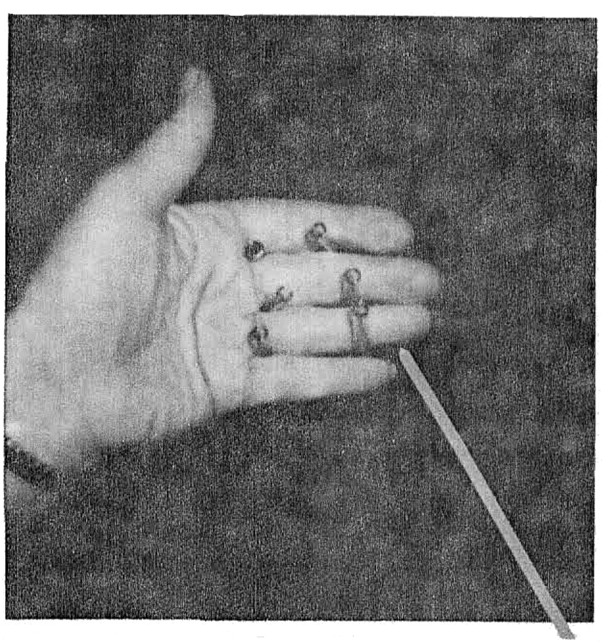
Activity: Pickup mounts from input conveyor, inspect and load to the sealing conveyor.



1. Pickup first two mounts with your left hand. Between 1 st two fingers.

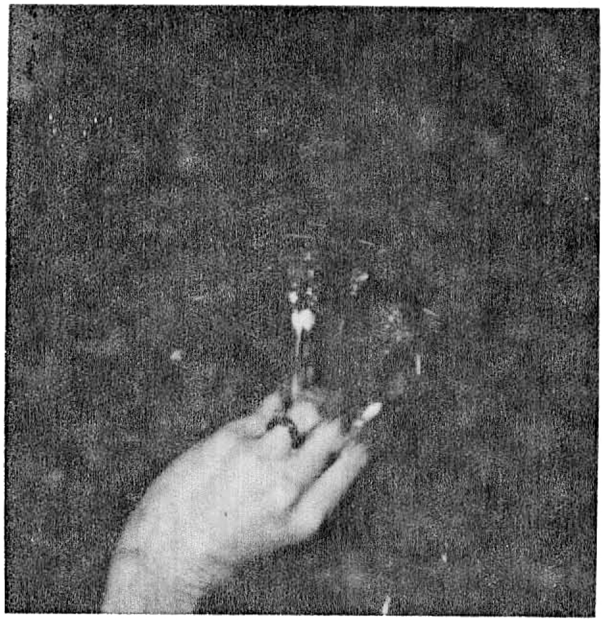


2. Pickup 3 rd and 4 th mount, between second and third finger.

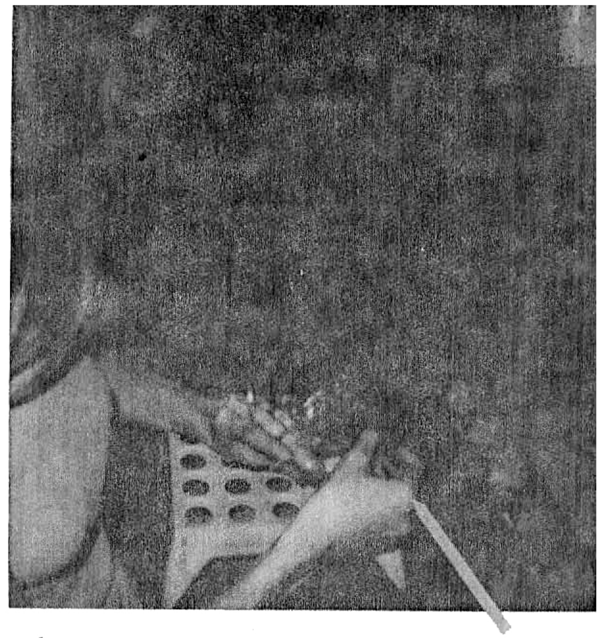


3. Pickup 5 th and 6 th mount, between ring and little finger.

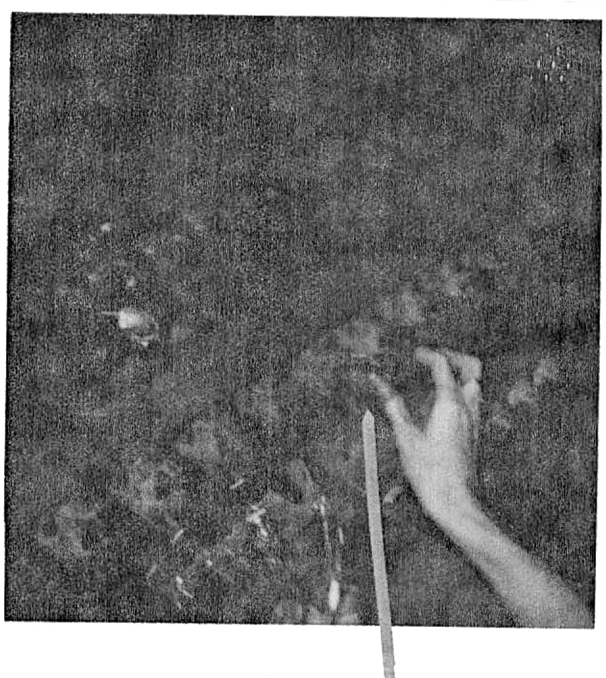
4. Turn your hand



5. Move the hand closer.
Inspect while moving.



6. Grasp the first mount.
Inspect for defects.
Move to sealing conveyor.

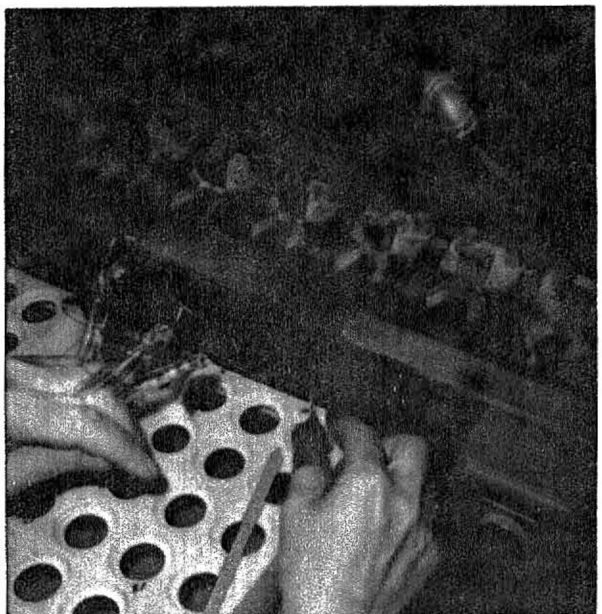


7. Load good mounts.

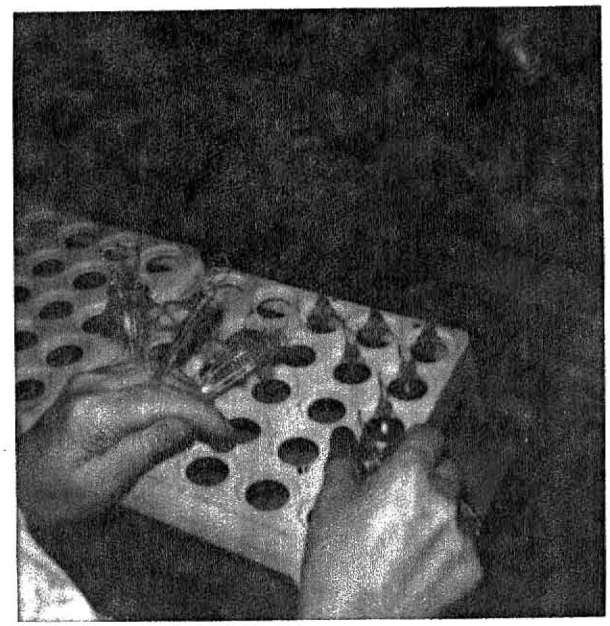
8. Orient while loading.

FOLLOW THESE HAND MOTIONS

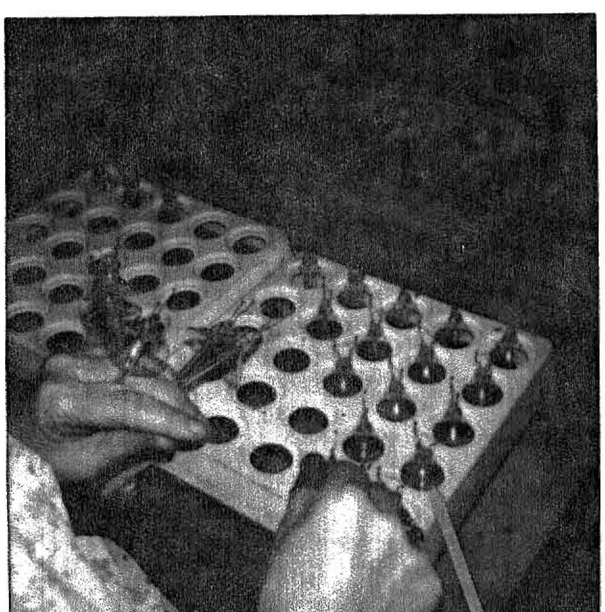
Activity: Pickup mounts from the input conveyor and fill the tray in the following manner.



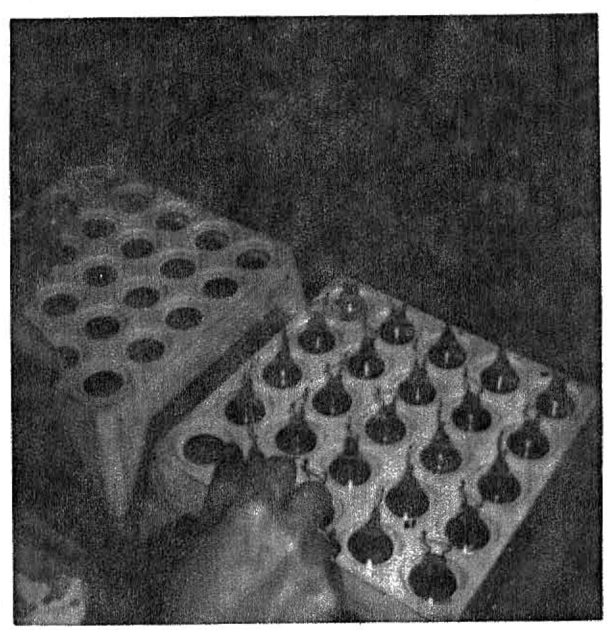
1. Start filling the tray from top right hand corner.



