NRL REPORT E-3365

# DEVELOPMENT OF FIRE ALARM THERMOSTAT OTHER THAN MERCURY-IN-GLASS

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## ABSTRACT

It was desired to investigate all types of mechanical and electrical fire alarm thermostats, other than mercurial, that would retain advantages of the mercurial and, in addition, be inherently resistant to high-impact shock. Attention was concentrated on a differential control thermostat recently modified for fixed-temperature (fire alarm) applications.

Preliminary shock tests disclosed the need for some shock protection. Various methods of shock mounting were considered, and a simple shock mount was developed adequately to protect the thermostat from high-impact shock. Tests show this shock-mounted thermostat may be used as alternate for the mercury-in-glass type provided the tolerance in operating point is increased to $\pm$ 5° F and the integral low-temperature alarm feature is not required.

## PROBLEM STATUS

This is a final report on NRL Problem E04-05D. Unless the Laboratory is otherwise advised by the Bureau, this problem will be closed one month from the mailing date of this report.

## AUTHORIZATION

NRL Problem No. E04-05D (BuShips No. S64-4(335) 12 April 1946).

## DEVELOPMENT OF FIRE ALARM THERMOSTAT OTHER THAN MERCURY-IN-GLASS

### INTRODUCTION

The mercury-in-glass fire alarm thermostat currently employed in shipboard fire alarm systems has not proven entirely satisfactory, largely because the mercury column has a tendency to separate in shipment. In addition, when the thermostat is subjected to high-impact (HI) shock, the mercury column separates and glass breakage occurs unless the thermostat is mounted in the very effective shock mount which was recently developed at this Laboratory.[1]

The primary purpose of this problem was to investigate all types of mechanical and electrical fire alarm thermostats with the aim of developing a particular type that would retain the advantages of the mercury-in-glass thermostat and also be satisfactorily resistant to high-impact shock without the application of elaborate shock mounts. A survey of the general types available and the proposal of several possible methods of detecting a temperature rise were presented in a previous report.[2] It was concluded at that time that the available types offered no distinct advantages over the present one and that possible further development seemed unlikely to present a solution without basic research beyond the scope of this problem.

Later, it was brought to the Laboratory's attention by BuShips that Fenwal Manufacturing Company was in process of modifying its differential control thermostat for fixed temperature (fire alarm) applications. Subsequent discussion with the manufacturer's engineers led to the opinion that the modified thermostats should be greatly superior to some adjustable models previously encountered and that further consideration for shipboard fire detection systems would be merited. Accordingly, it was agreed that this Laboratory would conduct preliminary tests on several fixed-temperature units to determine their susceptibility to damage or maloperation under HI shock and vibration, the conditions to which they were thought most vulnerable.

As the results of these preliminary tests were very encouraging, a larger number of samples, together with a temperature-calibrating unit, were furnished by the manufacturer for more extensive investigation. Most of these samples were employed in the development of a simple shock mount found necessary to protect the thermostats from injury under HI shock.

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[1] Hardesty, G. K. C., G. Pida, and D. T. Scuderi, "Development of Shock Mounting for Fire Alarm Thermostats" (Restricted), NRL Report No. B-2789, 26 August 1946.

[2] NRL Test Report No. 660, Serial 912-46/47, 7 August 1947.

During the course of this investigation, two Underwriters' reports[3] covering performance characteristics of similar thermostats became available. These supplementary data were accepted as sufficiently informative, when considered in conjunction with the Laboratory's work on this problem, to permit an accurate appraisal of the applicability of the thermostats for shipboard fire detection systems. For this reason, and because the Underwriters' procedures are better adapted to the Fenwal thermostats than are the oil bath procedures of the current specification, no sensitivity tests were made by the Laboratory.

## DESCRIPTION

The thermostat shown schematically in Figure 1 is basically a fixed temperature device, usually combining a limited rate-of-rise response to compensate for thermal lag. It consists of a stainless steel tube joined to a brass mounting bushing having a one-inch hexagonal head and half-inch pipe threads. Supported inside the tube are two arched springs having silver contacts at their midpoints. The arched springs have a different coefficient of expansion than that of the stainless steel tubing, and the choice of spring material determines the degree of rate-of-rise response. The silver contacts are mica-insulated from the springs, and glass-fiber-insulated, stranded copper wires extend from the contacts to the exterior to serve as lead-in wires. The lead-in wires are brought to the interior of the tube through two glass beads which provide hermetic seals.

