CONFIDENTIAL

Rec'd ED 10/28/58 1330

25X1

October 24, 1958

25X1

Delay Actuator, Silicone Delay

PROGRESS REPORTS T.O. J, FEB 57 TO OCT 58

Dear Sir:

This letter report describes the activity on Task Order No. J during the period from September 10 to October 10, 1958.

During this period, the design of some of the parts in the prototype timer was modified and the fabrication of a prototype unit was started.

Before fabrication of the prototype-timer parts was initiated, a production study was made of each part. As a result of this study, it was found that the small 0.010-inch-diameter orifice in the temperature-compensating housing could not be drilled by standard production methods. In order to solve this problem, we made the housing in three pieces and, instead of drilling the 0.010-inch-diameter hole, we drilled a 0.050-inch-diameter hole and inserted a piece of metal capillary tubing in order to obtain the proper orifice diameter. The capillary tubing used has a 0.010-inch ID and a 0.050-inch OD. In addition to the above, time was spent in designing the springs for the pressurizing piston.

During the coming month, the prototype timer will be completed and evaluation testing of the unit will be started. In

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October 24, 1958

addition, we shall continue the long-term testing of the laboratory model of the timing mechanism.

The total appropriation on this Task Order was $28,550. As of October 1, 1958, the unexpended balance was approximately $2,700.

Sincerely,

[redacted]

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ABW:mlm

In Duplicate

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[redacted]

September 24, 1958

Delay Actuator, Silicone

ED-183E

Dear Sir:

This letter report summarizes the activuty performed under Task Order No. J during the period from August 10 to September 10, 1958.

During this period, the effort has been concentrated on the long-term evaluation of the laboratory model of the timing mechanism, and on the design of the prototype timer.

The laboratory model of the timing mechanism has been modified for long-term testing, and the first test, of two weeks' duration, has been concluded. The modification of the setup consisted of inserting a low-pressure 0 to 5-psi gage and a low-rate spring into the existing equipment. The two-week test was performed under an ambient temperature of 120 F; a second test is being run under the same conditions, to determine the repeatability of the device.

The detailed design of the prototype timer is more than 50 per cent completed. This design is essentially the same as that discussed with you during your recent visit. One primary change has been made; a threaded ring around the case that will be used to set the prototype timer has been added. This represents an improvement on the previous design, since it simplifies the setting operation and is less likely to overtravel.

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 September 24, 1958

During the next month, we expect to complete the design and fabrication of the prototype timer. In addition, we shall continue the long-term testing of the laboratory model of the timing mechanism.

The total appropriation on this Task Order was $28,550. As of September 1, 1958, the unexpended balance was approximately $3,400.

Sincerely,

[redacted] 25X1

ABW:mjc

In Duplicate

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Decon 8/26/58

25X1

August 22, 1958

Delay Actuator, Silicone

Dear Sir:

This letter report summarizes the activity performed under Task Order No. J during the period from July 10 to August 10, 1958.

The project effort during this period was concentrated primarily on the short-term evaluation of the laboratory model of the timing mechanism. The short-term evaluation has now been concluded, and the results are shown graphically in Figure 1. The laboratory model was operated at three temperatures to obtain the data shown. Each of the three experimental points represents two or more tests at the same temperature. The total variation of flow was ±14 per cent. Since our design objective is ±10 per cent variation, we are not completely satisfied with the results and hope to improve them substantially. However, we believe that the evaluation program thus far has proven the basic components of the design, and, consequently, have now begun the design of a complete prototype timer.

In addition, we have prepared a preliminary cost estimate for these timing mechanisms in quantities of 10,000 units and the cost appears to be under $10 each. Since our prototype design has not yet been completed, we have based this cost estimate on the

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August 22, 1958

laboratory model. This figure should give a good indication of the final cost, since, as currently contemplated, most of the components needed in the prototype are incorporated in the laboratory model.

During the next month, a modified unit with a firing mechanism will be laid out and longer term evaluation experiments with the laboratory model of the timing mechanism will be started.

The total appropriation on this Task Order was $28,550. As of August 1, 1958, the unexpended balance was approximately $4,700.