2. Fill the tray diagonally.



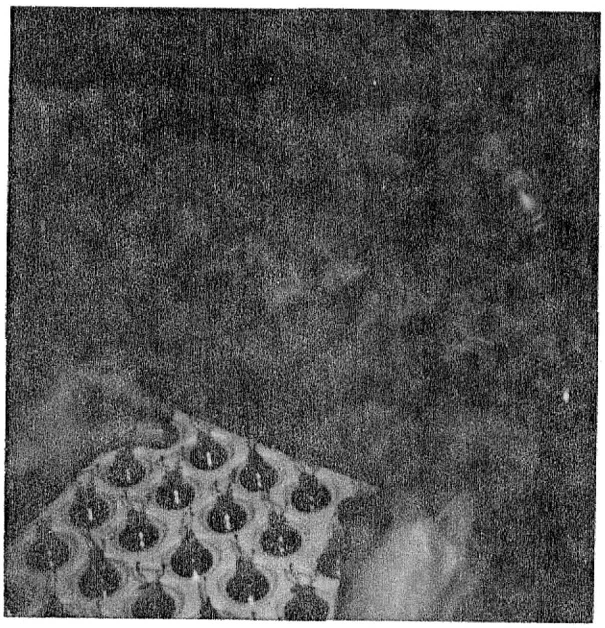
3. Continue the pattern.



4. Fill the tray to the left hand bottom corner.

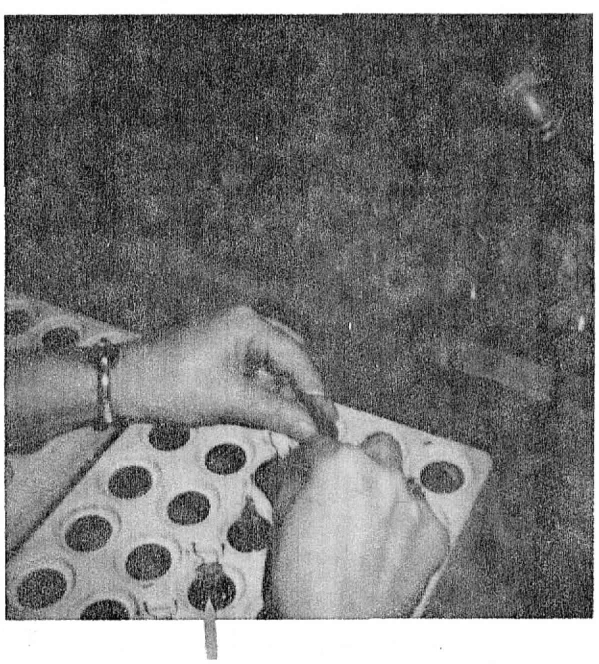
FOLLOW THESE HAND MOTIONS

Activity: Pickup mounts from the tray and load on the sealing conveyor.



1a. Pickup two mounts simultaneously. Use both hands. Start on outside columns.

1b. Next do the inner columns.



1c. Last pickup mounts from middle column.

2. Load the two mounts on adjacent fixtures. Orient coils.

APPENDIX D

TRAINING PROGRAM

LAMP GROUP OPERATOR - MOUNT INSPECTION STATION

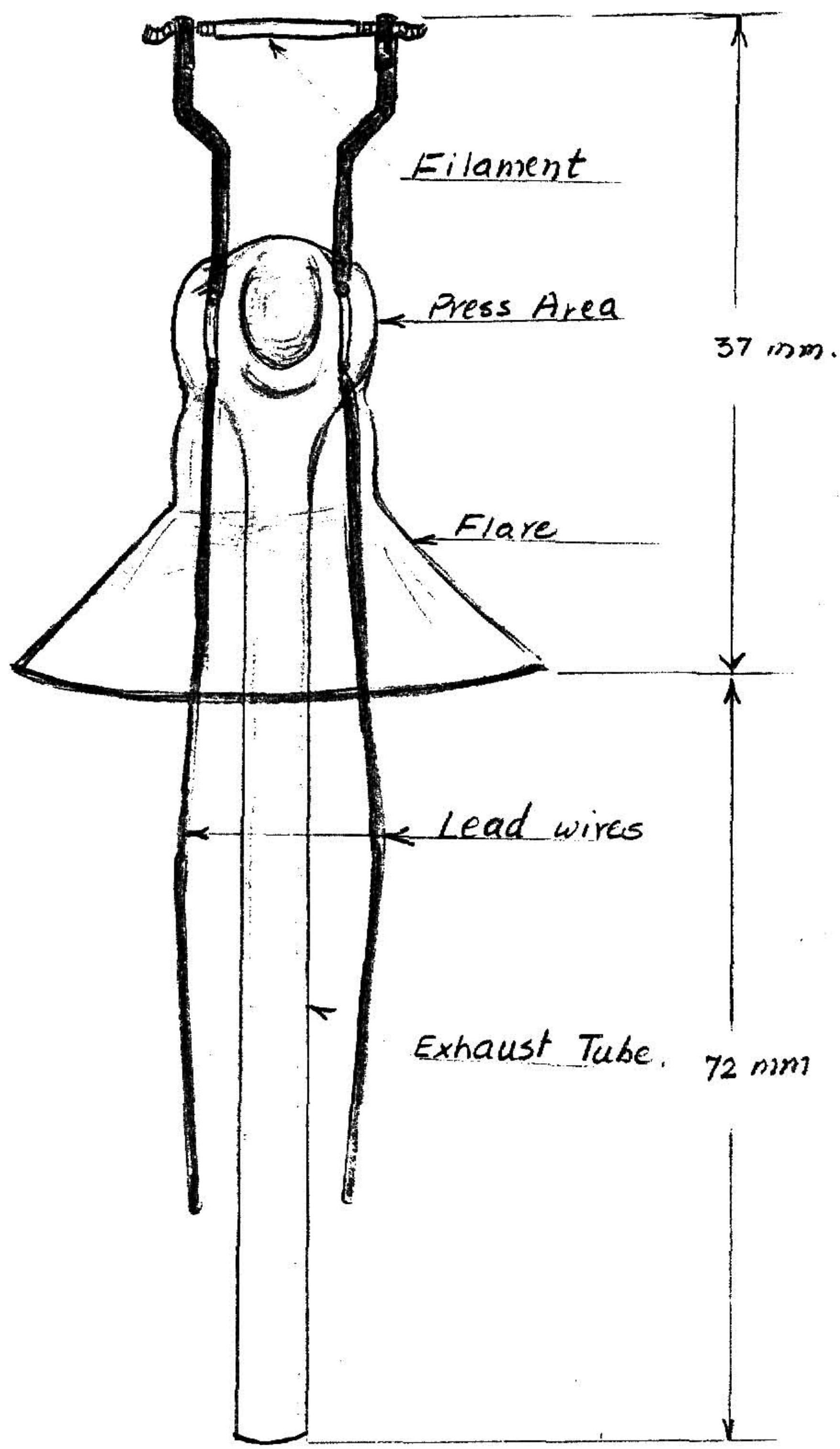
OBJECTIVE: To learn the various defects in mounts to look for and to understand the consequences of the defective mounts on the final quality.

TEACHER: 1. The sketches showing the defective mounts.
2. 'Mount Defects Display Board'.

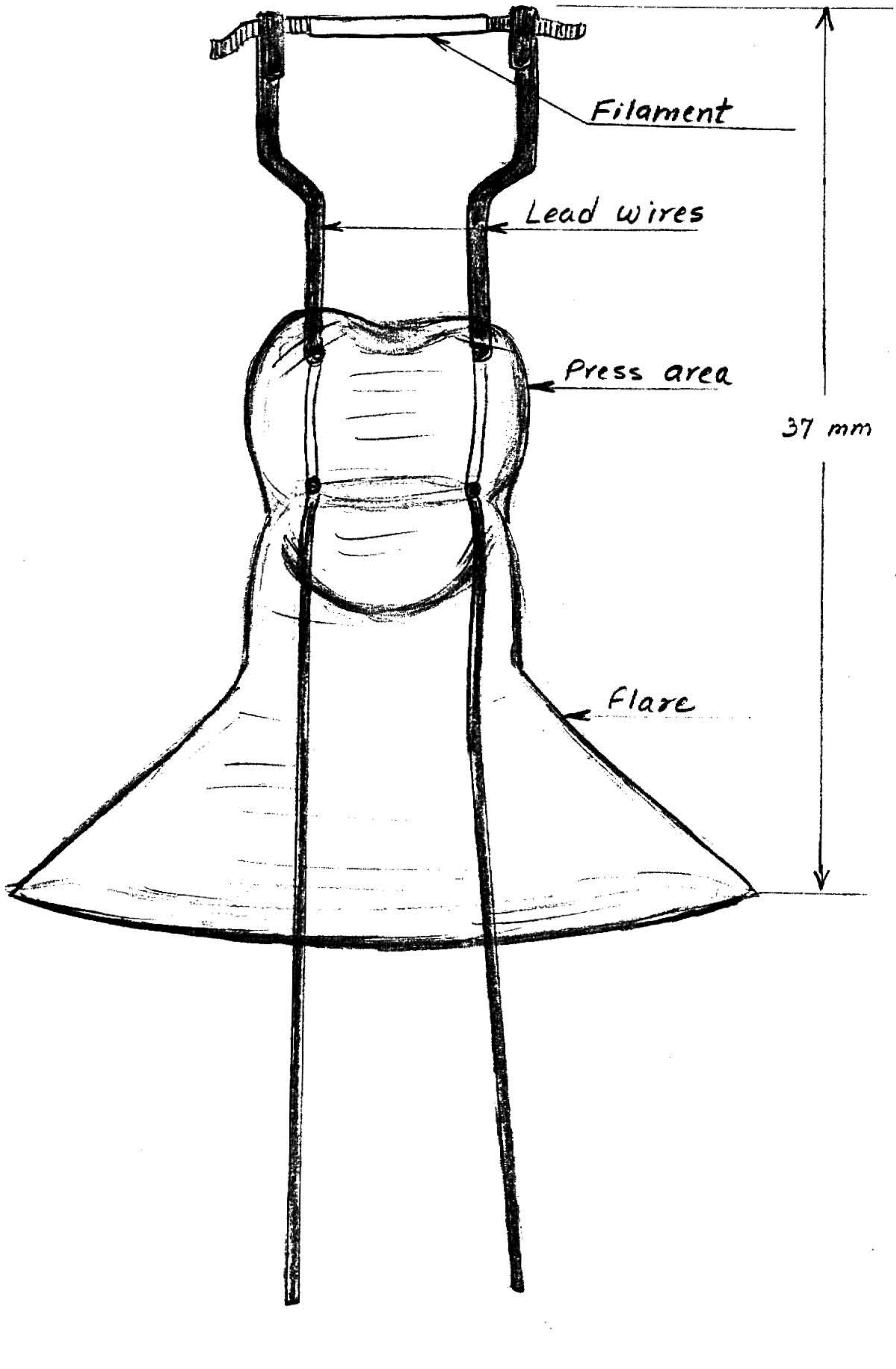
EXPLANATION: The defects are classified under three headings.