The degree of initial bowing or separation of the contacts (the dimension which establishes the operating point) is controlled by two set screws in the base of the tube. Once set for a given operating point, the screws are bonded to the end of the tube and hermetically sealed with silver solder. The heat applied during the silver-soldering process expands the air in the tube, and it is assumed that some of this air escapes and that this results in a partial vacuum when the thermostat reaches normal temperature.

In operation, upon being heated, the tube shell expands and lengthens, thus relieving the strut assembly stress which produced the bowed position and permitting the struts to straighten and close the circuit at a predetermined temperature. The thermostat has a limited rate-of-rise response so proportioned that for a small rate of temperature change (about 5 to $10^0$ F/min) it operates as a fixed temperature unit, while with a higher rate ($40^0$ F/min) the tube shell expands more rapidly than the strut assembly and in effect the operating point is lowered. Thus the effect of thermal lag is largely compensated under the conditions associated with fire detection.

## PROCEDURE

### Initial Accuracy

In the final lot of samples, the manufacturer submitted a total of 48 specimens, of which half were of the $105^0$ F and half of the $150^0$ F nominal operating temperature. Using the temperature calibrating unit (furnished to check the temperature setting and as reference for future checking of effects of shock, vibration, endurance, and so on), actual operating points were determined at the Laboratory.

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[3] Underwriters Laboratories Reports, Signal 492 (March 9, 1948) and Electrical 19310 (May 13, 1948).