Sincerely,

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ABW:mjc

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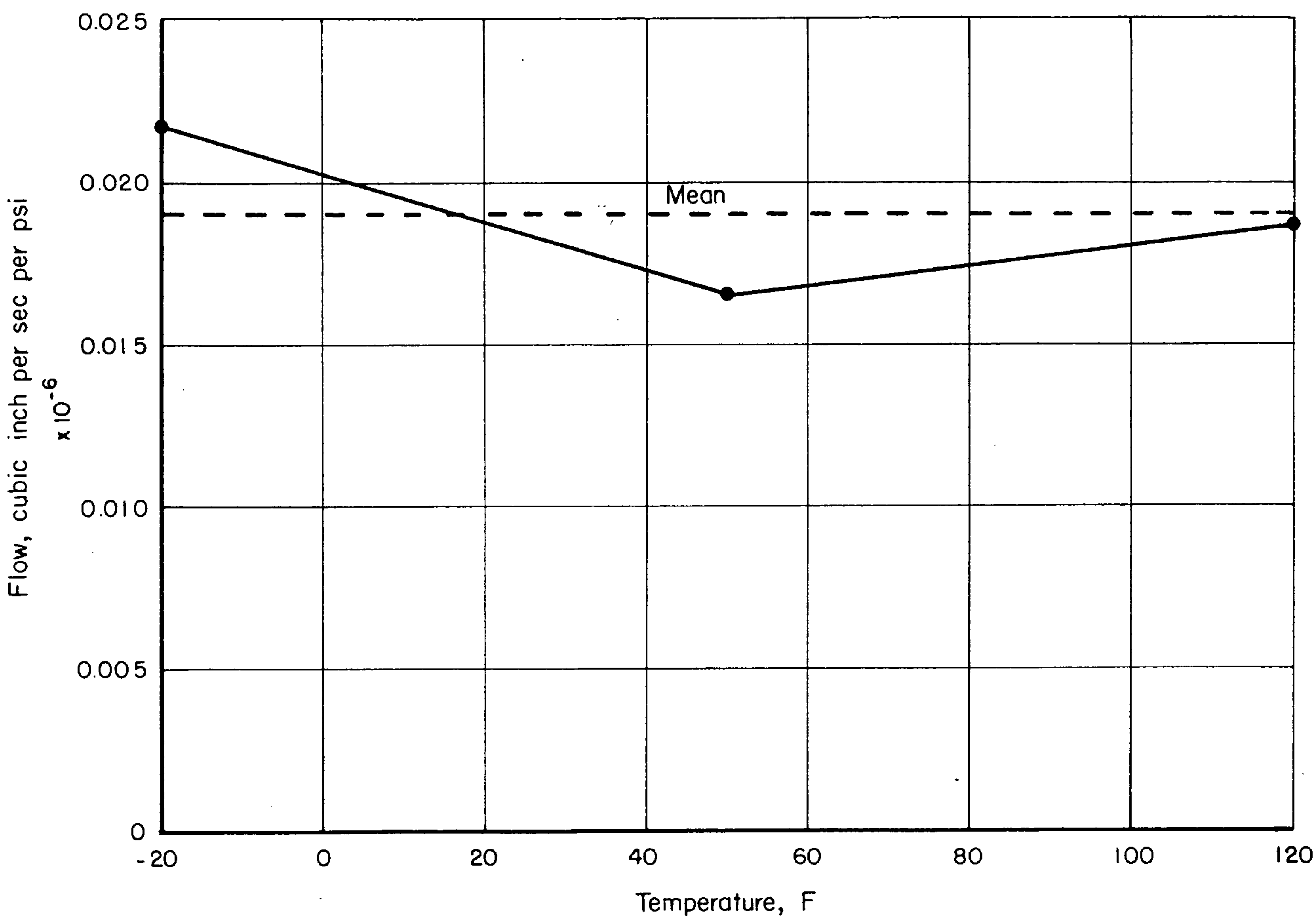

FIGURE I. DATA OBTAINED IN SHORT-TERM EVALUATION OF LABORATORY MODEL OF TIMING MECHANISM

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July 15, 1958

file: Delay Actuator, Silicone

Dear Sir:

This letter report describes the activity performed under Task Order No. J during the period June 12 through July 10, 1958.

During this period, the effort has been concentrated on an evaluation of the laboratory timing-mechanism portion of the delay device.

The evaluation program which has been set up consists of a series of tests under three different ambient temperatures, -20, 50, and 120 F. For a given temperature, the evaluation procedure is as follows:

(1) The timing mechanism is placed in the temperature chamber and rigidly fastened.

(2) The timing mechanism is allowed to "soak" in the temperature chamber overnight.

(3) The timing-mechanism valve is opened, thus initiating flow of the fluid from the timing mechanism.

(4) The fluid flow is measured indirectly by measuring, once every hour, the movement of the spring-loaded piston used to maintain fluid pressure.