1. Critical defect:
   Defects difficult to detect. May not cause immediate failure of the lamp.
2. Major defect:
   Defect somewhat difficult to detect. May and may not cause immediate failure of the lamp.
3. Minor defect:
   Defect less difficult to detect. The lamp may be rejected in the further operations.

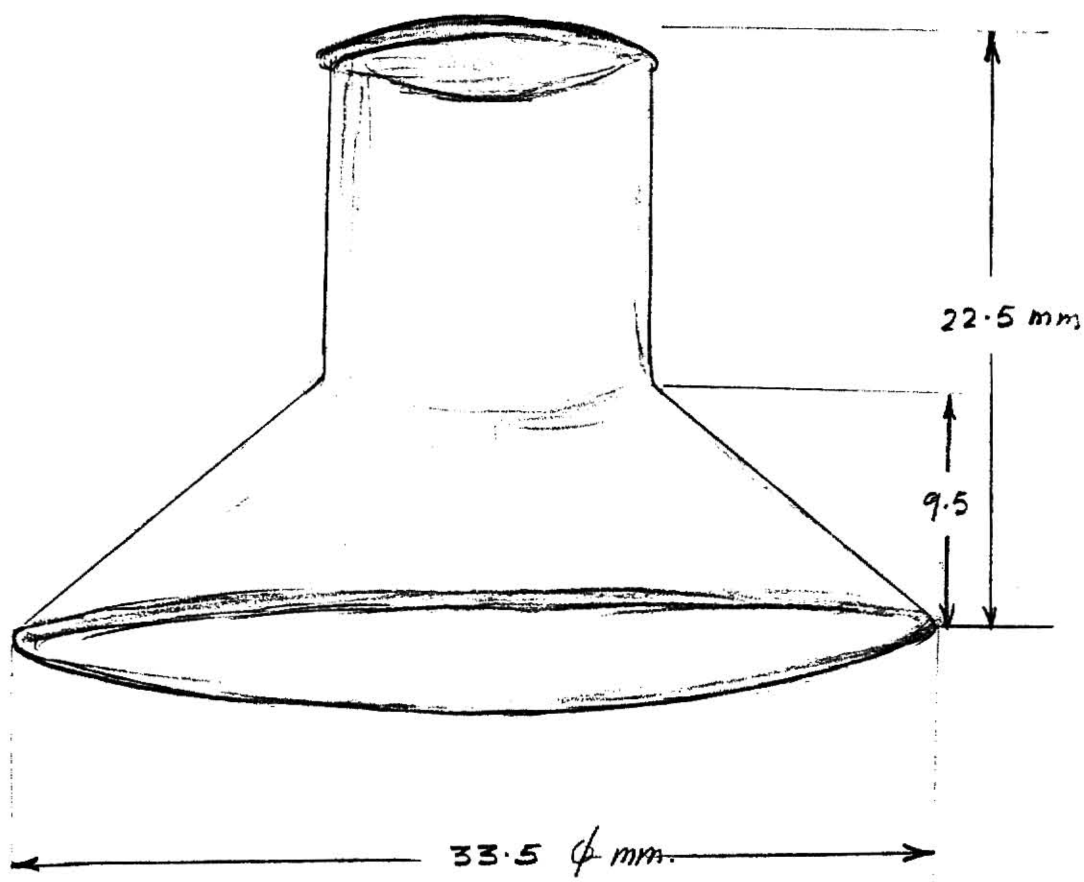
TUBULAR MOUNT



F 40 NON TUBULAR MOUNT

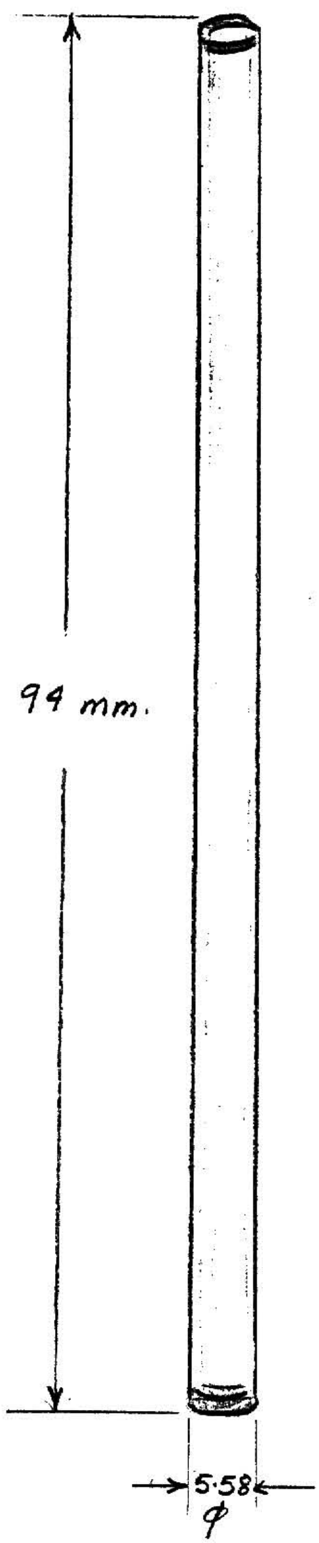


FLARE



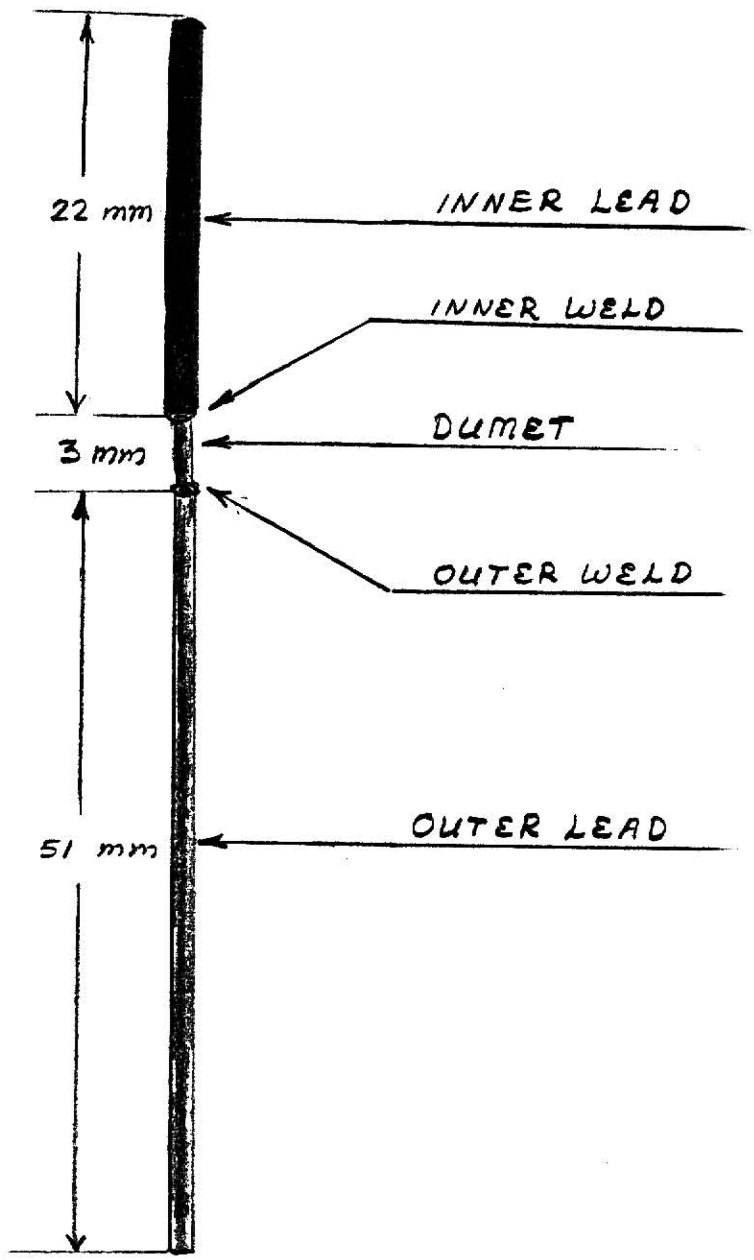
All dimensions are subject to change.

EXHAUST TUBING



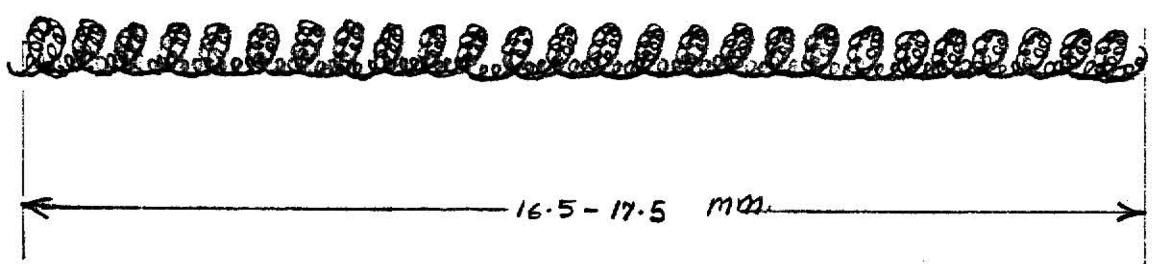
All dimensions are subject to change.