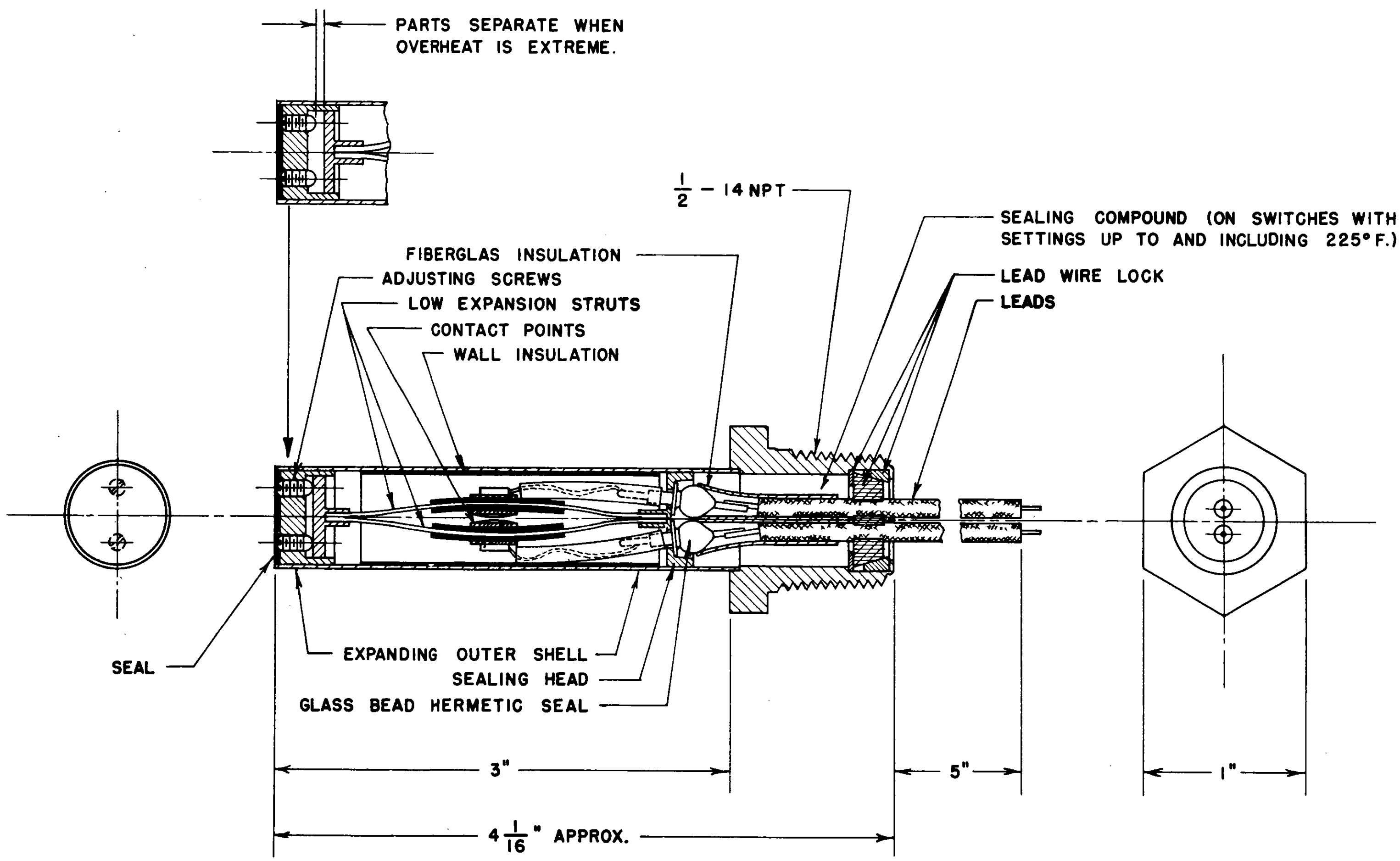


Fig. 1 - Cross-section of fire alarm thermostat

Since only relative changes from an initial operating point were needed to determine the effects of the various test conditions, standardization of the thermometer (used in connection with the temperature calibrating unit) by comparison with a calibrated thermometer was considered unnecessary. But even without standardization it was possible to check the operating points within ± 1/2° F with this unit.

Selection of Mount

The ability of the thermostat to withstand shock, and the kind of mount to be used for protection, were of immediate concern. For the shock tests, the thermostat was attached to the shock machine by a rigid right-angle bracket (Figure 2) which was bolted to the panel of the Light-Weight HI Shock Machine. Throughout the shock tests, this bracket supported the thermostat in its normal position, and only "top" and "back" blows were applied. When it was desired to change the direction of the blow relative to the contact-supporting structure, the thermostat was rotated 90 degrees.

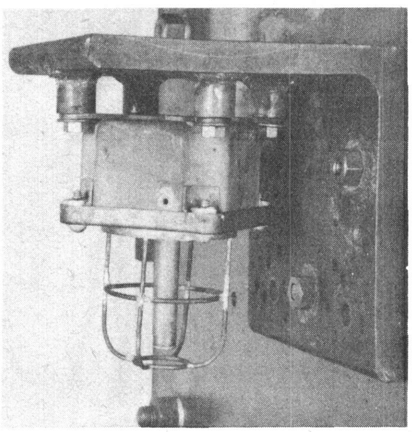

Fig. 2 - Bracket used to mount thermostats to panel of light-weight HI shock machine

A few preliminary shock tests, with a rigid mount consisting of a half-inch pipe flange bolted to the right-angle bracket, disclosed that a more resilient mount was needed.

A necessary preliminary to the design of a shock mount was the selection of a connection box for the thermostat, and the ideal choice would be one that is small, lightweight, watertight, and capable of withstanding HI shock. The Bureau of Ships has standard plans for a number of different-sized enclosures that meet these general requirements. A four-inch square enclosure (BuShips drawing 5334-2) was chosen from these plans because this was believed the minimum size providing enough design latitude for shock protection of the thermostat. There remained two alternatives: to shock-mount either the enclosure or the thermostat.

As a preliminary shock mount, the enclosure cover, consisting of 1/16-inch sheet steel, was modified by silver soldering into a hole bored in the center of the cover a hexagonal bushing tapped with a half-inch pipe thread. This mount protected the thermostat from the shock of the top blows (parallel to longitudinal axis of thermostat). The back blows (perpendicular to longitudinal axis of thermostat) caused an excessive shift in the operating point. High-speed motion pictures reveal that for the back blows the thermostat and enclosure moved as a unit with hardly any relative movement between the two, indicating that the mount was much too stiff in this direction.

The feasibility of shock-mounting the enclosure was considered in two[4] ways, both designed to lower the natural frequency of the assembly:

(a) bolting to the bottom center base of the enclosure a "Barry Compression Shock-Mount," to be used as a one-point suspension for the enclosure, or

[4] It is also possible to shock-mount an enclosure by using U-shaped sheet steel shock mounts, but this method was not investigated.

(b) attaching to the four mounting lugs of the enclosure four 1/4-inch bolts three inches long, with which to mount the enclosure to the shock machine.

While these methods provided the necessary shock protection, they contained some inherent disadvantages. First, there is the possibility of a change in characteristics caused by different cable connections, and, second, there is an undue increase in the over-all length of the assembly. It was therefore decided that shock-mounting the enclosure assembly was to be adopted only as a last resort.

The shock-mounting of the thermostat was further considered, and the cover of the four-inch steel enclosure was modified by using different gauge thicknesses of hot-rolled sheet steel varying from 0.021 to 0.047 inch.