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July 15, 1958

In addition to measuring the piston movement, we also read the temperature and the fluid pressure. This information is used to calculate fluid flow in terms of cubic inches per second per psi of pressure. Flow data in this form are valuable for use in determining the constant-flow characteristics of the timing mechanism, and in addition, in the subsequent design of a complete time-delay device.

The results of the tests to date have been erratic, primarily because of the human element in the test setup. However, the test technique has been worked out and the results now being obtained are consistent.

If the present rate of testing is continued, we anticipate completing the short-period tests in about two weeks. Then, if the results of this test program show the basic design of the timing mechanism to be feasible, we expect to begin the design of a complete model of the time-delay device, which will incorporate a time-setting device, a firing-pin release, and a mechanism for compensating for the volume change of the fluid as a result of temperature changes.

The total appropriation on this Task Order was $28,550. As of July 1, 1958, the unexpended balance was approximately $6,000.

Sincerely,

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8 July 58

Delay Actuator
Silicone Delay

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Development of a Silicon-Fluid Time-Delay Mechanism

Design Objectives:

1. should have high degree of reliability
2. it should be accurate to within ±10 per cent of time setting
3. it should retain its accuracy over a temperature range of -20 to +120 F
4. it should have an adjustable time range from 15 minutes to 2 months
5. it should weigh no more than 1/2 pound   lab sample = 10 oz. w/ firing mech.
6. it should not be larger than about 1 inch in diameter and about 4 inches in length   5" long   1¼" dia.

Laboratory sample

Only a few test runs were completed at the time of my visit on 8 July. These are not too indicative of performance of the unit because they were still learning how to get the best results from their test set-up. Even these results, although somewhat erratic, hold the promise of good performance for this unit.

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—HB.

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8 July '58

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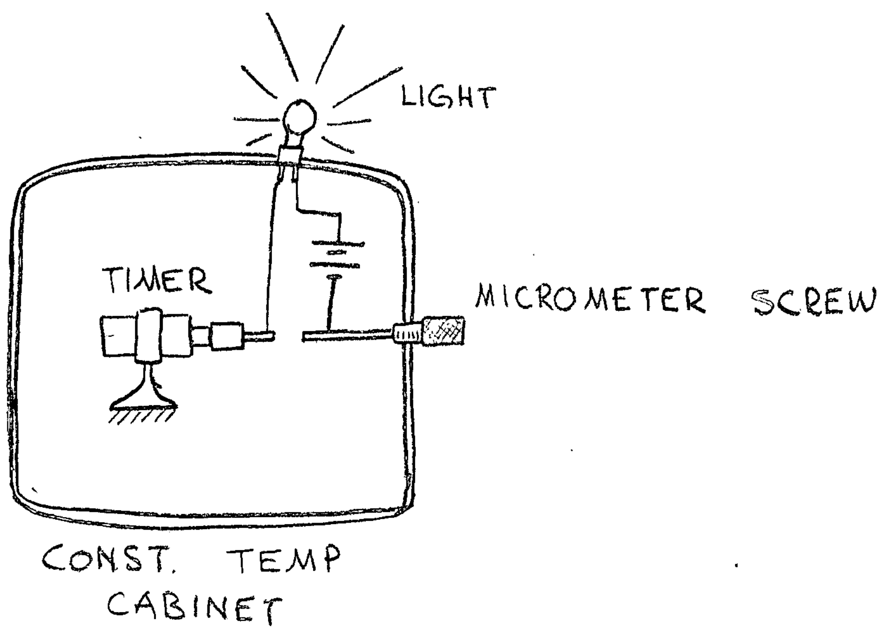
Development Program

completed
1. determine optimum dimensions for temperature-compensation device by calculation
2. design experimental laboratory timer mechanism incorporating design features that would be used in the final design.
3. fabricate experimental laboratory timer mechanism.

NOW → 4. test experimental laboratory timer mechanism.
5. design complete prototype unit incorporating timer and firing pin release.
6. fabricate prototype.
7. test prototype



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[redacted]

Rec'd 6/18/58

25X1

Joe

June 12, 1958

Delay Actuator
Silicone Delay

Dear Sir:

This letter report describes the activity performed under Task Order No. J during the period May 11 through June 11, 1958.

During this period, the effort has been concentrated primarily on the fabrication of an engineering prototype time-delay unit and suitable equipment for evaluating this prototype.