LEAD WIRE

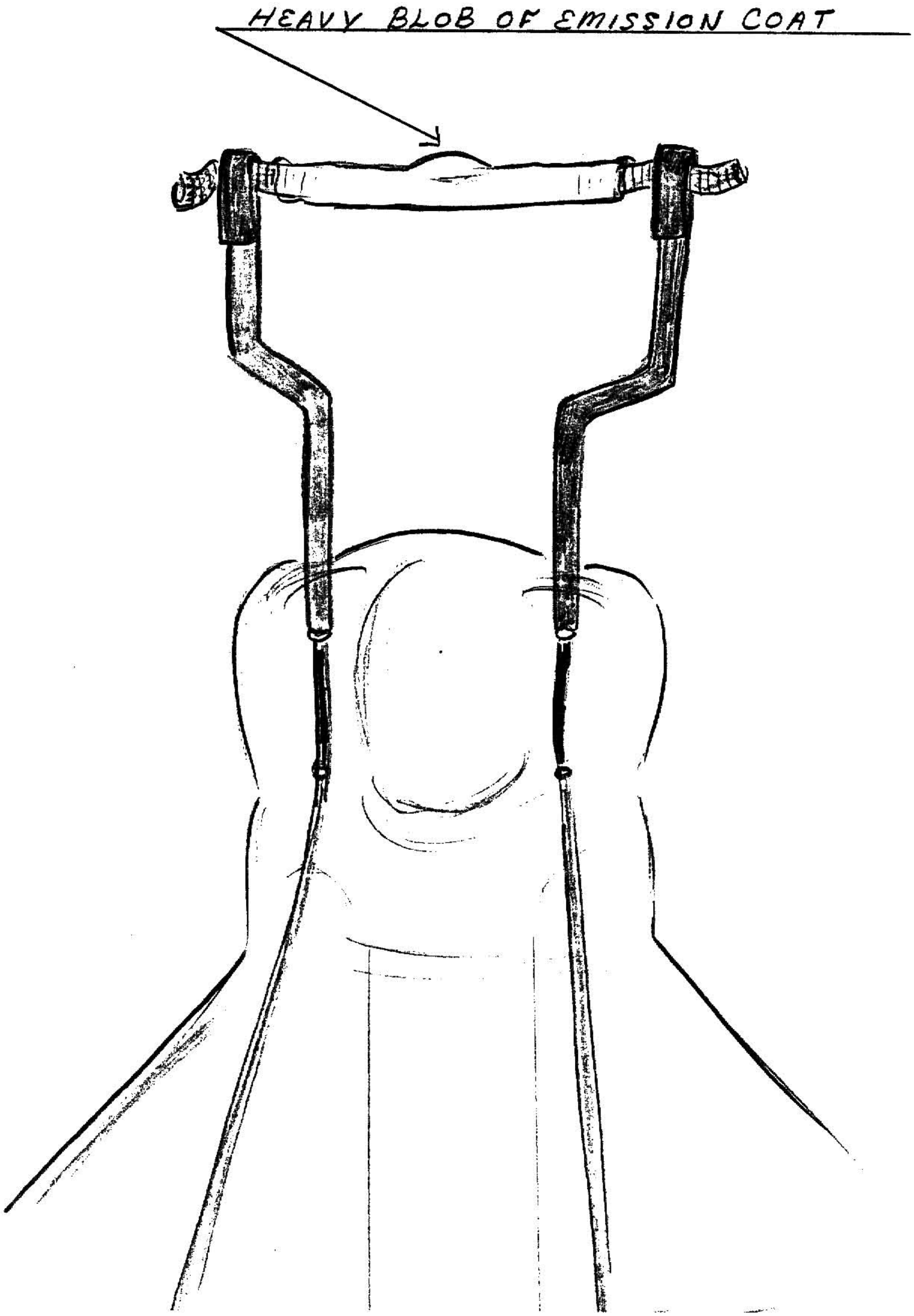


All dimensions are subject to change.

F 40 COIL (FILAMENT)



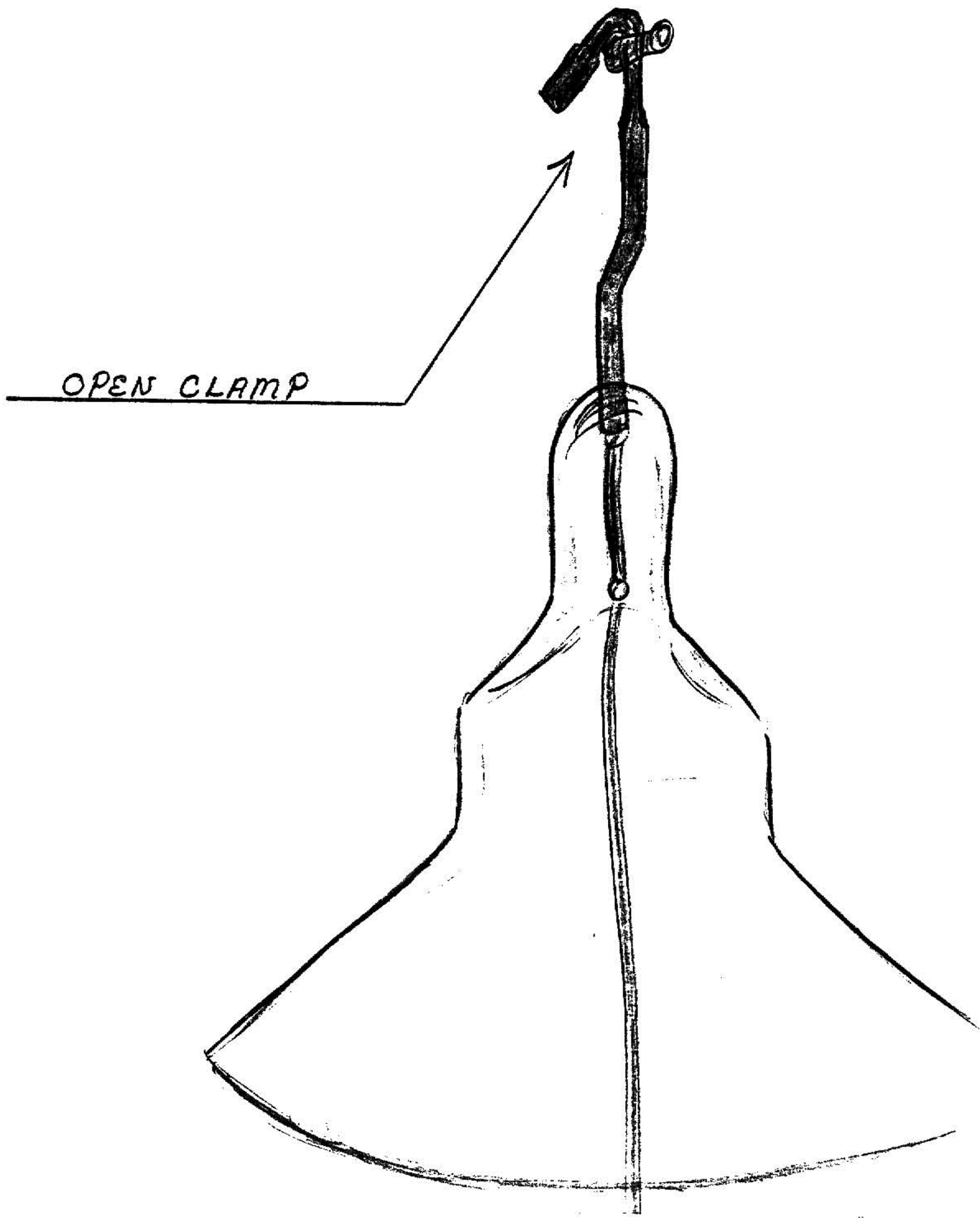
All dimensions are subject to change.