Shock tests disclosed that a sheet-steel diaphragm 1/32-inch thick afforded the necessary protection, and a final model was designed to fit a four-inch sheet-steel enclosure and to retain the desired waterproof characteristic of this enclosure.

### Operational Tests

The effects of vibration and endurance on the operating point were also determined. The sensitivity of the thermostat was not determined since available data[5] were considered sufficiently informative.

## RESULTS

### Initial Accuracy

The initial operating points of the thermostats were as shown below:

| Quantity of Thermostats | Nominal Operating Point | Average Deviation | Maximum Deviation |
|---|---|---|---|
| 24 | 105°F | + 2°F | ± 5°F |
| 24 | 150°F | - 2°F | ± 5°F |

Subsequent checks disclosed that the thermostats maintained their initial operating points and did not shift as a result of normal handling or elapsed time over the approximately three-month period of investigation.

### 250-Foot-Pound Shock Test

Several rigidly mounted thermostats were subjected to the 250-foot-pound blows with no change in operating points. During one part of this test, each thermostat was connected to a standard fire alarm circuit and heated to a temperature just above its operating point. Upon cooling, the hammer was dropped at the moment the contacts opened. Under these circumstances there was no evidence of the contacts closing long enough to energize a fire alarm switchboard unit.

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[5] Underwriters Laboratories Report, Signal 492-9 (March 1948).

2000-Foot-Pound Shock Tests

Several thermostats, mounted directly to the right-angle bracket shown in Figure 2, were subjected to various hammer blows up to 2000-foot-pounds. Results were as follows:

| Thermostat Sample | Initial Operating Point, °F | Operating Point after Shock, °F: Top Blow, Foot-Pounds 1200 | Top Blow 2000 | Back Blow, Foot-Pounds 400 | Back Blow 800 | Back Blow 1200 | Back Blow 1600 | Back Blow 2000 |
|---|---|---|---|---|---|---|---|---|
| 3 | 148 | -- | -- | 147 | 144 | 140 | 139 | 132 |
| 4 | 152 | -- | -- | 152 | 152 | 151 | 148 | 146 |
| 7 | 106 | 106 | 105 | -- | -- | 100 | -- | 95 |
| 8 | 147 | 146 | 146 | -- | -- | 145 | -- | 134 |

Three thermostats were mounted to the 1/16-inch cover of the enclosure. Results were:

| Thermostat Sample | Initial Operating Point, °F | Operating Point after Shock, °F: Top Blow, Foot-Pounds 1000 | Top Blow 2000 | Back Blow, Foot-Pounds 1000 | Back Blow 2000 |
|---|---|---|---|---|---|
| 2 | 103 | 102 | 101 | 98 | 94 |
| 5 | 106 | 106 | 105 | 100 | 98 |
| 6 | 147 | 146.5 | 146.0 | 145.5 | 140.0 |

Finally, a number of thermostats mounted in the final shock-mount assembly were subjected to several blows of 2000 foot-pounds. Results then were:

| Thermostat Sample | Initial Operating Point, °F | Operating Point after Shock, °F: Three Blows Progressively to 2000 foot-pounds: Top | Back | *Back |
|---|---|---|---|---|
| 19 | 148 | 149 | 149 | 148 |
| 11 | 147 | 146 | 146 | 146 |
| 14 | 147 | 146 | 144 | 145 |
| 17 | 147 | 146 | 145 | 145 |
| 24 | 151 | 150 | 148 | 148 |
| 17 | 108 | 108 | 106 | 105 |
| 12 | 110 | 111 | 110 | 110 |
| 14 | 109 | 108 | 107 | 107 |

*Rotated 90° to change orientation of contact assembly.

Vibration

The resonant frequency of the internal strut assembly of the thermostat was found to be about 1500 cps. Vibrating the complete (shock-mounted) assembly in the range of 5 to 60 cps at 0.125-inch double amplitude had no effect on the operating point, and there was no evidence of resonance in the mount or in any of the components in so far as could be detected either by direct observation or by an oscilloscope connected in a circuit with the contacts.

### Endurance

Several thermostats were connected to a standard switchboard fire alarm unit and were cycled on and off with the following results:

| Thermostat Sample | Initial Operating Point, °F | Number of Operations | Final Operating Point, °F |
|---|---|---|---|
| 18 | 108 | 3000 | 108 |
| 10 | 108 | 2000 | 108 |
| 15 | 144 | 10,000 | 144 |

### Temperature Tests

No change in the operating point of the thermostats was observed when temperature-saturated either in an air bath at 170°F or in a dry ice bath.