The engineering prototype has been completed and the unit is now ready for testing. The test equipment is being assembled and will permit the accurate determination of the rate of piston motion in the time-delay unit. Piston travel rather than actual flow was chosen for measurement since piston travel is used to actuate the time-delay device.

During the next month, we contemplate conducting the short-term evaluation of the engineering prototype and making any necessary modifications. The remaining time available will be used for long-term testing, final design, and any other experimental work needed to prove out the features of the final design.

The total appropriation under this Task Order was $28,550. As of June 1, 1958, the unexpended balance was approximately $7,100.

Sincerely,

[redacted]

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Delay Action
Silicone Delay

May 19, 1958

Dear Sir:

This letter report describes the activity performed under Task Order No. J during the period March 24 through May 10, 1958.

During this research period, development activities have been concentrated in two distinct areas:

(1) Calculations of optimum orifice and annulus proportions needed to obtain constant liquid flow under varying ambient temperatures.

(2) Design of a working model both to prove out the calculations and to check design features for incorporation into a final time-delay design.

Considerable effort was devoted to making calculations of fluid flow. These calculations were made in order to arrive at the optimum dimensions for the fluid-flow-control device. On the basis of these calculations, optimum dimensions were determined; in addition, a procedure was developed that permits the extension of these calculations to include increased or decreased sizes and different materials.

Theoretically, there are no optimum dimensions for this device. However, as the over-all size of the device is reduced, the necessary tolerances required to maintain constant flow become

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very small. With this fact in mind, the metering device was designed to be as large as possible, and yet compatible with the over-all size requirements of the time-delay unit.

The design of a working model of the time-delay unit, as presently developed, is simpler than we had anticipated since it covers the complete range of time settings without there being a need to change components. This design was discussed during your visit of May 8, 1958. Particularly pertinent is the following list of characteristics of interest:

Time-Delay-Unit Characteristics

Length	5 inches
Diameter	1-1/4 inches
Time Setting Range	15 minutes to 1,440 hours
Theoretical Accuracy	±3.5 per cent.

The theoretical accuracy, as mentioned above, includes no allowance for machining and material variations. Since the original accuracy requirement was ±10 per cent, we feel that our chances of achieving this in the current design are very promising.

At the present time, we are completing the detail design of this working model and preparing the evaluation equipment. During the next month, we plan to complete the fabrication of the working device and begin to evaluate it.

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May 19, 1958

The total appropriation under this Task Order was $28,550. As of May 1, 1958, the unexpended balance was approximately $8,900.

Sincerely,

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September 20, 1957

Dear Sir:

This letter report describes the progress of Task Order No. J from August 8 to September 8, 1957.

During this period, the leakage rate of the experimental model was measured when the Viscasil was subjected to the maximum design pressure. In addition, we calculated the clearance required between the main body and the outer sleeve in order to achieve a reasonable leakage rate, and we obtained data on the force required to rotate the outer sleeve. The size of the thermostat spring needed to exert such a force would be impractical for this application. Since the current design is not entirely satisfactory, other types of compensators are being investigated.

During August, we measured the leakage rate of the experimental model. When the Viscasil was subjected to the maximum design pressure, the leakage rate was more than twice the flow rate through the port when the clearance between the main body and the outer sleeve was 0.001 inch. This clearance could be reduced to 0.0003 inch, in which case the calculated leakage rate would represent about 5 per cent of the flow rate through the smallest orifice. However, small machining errors would have a pronounced effect; an increase from 0.0003 to 0.0005 inch in the clearance would increase the leakage rate to about 20 per cent of the total flow rate.

At a temperature of 85 F and with a clearance of 0.001 inch,

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measurements indicated that a force of approximately 0.5 pound was required to turn the outer sleeve at a rate of 0.0023 inch per second. These conditions were more severe, but more realistic, than those used in the experiments mentioned in the August 13, 1957, report. (The rate indicated in the previous report should have been 1 inch per minute instead of 1 inch per second.) As calculated, the force required to rotate the outer sleeve at -20 F would be about 7 pounds if the clearance was reduced to 0.0003 inch. Calculations show that a thermostat spring 7 inches wide would be needed to exert this force. It appears that this type of temperature compensator has serious practical limitations.

Since we are not satisfied with the current design, a more practical solution to the problem is being sought. We believe that the design criteria required to meet the specifications have been established. Ideally, the temperature compensator should not move and the ports should not have movable sides. The Bellofram piston seal, described in the May 10, 1957, report, and the adjustable springs which provide the pressure would probably be useful in any pertinent design.