Emission coverage out of specification

CRITICAL DEFECT

Consequence: End discoloration

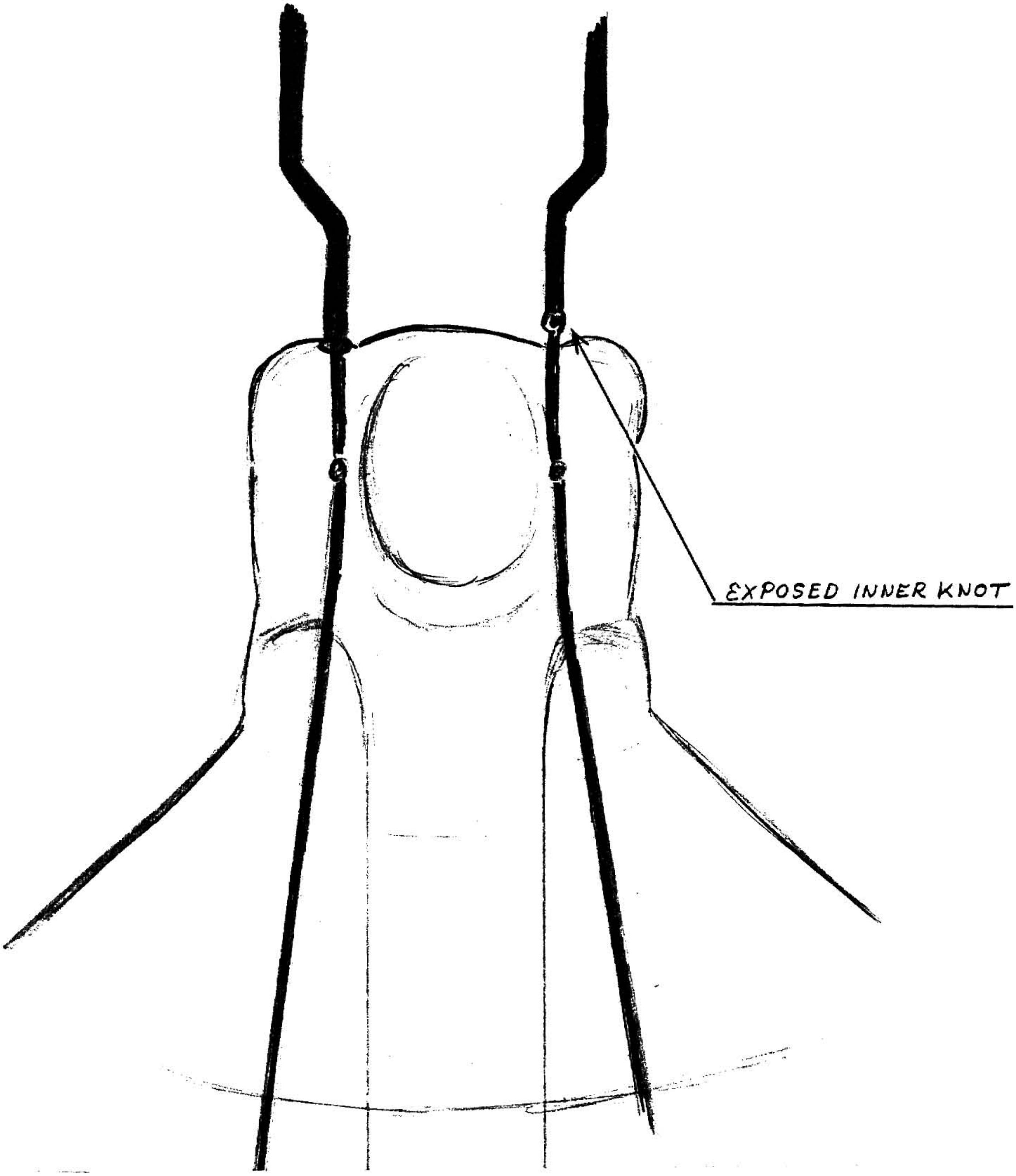


coil not properly clamped

<u>CRITICAL DEFECT</u>

Consequence: Lamp may not be rejected

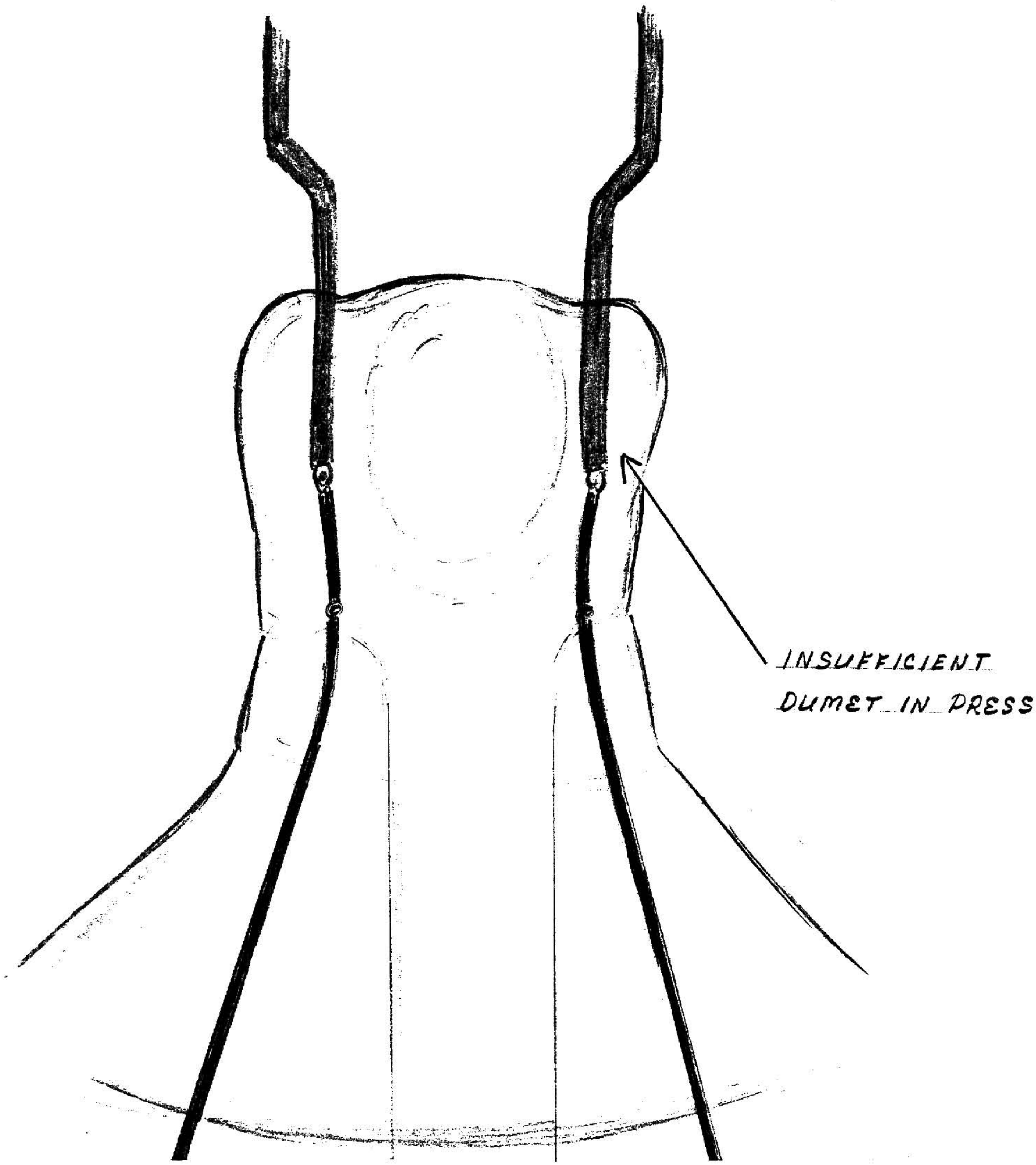
Shortened life



Lead weld knot partially or completely outside of glass

CRITICAL DEFECT

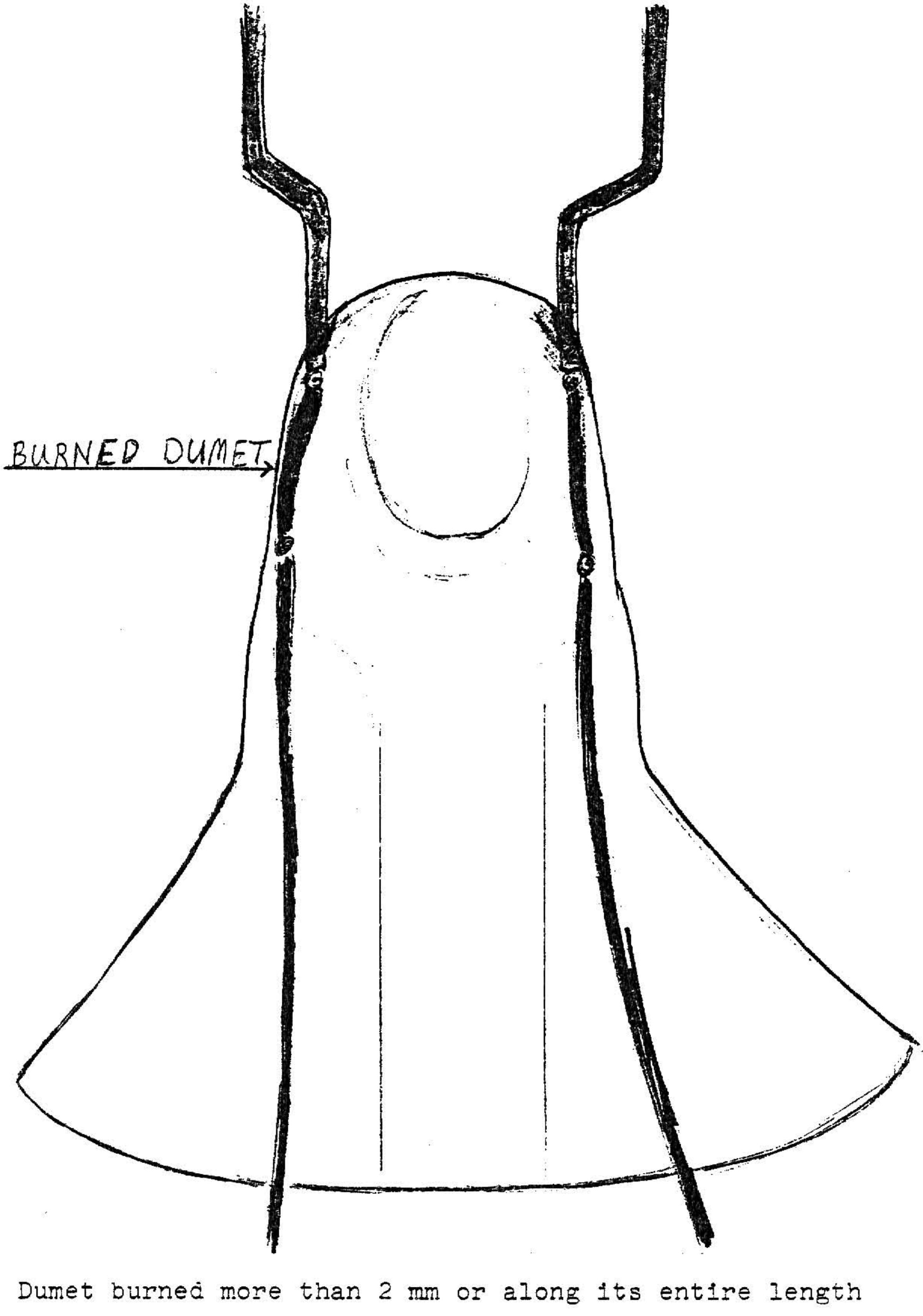
Consequence: Possible leakage in 'press'.



Any mount with less than 2 mm good dumet in press

CRITICAL DEFECT

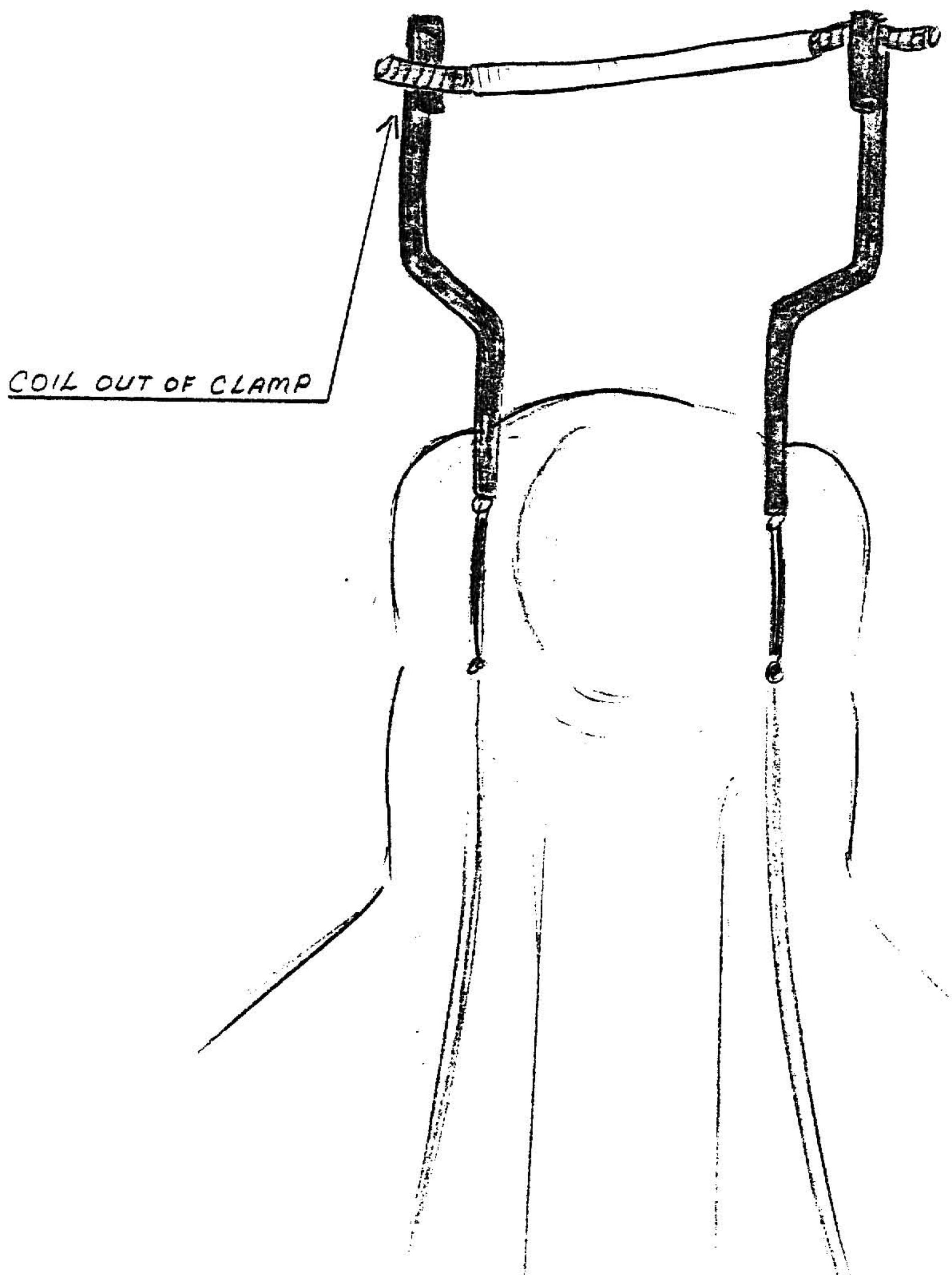
Consequence: Shortened life due to slow leak in press