### Description of Final Model

The final sample mount that gave sufficient shock protection for the 2000-foot-pound blow is shown in Figures 3 to 7. It is essentially a modification of the cover of a four-inch sheet-steel enclosure to incorporate a resilient mount for the thermostat, and is in the form of a hot-rolled sheet-steel diaphragm 1/32-inch thick with a tapped hexagonal bushing copper-brazed to its center. Hexagonal stock was used for the tapped bushing to permit clamping the bushing in a vise and thus facilitate screwing the threaded thermostat bushing into the mount. Other means (Figure 8) of securing the thermostat to the diaphragm could be used with the sole restriction that the diameter of the securing element not exceed that of the bushing shown in Figure 3.

The gasket-retaining "ring" and "clips" were spot-welded to the diaphragm. A reinforcing ring was incorporated in the modified cover to assure the rigidity necessary to force the rubber gasket into uniform contact with the top of the enclosure and maintain watertightness. A protecting guard was included in the final model, not so much to prevent damage to the thermostat as to protect personnel from head injuries.

## DISCUSSION

### Accuracy of Initial Operating Point

The average deviation from the nominal operating point is only ± 2°F, but the maximum deviations are ± 5°F. These values are greater than those allowed for the mercury-in-glass type, namely, ± 2°F for the 105°F and ± 3°F for the 150°F type. According to the manufacturer, deviations from the desired operating point are believed to be caused by small changes in positions of the set screws when they are being silver-soldered. An attempt is being made by the manufacturer to eliminate this undesirable shift.