One idea, which has not been thoroughly investigated, may have possibilities as indicated by preliminary calculations. This makes use of the leakage as part of the total flow. Most of the material would be extruded through a port while the leakage would be controlled by the temperature-compensating orifice formed by the annular space between two concentric cylinders of different metals. As mentioned in the August 13, 1957, report, this type of compensator would not be satisfactory by itself. However, if it were to control only a fraction of the flow, we estimate

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September 20, 1957

that the error in timing would be only ± 5 per cent over the entire temperature range. In addition to this design, we are investigating other possibilities.

In September, we plan to search for other types of temperature compensators and investigate their feasibility.

The original appropriation on this Task Order was $18,550. As of September 1, 1957, the unexpended balance was approximately $4,700.

Sincerely,

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In Duplicate

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[redacted]

August 13, 1957

Dear Sir:

This letter report describes the progress of Task Order No. J from July 8 to August 8, 1957.

During this period, the temperature compensator of the experimental unit was evaluated with a thermostat spring installed. The compensator did not perform satisfactorily. The forces in the Viscasil film between the outer sleeve and the main body, and ice formation on the two parts (while in a cold chamber) prevented relative movement. Although experiments are continuing on this type of compensator, we have again investigated the use of the annular clearance space between two different metals as a temperature-compensating orifice. This system still appears to be theoretically possible, but with serious practical limitations.

The outer sleeve and the main body of the temperature compensator were lapped together to obtain a clearance of approximately 0.0003 inch. With a thermostat spring (supplied by W. M. Chase Company) installed, the load developed was not sufficient to rotate the outer sleeve when the temperature was changed by as much as 50 F. The high resistance was created by the forces in the Viscasil film and by ice formation on the two parts during exposure to the lower temperature of the test range (25 F). Coating the entire main body with Viscasil would probably minimize the effect of the ice formation, but would increase the drag forces.

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The next step was to measure the force required to rotate the outer sleeve with a 0.0003-inch clearance between it and the main body. At an ambient temperature of 84 F, an 8.5-ounce load could rotate the sleeve at a rate of approximately 1 in./sec. Our present thermostat spring is too weak to exert such a load. Possibly, by coating the main body with Viscasil and by increasing the clearance to 0.001 inch, we could reduce the frictional forces, and consequently utilize to advantage a thermostat spring of the same general type as, but slightly stronger than, our present spring. Preliminary calculations show that the leakage under such conditions would be less than 2 per cent of the minimum flow. We are currently modifying the experimental unit to permit measuring the actual leakage.

Since these two problems (ice formation and machining tolerances) have become increasingly significant, we again investigated the use of the clearance space formed between two different metals as an orifice. It is possible to design a unit from aluminum and steel that would have an error of ± 10 per cent (in delay time) when operating over a temperature range of -10 to 109 F. However, in covering the range of time periods for a given orifice length, the ratio of the average pressures (exerted on the Viscasil by the spring) corresponding to the shortest and longest time periods would be approximately 6,000 to 1. So far, we have been unable to devise a satisfactory method for handling such a large pressure variation.

In August, we plan to measure the leakage rate from the experimental unit when the Viscasil is subjected to the maximum design pressure.

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The diametral clearance will be increased in increments, to permit determining the maximum clearance allowable within the design specifications. In addition, the torque required to rotate the outer sleeve will be determined for the proper clearance, so that a suitable thermostat spring can be selected and evaluated.

The original appropriation on this Task Order was $18,550. As of August 1, 1957, the unexpended balance was approximately $5,000.

Sincerely,

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Recd ED 7/16/57 11:30

July 11, 1957

Delay Actuators, Silicone Delay

Dear Sir:

This letter report describes the work done under Task Order No. J from June 8 to July 8, 1957.

During June, we tested two additional ports at -20 and 50 F. The calculated viscosity values were compared to the actual value and the variation was less than ±5 per cent. On the basis of the information obtained from these and previous tests, we started the design of the first complete experimental unit. Most of the parts needed for this unit have been ordered and received, and construction was started at the end of June.

We tested two additional ports in both the -20 F and the 50 F temperature chambers. The results were very encouraging. Our calculated viscosities for the two ports at -20 F were 0.268 and 0.264 lb-sec/in.^{2} as compared to an actual viscosity of 0.270 lb-sec/in.^{2}. The calculated viscosities at 50 F were 0.099 and 0.098 lb-sec/in.^{2} as compared to 0.099 lb-sec/in.^{2}.