Dumet burned more than 2 mm or along its entire length

MAJOR DEFECT

Consequence: Shortened life due to slow leak in press



Any coil completely out of clamp

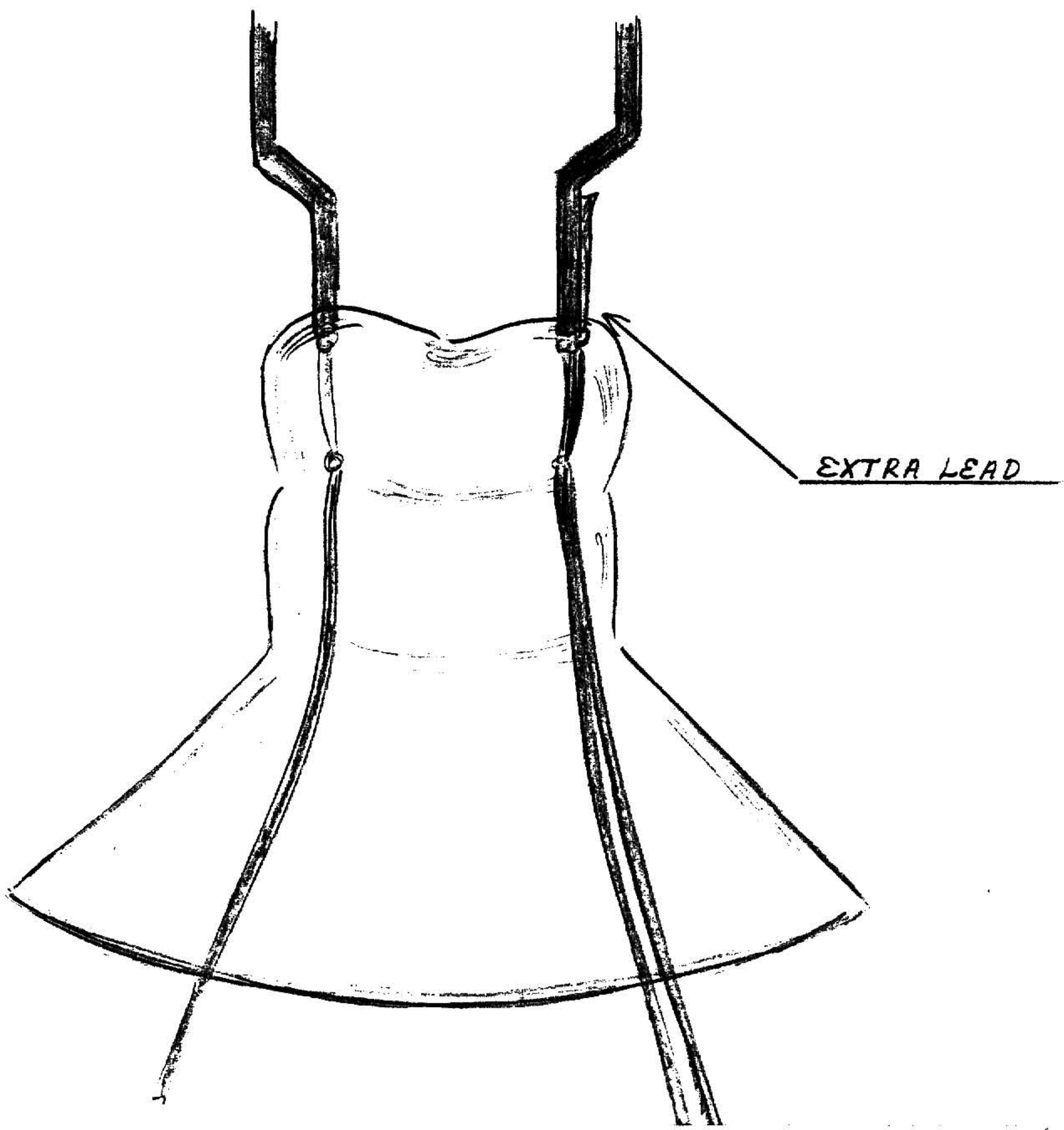
MAJOR DEFECT

Consequence: Lamp may be rejected at Top Pan

The ridged glass flare

MAJOR DEFECT

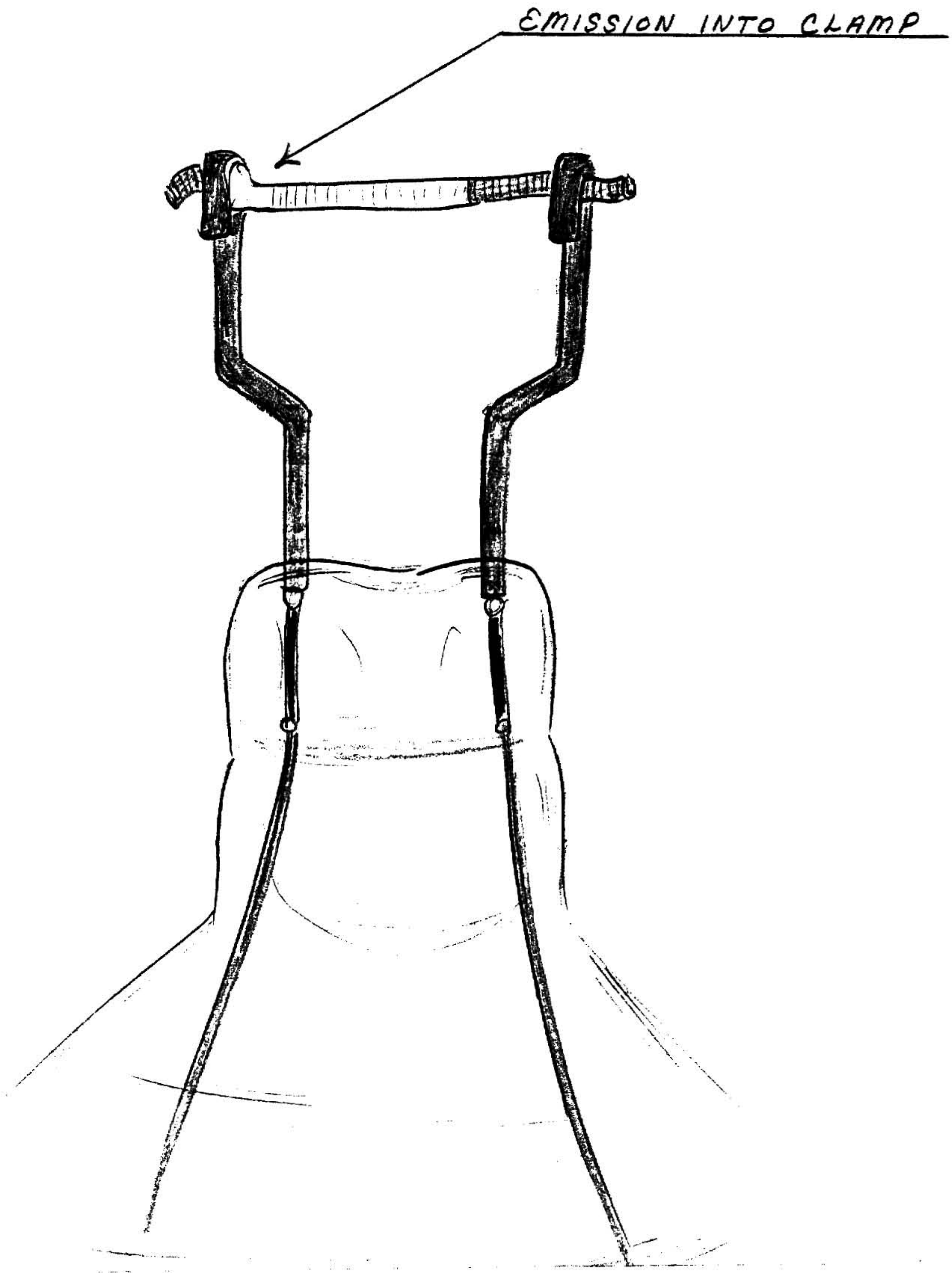
Consequence: Prevent sealing



More than two lead wires

MAJOR DEFECT

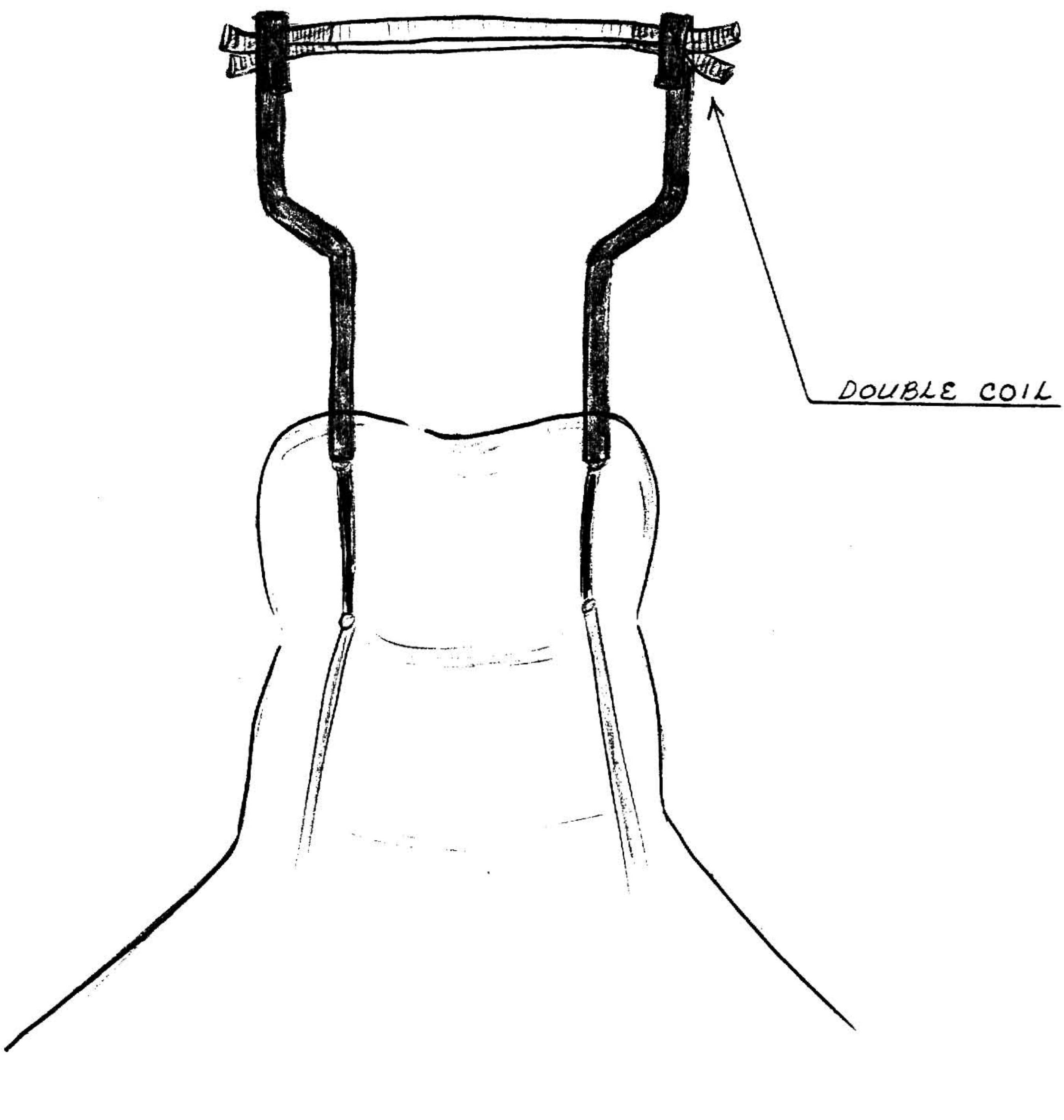
Consequence: Lamp may be rejected at leaky tube station



Emission on the clamp or outer leadwire

MINOR DEFECT

Consequence: End discoloration

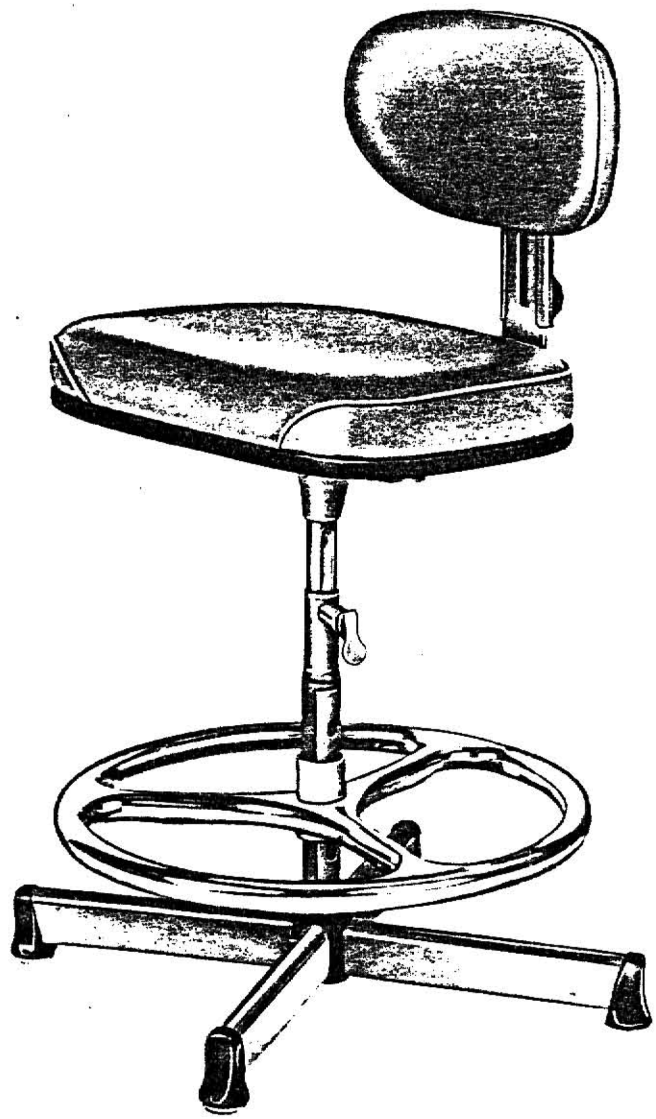


Two coils on the mount

MINOR DEFECT

Consequence: Lamp may be rejected at Bottom Pan station

APPENDIX E



The New Chair

APPENDIX F

On Jan. 15, 1980 the rejected lamps on HAP I at the Bottom Pan Station were saved. These lamps were broken and the defective mounts were classified under five main headings. Following is the summary of observed defects.

Defects	No. of Tubular	No. of Non-Tubular	Total	% in a Given Lot
Dumet				
Red	16	13		
Burnt	8	5	42	31.5%
Coil				
Double	7	4		
Skeleton	1	0		
Broken	8	8		
No coil	2	3	33	25.0%
Clamp				
Out of clamp	19	2		
Loose	3	5		
Scissor	5	2	36	27.0%
Emission				
Length	1	1		
Weight	0	0		
Coverage	0	0	2	1.5%
Misc.				
Glass chipped or cracked	1	3		
Air bubles	2	2		
Bad lead wire	2	3		
Triple wire	0	0		
Knot	5	2	20	15.0%
Total	80	53	133	100.0%

On Jan. 15, 1980 the rejected mounts on HAP I at the Manual Mount Inspection Station were saved. These defective mounts were classified under five main headings. Following is the summary of the observed defects.

Defects	No. of Tubular	No. of Non-Tubular	Total	% in a Given Lot
Dumet				
Red	11	9		
Burnt	2	4	26	5.0%
Coil				
Double	21	43		
Skeleton	3	1		
Broken	5	1		
No coil	36	8	118	21.5%
Clamp				
Out of clamp	5	8		
Loose	5	3		
Scissor	53	31	105	19.0%
Emission				
Length	29	2		
Weight	3	1		
Coverage	3	4	42	7.5%
Misc.				
Glass chipped or cracked	63	49	112	20.5%
Air bubles	11	4		
Bad lead wires	19	9		
Triple wires	17	16		
Knot	31	3		
Misc.	3	10	123	22.5%
Good mounts	17	6	23	4.0%
Total	337	212	549	100.0%

APPENDIX G

Results of inserting known defects into line.

Defects	Rejected at
Dumet	
Red	Bottom pan
Burnt	Not tested
Coil	
Double	Bottom pan
Skeleton	Not tested
Broken	No light
Stretched	Not rejected
No coil	Not tested
Clamp	
Out of clamp	Not tested
Loose	Leaky tube
Scissor	Not rejected
Emission	
Length	Top pan
Weight	Not tested
Coverage	Top pan
Misc.	
Glass chipped or cracked	Not tested
Air bubles	Not tested
Bad lead wires	Not tested
Three lead wires	Leaky tube
Deformed(angular)flare	Leaky tube, bulb was broken at the end.

APPENDIX H

Written Instructions

You are participating in an Industrial Engineering research project. Your cooperation will be greatly appreciated. Your privacy will be maintained throughout the experiment. The results will be identified by numbers only.

You will inspect mounts for various defects. The mounts are kept in the trays. When you locate a defective mount, call out the 'number' on the mount along with the name of the defect. You will be given 15 sec. per tray.