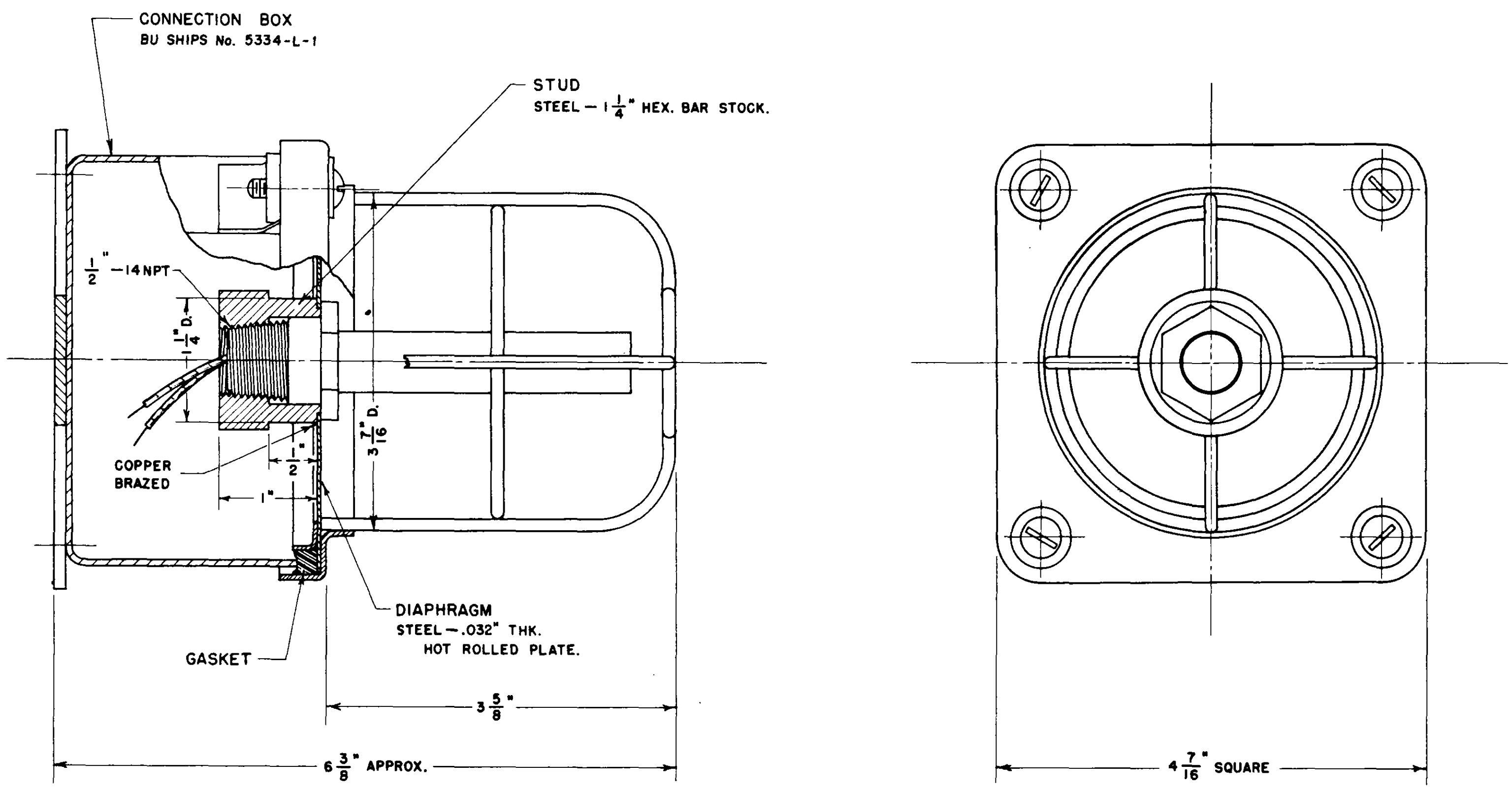


Fig. 3 - Assembly of shock-mounted thermostat

Shock Protection

The shock mount developed so protected the thermostat that the average change in operating point was only $-1.5^{0}$ F. Further development of the shock mount was considered unwarranted as a greater amount of shock protection would have required a larger connection box or a method of shock-mounting the connection box. Both of these methods are objectionable from the standpoint of weight and space.

Vibration and Endurance

Effects of vibration and endurance were negligible.

Sensitivity

The thermostat incorporates a limited degree of rate-of-rise response which is dependent on the kind of material employed for the strut assembly. Since the sensitivity tests in Navy Specification 17F11b for fire alarm thermostats are not directly applicable to any but mercurial thermostats, no sensitivity tests were conducted at the Laboratory, but the data incorporated in an Underwriters Report[6] were referred to in considering this characteristic.

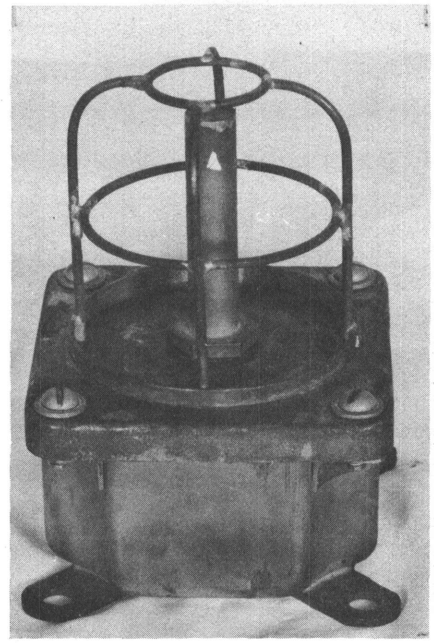

Fig. 4 - Assembly of thermostat and mount

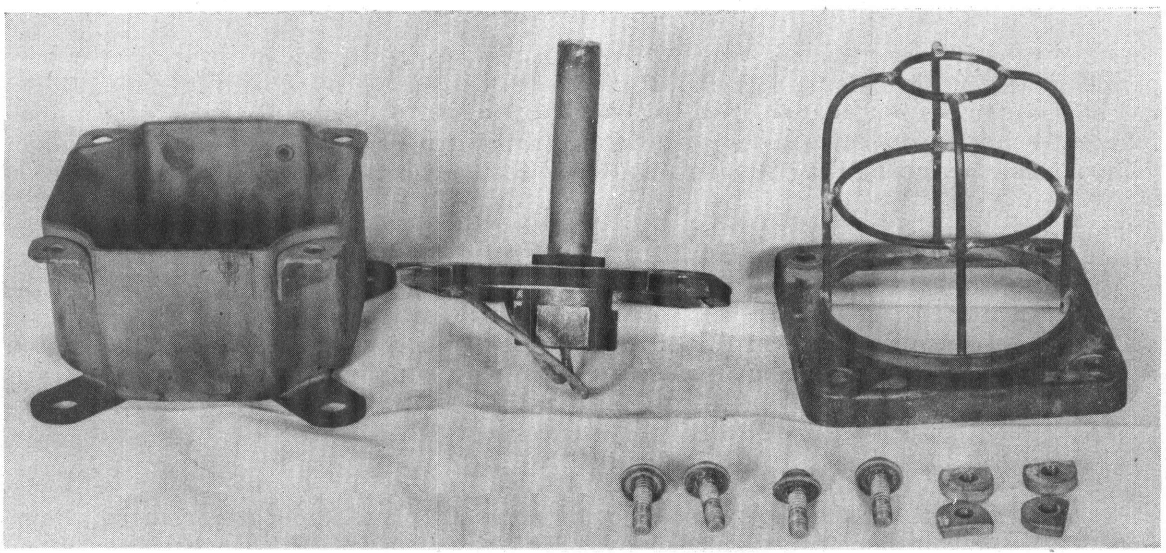

Fig. 5 - Components of thermostat and mount

[6] Signal 492 (March 9, 1948)