Because of this information and the equally encouraging results from the previous tests that were reported last month, we started the design of a complete experimental unit. So far, our effort has been concentrated on the design and construction of the temperature compensator of this unit. If the test of the compensator is satisfactory, then the remaining parts for a complete unit will be made.

We contacted the W. M. Chase Company, Detroit, Michigan, a manufacturer of thermostatic bimetallic elements, and requested a compensator spring. They forwarded an element, with the provision that, if it

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was not satisfactory, they would send additional samples. We also contacted the Bellofram Corporation, Burlington, Massachusetts, and ordered one type of Bellofram piston seal. This seal, which is shown on the enclosed print of Laboratory Model 1, should allow us to reduce friction in the device to a negligible value.

In July, we plan to test the bimetallic element received from W. M. Chase Company. We shall also try to simplify the temperature compensator, since the current type requires extensive milling and finishing by hand. The remaining parts for the complete experimental unit will be designed and made.

The original appropriation on this Task Order was $18,550. As of July 1, 1957, the unexpended balance was approximately $5,900.

Sincerely,

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ABW/ba

Enclosure

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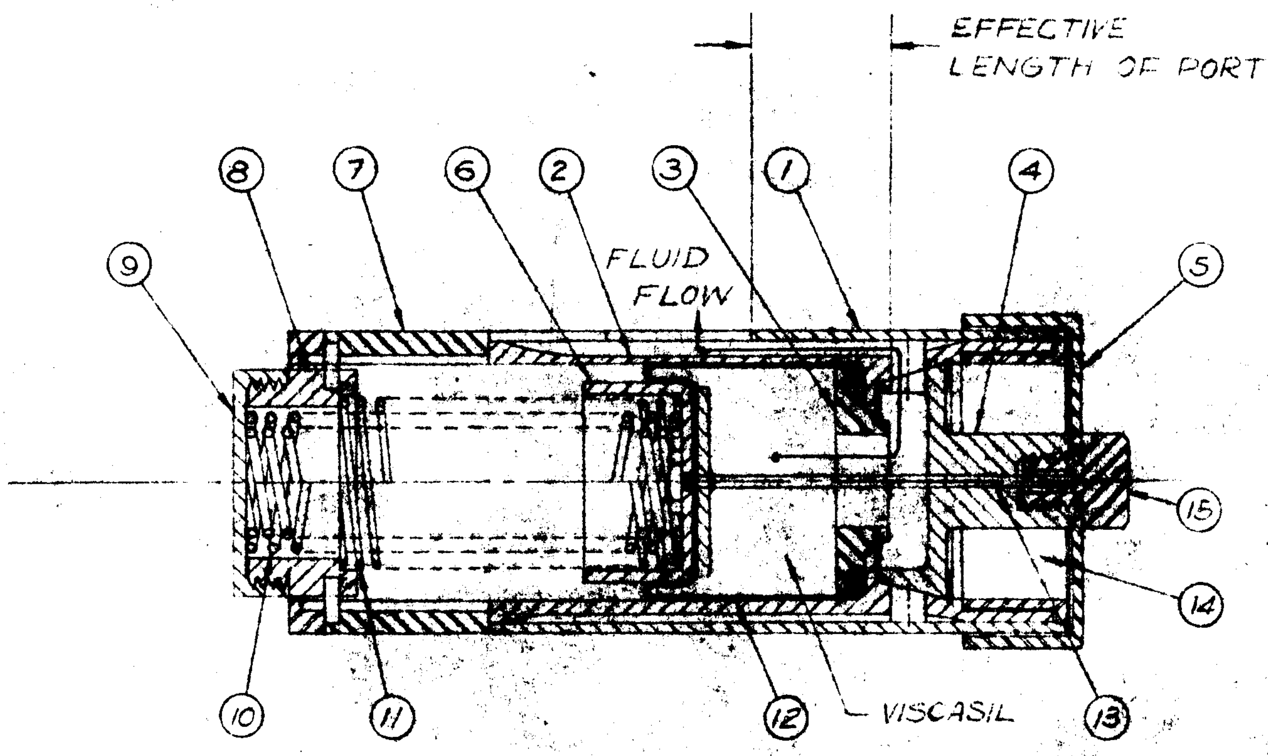

(1) TEMPERATURE COMPENSATOR
(2) MAIN BODY
(3) RETAINER PLATE
(4) PORT SELECTOR
(5) ADJUSTER KNOB
(6) PISTON
(7) SPRING ADJUSTER
(8) LOW PRESSURE SPRING STOP
(9) HIGH PRESSURE SPRING STOP
(10) HIGH PRESSURE SPRINGS
(11) LOW PRESSURE SPRING
(12) BELLOFRAM PISTON SEAL
(13) INDICATING ROD
(14) THERMOSTAT
(15) RELEASE BUTTON

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rec'd 6/17/57
9:00

#3
Joe 25X1
(please return)

June 12, 1957

Firing Device, Silicone Delay

Dear Sir:

This letter report describes the work done under Task Order No. J from May 1 to June 8, 1957.