Next you will undergo a training session with Mary. She will explain you various defects, their consequences on the final product and will show you the 'Mount Defects Display Board'.

After the training session you will perform the same task in the similar manner.

Two weeks later from today you will inspect the mounts once again. Meanwhile you are encouraged to read the training manual and study the Display Board.

Do you have any questions?

Ready?

Begin..

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

THIS IS AS RECEIVED FROM CUSTOMER.

APPENDIX I

Sr. No.	Defective Mount No.	Description of the Defect	SUBJECT 1			SUBJECT 2			SUBJECT 3			SUBJECT 4		
			Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
1	2	Insufficient dumet in press												
2	28	Upside down lead wire		X		X		X	X					
3	43	Exposed inner knot		X										
4	77	Multiple lead wires	X	X	X	X	X	X		X	X	X	X	X
5	92	Skeleton coil	X	X	X	X	X	X	X		X	X	X	X
6	103	No coil	X	X	X	X	X	X	X	X		X	X	X
7	116	Double coil	X	X	X	X	X	X	X	X	X		X	X
8	117	Broken flare		X								X		
9	134	Foreign material on glass	X	X	X	X	X	X	X	X	X	X	X	X
10	143	Coil off-center						X					X	
11	161	Emission too far from clamp				X	X	X						
12	167	Hole through press(Red wire etc.)	X		X		X	X	X		X	X	X	X
13	177	Press poorly formed	X	X	X		X	X	X	X		X	X	X
14	186	Ridged flare		X							X			
15	196	Broken flare		X	X									
16	197	Emission too close to clamp												
17	204	Upside down lead wire		X	X	X	X	X	X	X			X	
18	205	Emission too close to clamp				X								
19	215	Dirt or grease on the flare												
20	220	Exposed inner knot						X			X		X	
21	233	Blob on emission				X	X	X	X			X	X	X
22	236	Broken flare					X				X			
23	244	Scissor clamp											X	
24	246	Stretched coil		X	X	X	X	X	X	X	X	X	X	X
25	249	Burned dumet		X	X		X	X			X	X	X	X

Sr. No.	Defective Mount No.	Description of the Defect	SUBJECT 1			SUBJECT 2			SUBJECT 3			SUBJECT 4		
			Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
26	261	Chipped blow hole	X	X	X			X	X	X	X	X	X	X
27	279	Burned dumet	X	X		X	X	X	X	X	X	X		X
28	307	Multiple lead wires	X	X	X	X	X		X	X	X	X		X
29	326	Double coil					X			X	X	X		
30	329	Burned dumet												
31	336	Broken flare			X			X		X	X		X	X
32	342	Ridged flare						X						
33	362	Burned dumet	X	X		X	X				X			
34	370	Multiple lead wires	X	X	X	X		X	X	X			X	
35	419	Broken exhaust tube								X	X			
36	420	Double coil	X	X	X	X	X	X	X	X	X	X	X	X
37	422	Upside down lead wires												
38	432	No coil	X	X		X	X	X	X	X	X	X	X	X
39	436	No blow hole			X	X	X	X		X		X	X	X
40	442	Scissor clamp	X	X	X			X				X		
41	445	Chipped and small blow hole			X		X					X		
42	449	No blow hole		X	X		X	X		X	X		X	X
43	458	Chipped blow hole						X						
44	461	Burned dumet	X			X								
45	471	Coil off-center				X		X		X		X	X	X
46	474	Blob on emission	X	X	X	X		X	X	X	X	X	X	
47	476	Burned dumet				X	X					X		
48	481	Multiple lead wires		X	X	X	X	X	X	X			X	X
49	488	No blow hole				X	X	X	X	X	X		X	X
50	491	Ridged flare	X		X	X	X	X		X	X			

APPENDIX J

Summary of 50 known defects in sample of 500.