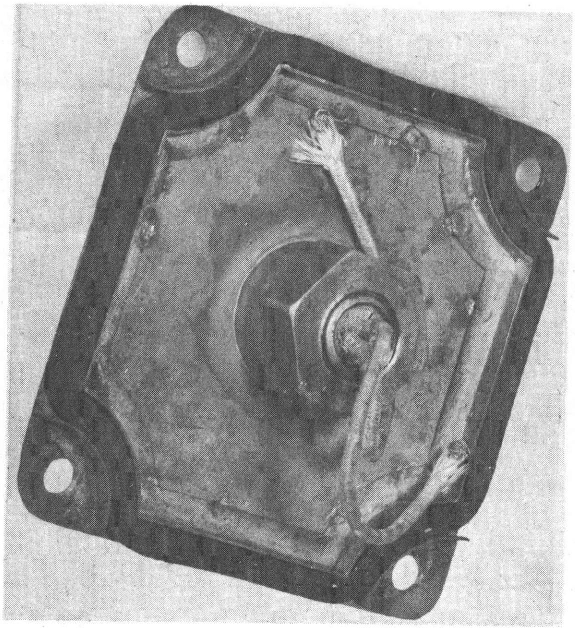

Fig. 6 - Bottom view of diaphragm

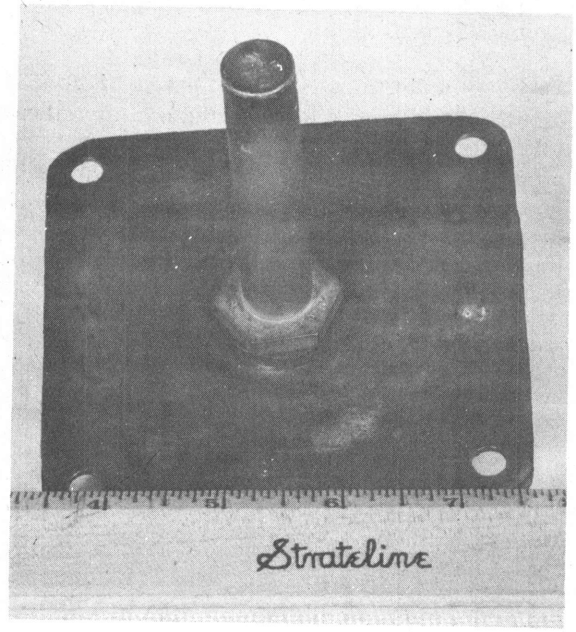


Fig. 7 - Top view of diaphragm and mount

These data show that the thermostat has the capacity to absorb heat as applied in oven tests at rates of 5 and 10°F per minute without appreciable thermal lag, while under higher rates of temperature rise (40°F per minute) the thermal lag is about 6°F per minute.

The rate-of-rise response would probably not be of any particular advantage for the powder magazine fire alarm application where the desired operating point is only 105°F and normal temperatures are not much below this figure. This type of thermostat is thus inherently more responsive under conditions of rapid temperature rise because it can be compensated for thermal lag by the rate-of-rise feature.

## Explosion Proofness

It is also noted that this thermostat has been accepted as being explosion proof.[7] But full advantage cannot be taken of this feature in the present application, because neither the sheet metal enclosure used for mounting nor the cable connections are explosion proof. No attempt was made to develop an explosion proof connection box for the thermostat.

## CONCLUSIONS

The present thermostat is believed superior to any other type of mechanical thermostat investigated. As the thermostat is inherently rugged, vibration does not change its operation point, and only a simple mount is required to provide sufficient shock resistance. The thermostat demonstrated stability by maintaining its operating point over a wide temperature range above and below the normal and throughout usual handling for three months. The stainless

[7] Underwriters Laboratories Report, Electrical 19310 (May 13, 1948)