Our letter report dated April 23, 1957, mentioned our plans to determine the flow characteristics of Viscasil through square ports. During May, the dimensions of the ports were measured with a traveling microscope, and then the 1-inch laboratory unit was tested in the 120 F chamber. We calculated the viscosity from the flow measurements and compared it to the actual viscosity. In all cases, the error was less than ± 5 per cent of the actual viscosity.

With the aid of a traveling microscope, the ports of all of the units were measured to the nearest 0.00005 inch. The majority were satisfactory, but some were wedge shaped or had rounded corners. The effect of these machining errors on fluid flow must be evaluated since they may also occur in the production model of the unit.

After cleaning the laboratory units and filling them with Viscasil, we placed them in the temperature chambers. The tests in May were run on the 1-inch-long port assembly at 120 F. To determine how accurately flow could be controlled by changing the areas, we calculated the viscosity based on the flow measurements for each port and compared these values with the actual viscosity. The calculated values varied from 0.044 to 0.049 lb-sec/in.^{2}; they compared favorably with 0.046 lb-sec/in.^{2} for the actual viscosity at 120 F. These results are quite encouraging, and we believe

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 June 12, 1957

that the measurements at the other temperatures will be equally good.

During the month of June, we plan to test the ports at the other temperatures. With the resulting information in hand, the plans for the prototype can be drawn. In addition, we shall determine whether the thermostatic spring is satisfactory as a temperature compensator.

The original appropriation on this Task Order was $18,550. As of June 1, 1957, the unexpended balance was approximately $7,400.

Sincerely,

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ABW/ba

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Silicone delay

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recd 5/14 9:00

4B

Joe

May 10, 1957

Dear Sir:

This letter report describes the work done under Task Order No. J from April 12 to May 1, 1957.

The timing test unit was modified to minimize the effects of the fluid friction forces, and also pressure tested so that leaks could be located and other difficulties eliminated. In addition, a leakproof piston, which has much lower frictional characteristics than a closely fitted piston, is being investigated for use in the prototype.

Since the frictional forces on a closely fitted piston were much higher than anticipated, we modified the laboratory test unit and eliminated the piston. This was done by using a column of mercury to displace the Viscasil fluid and force it through a hose connected to the test unit.

Static pressure tests were made to enable us to repair any leaks. The first timed tests were made in the -20 F chamber. Starting at a constant pressure, we timed the flow of a measured volume of mercury. Without changing any of the test conditions and starting at the same pressure, we found that the flow decreased for each consecutive test. It is believed that this progressive decrease in flow was a result of the low-pressure hose acting as an accumulator. This hose is being replaced with a high-pressure hose.

We are currently investigating a bellows diaphragm manufactured by the Bellofram Corporation for use as a low-friction, leakproof piston to replace the close-fitting piston in the prototype. This device is a closed rubber boot which fits into a cylinder. The clearance between a piston and

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the cylinder is sufficient to permit the rubber boot to roll on itself. In this system, the fluid friction forces should be much lower than in a system using a tight piston.

During May, the laboratory unit will be tested for reproducibility. If these tests are satisfactory, the other experimental units will be assembled and tested in the other temperature chambers.

The original appropriation on this Task Order was $18,550. As of May 1, 1957, the unexpended balance was approximately $9,700.

Sincerely,

25X1

ABW:vh

In Duplicate

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CONFIDENTIAL

April 23, 1957

Dear Sir:

This letter report describes the work done under Task Order No. J from March 8 to April 12, 1957.

A laboratory-timing device has been constructed to evaluate some of our ideas. The initial test indicated that part of this model was unsatisfactory, but a successful modification was devised. In addition, a temperature compensator for the prototype was designed that appears promising.

Because most of our best ideas for an appropriate timing device involve square ports for control, a laboratory unit was built to determine the flow characteristics of Viscasil through this type of port. Six different-sized ports were selected. In addition, since we may compensate for temperature changes by varying the length of these ports, four port assemblies of different lengths were prepared. Experimentation with these 24 port combinations should give us sufficient data to permit determining the effect of the port area and length on the flow rate.