Name of the defect	Category	Number of in 50	Results/ Remarks
Burned dumet	Critical	7	Difficult
Upside down lead	Critical	3	Difficult
Scissor clamp	Critical	2	Very Difficult
Coil off-center	Critical	2	Difficult
Blob on emission	Critical	2	Not difficult
Insufficient dumet in press	Critical	1	Not detected*
Exposed inner knot	Critical	2	Very difficult
Skeleton coil	Critical	1	Not difficult
Emission too far from clamp	Critical	1	Very difficult
Emission too close to clamp	Critical	2	Not detected*
Multiple wires	Major	4	Not difficult
Double coil	Major	3	Not difficult
Ridged flare	Major	3	Difficult
Dirt on the flare	Major	1	Not detected*
Foreign material on the flare	Major	1	Not difficult
Poor press area	Major	1	Not difficult
Stretched coil	Major	1	Not difficult
Broken flare	Minor	4	Difficult
Broken exhaust tube	Minor	1	Not difficult
No coil	Minor	2	Not difficult
Chipped/No blow hole	Minor	6	Difficult
	Total	50	

* Inspectors could not detect these defects.

APPENDIX K

Detailed Calculations of Inspection Training Test

On the following pages the detailed analysis of the Inspection Training Test is given.

Sample size: 500 mounts, including 50 defective mounts.

SUBJECT 1

Test 1: Before training session.

	Defective	Good	Total
Accept	32	447	479
Reject	18	3	21
Total	50	450	500

$$\text{Hit Rate} = \frac{18}{50} = 36\%$$

$$\text{Efficiency} = \frac{\frac{447}{479} - \frac{450}{500}}{1 - \frac{450}{500}} = 33.19\%$$

$$\%\ \text{Errors} = \frac{35}{500} = 7\%$$

Test 2: After training session.

	Defective	Good	Total
Accept	25	448	473
Reject	25	2	27
Total	50	450	500

$$\text{Hit Rate} = \frac{25}{50} = 50\%$$

$$\text{Efficiency} = \frac{\frac{448}{473} - \frac{450}{500}}{1 - \frac{450}{500}} = 47.14\%$$

$$\%\ \text{Errors} = \frac{27}{500} = 5.4\%$$

Test 3: After two weeks.

	Defective	Good	Total
Accept	27	450	477
Reject	23	0	23
Total	50	450	500

$$\text{Hit Rate} = \frac{23}{50} = 46\%$$

$$\text{Efficiency} = \frac{\frac{450}{477} - \frac{450}{500}}{1 - \frac{450}{500}} = 43.39\%$$

$$\%\ \text{Errors} = \frac{27}{500} = 5.4\%$$

SUBJECT 2

Test 1: Before training session.

	Defective	Good	Total
Accept	25	446	471
Reject	25	4	29
Total	50	450	500

$$\text{Hit Rate} = \frac{25}{50} = 50\%$$

$$\text{Efficiency} = \frac{\frac{446}{471} - \frac{450}{500}}{1 - \frac{450}{500}} = 46.92\%$$

$$\%\ \text{Errors} = \frac{29}{500} = 5.8\%$$

Test 2: After training session.

	Defective	Good	Total
Accept	19	442	471
Reject	31	8	39
Total	50	450	500

$$\text{Hit Rate} = \frac{31}{50} = 62\%$$

$$\text{Efficiency} = \frac{\frac{442}{461} - \frac{450}{500}}{1 - \frac{450}{500}} = 58.78\%$$

$$\%\ \text{Errors} = \frac{27}{500} = 5.4\%$$

Test 3: After two weeks.

	Defective	Good	Total
Accept	17	439	456
Reject	33	11	44
Total	50	450	500

$$\text{Hit Rate} = \frac{33}{50} = 66\%$$

$$\text{Efficiency} = \frac{\frac{439}{456} - \frac{450}{500}}{1 - \frac{450}{500}} = 62.72\%$$

$$\%\ \text{Errors} = \frac{28}{500} = 5.6\%$$

SUBJECT 3

Test 1: Before training session.

	Defective	Good	Total
Accept	31	442	473
Reject	19	8	27
Total	50	450	500

$$\text{Hit Rate} = \frac{19}{50} = 38\%$$

$$\text{Efficiency} = \frac{\frac{442}{473} - \frac{450}{500}}{1 - \frac{450}{500}} = 34.46\%$$

$$\%\ \text{Errors} = \frac{39}{500} = 7.8\%$$

Test 2: After training session.

	Defective	Good	Total
Accept	25	445	470
Reject	25	5	30
Total	50	450	500

$$\text{Hit Rate} = \frac{25}{50} = 50\%$$

$$\text{Efficiency} = \frac{\frac{445}{470} - \frac{450}{500}}{1 - \frac{450}{500}} = 46.8\%$$

$$\%\ \text{Errors} = \frac{30}{500} = 6.0\%$$

Test 3: After two weeks.

	Defective	Good	Total
Accept	26	445	471
Reject	24	5	29
Total	50	450	500

$$\text{Hit Rate} = \frac{24}{50} = 48\%$$

$$\text{Efficiency} = \frac{\frac{445}{471} - \frac{450}{500}}{1 - \frac{450}{500}} = 44.79\%$$

$$\%\ \text{Errors} = \frac{31}{500} = 6.2\%$$

SUBJECT 4

Test 1: Before training session.

	Defective	Good	Total
Accept	28	446	474
Reject	22	4	26
Total	50	450	500

$$\text{Hit Rate} = \frac{22}{50} = 44\%$$

$$\text{Efficiency} = \frac{\frac{446}{474} - \frac{450}{500}}{1 - \frac{450}{500}} = 36.97\%$$

$$\%\ \text{Errors} = \frac{32}{500} = 6.4\%$$

Test 2: After training session.

	Defective	Good	Total
Accept	25	440	465
Reject	25	10	35
Total	50	450	500

$$\text{Hit Rate} = \frac{25}{50} = 50\%$$

$$\text{Efficiency} = \frac{\frac{440}{465} - \frac{450}{500}}{1 - \frac{450}{500}} = 46.23\%$$

$$\%\ \text{Errors} = \frac{32}{500} = 6.4\%$$

Test 3: After two weeks.

	Defective	Good	Total
Accept	26	442	468
Reject	24	8	32
Total	50	450	500

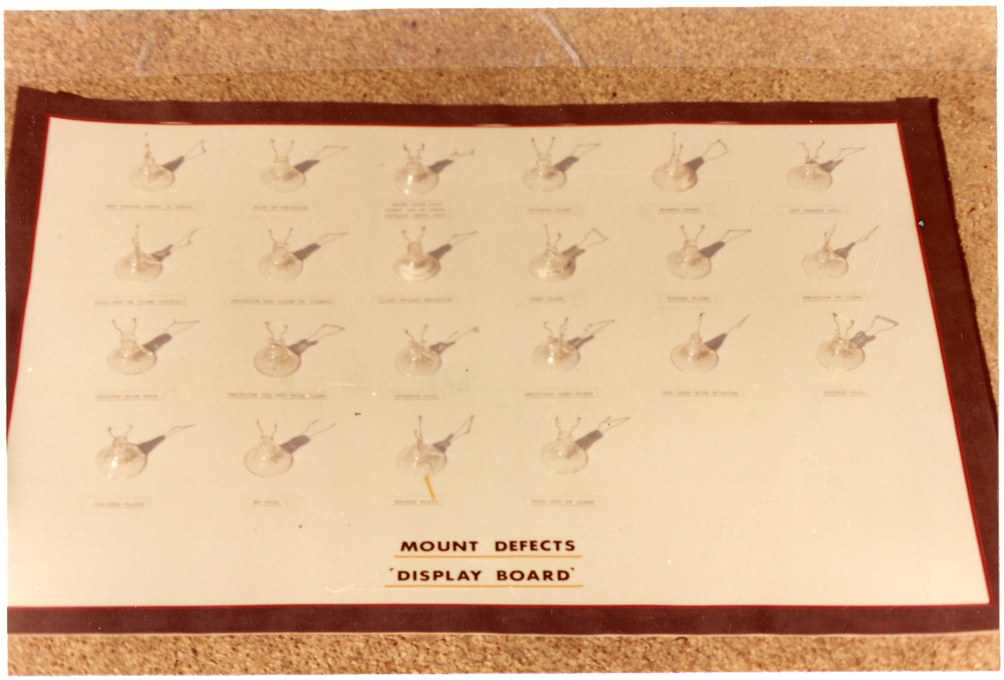
$$\text{Hit Rate} = \frac{24}{50} = 48\%$$

$$\text{Efficiency} = \frac{\frac{442}{468} - \frac{450}{500}}{1 - \frac{450}{500}} = 44.44\%$$

$$\%\ \text{Errors} = \frac{34}{500} = 6.8\%$$

APPENDIX L

MOUNT DEFECTS DISPLAY BOARD



IMPROVING INSPECTION PERFORMANCE

by

ARUN SHRIDHAR JOSHI

B.E., Bombay University, India, 1976

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1980

ABSTRACT

Westinghouse Electric Corporation,at Salina, Kansas manufactures two types of fluorescent lamps. One is a four foot long 40 Watt bulb, while the other is an eight foot slimline model.

Knowing the concern of the company over the outgoing quality and high amount of shrinkage due to inprocess rejection, it was decided to study the inspection procedure of the fluorescent tube ends(called mounts henceforth).

The objective of the study was to improve the inspection performance at the manual mount inspection station. To achieve this the following areas were given special attention:

1. Inspector training and training aids.
2. Improvements in the workplace layout.
3. Inspection procedure.

A training manual including pictures of improved hand motions and the sketches of the defective mounts was prepared. Also a 'Mount Defects Display Board' was designed. Using this training package an Inspection Training Test was conducted. Four experienced inspectors participated in the experiment. After undergoing the training session, the inspector's Hit Rate improved

from 40% to 53%; the efficiency improved from 34% to 50%. In addition, the improved performance was consistent even after two weeks. With the improved inspection performance, the company can save in the region of $120,000 per year.

Various modifications in the workplace layout and in the storage system were suggested. The MTM analysis of the improved method showed about .196 sec./mount saving. With this a 19% increase in the productivity is possible.