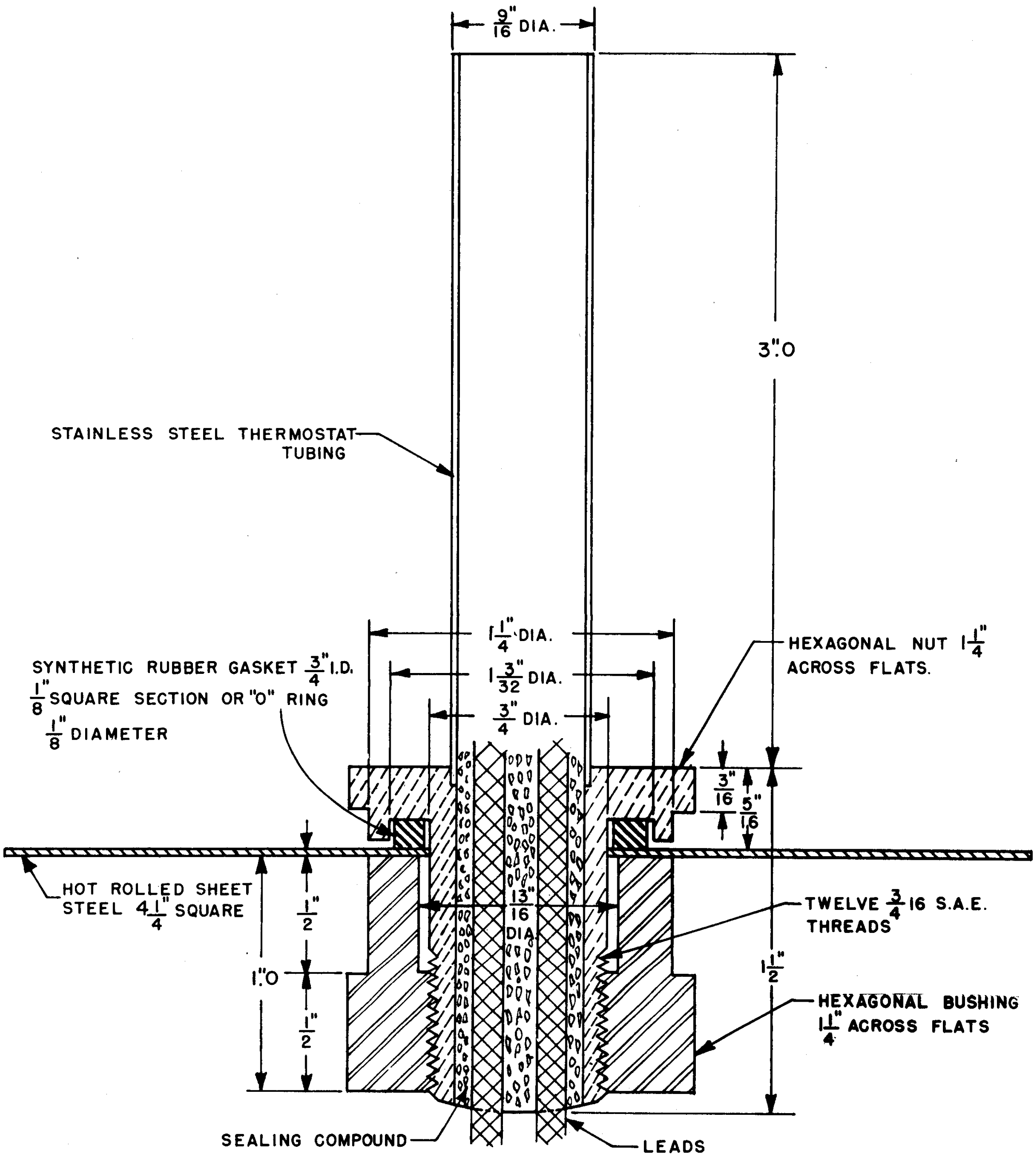


Fig. 8 - Alternate method of mounting thermostat to sheet steel diaphragm

steel material of the tube minimizes the effects of corrosion. The contacts are hermetically sealed and are adequate to make and break the currents of the fire alarm circuit.

This thermostat and mount can be directly substituted for the mercurial type if a tolerance of $\pm 5^0$ F in the operating point is permissible and if the provision for opening the supervisory fire alarm circuit at 20°F is not considered necessary. If essential, auxiliary low-temperature thermostats of the same basic design could be installed to retain the low-temperature alarm feature in the fire alarm system.

## RECOMMENDATIONS

It is recommended that:

(a) the Bureau consider the present thermostat and mount as an alternate for the mercurial thermostat but that, before final approval, the manufacturer be required to submit shock-mounted samples to a designated agency for complete type-approval tests, and

(b) the specification requirements of Specification 17F11b be broadened to include sensitivity tests comparable to those used by the Bureau of Standards and the Underwriters Laboratories so that other than mercurial-type thermostats may be evaluated properly.

* * *

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