To force the fluid through these ports, we used a closely fitted piston. The diametral clearance between the piston and cylinder was 0.0003 inch, which limited the leakage past the piston to less than 1 per cent of the minimum design flow. Since this leakage is low, O-rings, which have frictional characteristics and dimensional tolerances that are not adequately controlled for this application, were not required.

In the initial test on this laboratory unit, the force required to move the piston was much higher than anticipated. Although we might be

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able to reduce the shearing force sufficiently to permit the use of a close-fitting piston in the final design, the force required had to be minimized in the laboratory model. At present, the laboratory unit can be satisfactorily modified by using mercury to displace the Viscasil. By regulation of the height of a mercury column, the pressure for extruding the Viscasil through a selected port can be varied.

A promising temperature compensator has been designed which automatically changes the length of the orifice as the temperature varies. The device consists of two concentric plugs; one plug has the ports milled longitudinally on its periphery,and the other fits around the first plug and forms the outside surface of the port. Particular areas have been milled from the outer plug so that turning the outside plug changes the length of the port. A bimetallic thermostat spring produces the force required to turn the outside plug.

During the coming month, the laboratory unit will be modified as indicated and tested. If it proves to be satisfactory, additional units will be built and tested in each temperature chamber.

The original appropriation on this Task Order was $18,550. As of April 1, 1957, the unexpended balance was approximately $11,900.

Sincerely,

[redacted] 25X1

ABW:vh

In Duplicate

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March 15, 1957

Dear Sir:

This letter report describes the work done under Task Order No. J from February 8 to March 8, 1957. The three temperature chambers have been completed and are operating satisfactorily. Several practical designs were analyzed for the time-delay mechanism and one has been selected for detailing and construction. In addition, the fluids which we plan to test in the laboratory have been received.

The three test chambers have been operated satisfactorily at the respective temperatures of -20, 50, and 120 F. Temperature fluctuations have been limited to ±3 F, with a constant ambient temperature of 70 F.

In considering the extrusion of the silicone fluid through an orifice, we assumed that the shear stress would be proportional to the rate of shear. In the flow equation, the time of flow varies with the pressure differential, the volume of material extruded, the radius and length of the orifice, and the viscosity of the fluid. All of these factors were evaluated separately to determine if any could be easily varied and, hence, be used for temperature or pressure compensation. A number of possible solutions resulted.

One system which was considered made use of the clearance space between a piston and the cylinder as an orifice. By selection

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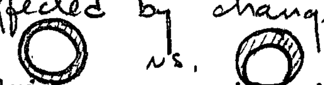
of the proper dimensions and materials, this orifice could be varied with temperature to compensate for the change in the fluid viscosity. However, the analysis of this system showed that the desired accuracy could be obtained only within a temperature range of 0 to 80 F, instead of the required -20 to 120 F. Wouldn't this be affected by change in the geometry of the orifice?



In another design, two different fluids were considered, one for each of two timing periods. One time period ranged from 15 minutes to 20 hours and the other from 20 hours to 2 months. Theoretically, two materials, Viscasil 210,000 for the shorter time range and Silicone Gum SE-76 for the longer periods, would be satisfactory. However, the use of two fluids would not be conducive to simplicity. Either separate units would be needed for the two time ranges, or the proper fluid would have to be loaded just prior to operation. Because of the high viscosity of the fluids, the loading operation would be cumbersome and difficult.
How about silicone gum ampoules just like A.C. Delay ampoules?

A third unit combining ease of production and simplicity of operation has been devised and is currently being studied and detailed. One fluid would be used, namely, Viscasil 500,000. Separate concentric springs would be enclosed within the unit so that the proper spring could be selected for use, on the basis of the time-delay period desired. In addition, the length of the orifice could be varied to provide increased accuracy.

Four fluids have been received for evaluation. General Electric Company, Silicone Products Department, Waterford, New York, supplied us with their Silicone Gum SE-76, and two of their high-viscosity silicone

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March 15, 1957

fluids, Viscasil 500,000 and Viscasil 60,000. These Viscasil fluids exhibit a relatively flat viscosity-temperature curve. The viscosity of Silicone Putty SS-91, previously discussed, changes markedly with temperature and thus its application is limited. However, one pound of putty was received for evaluation from S. R. Gittens, 1620 Callowhill Street, Philadelphia 30, Pennsylvania.

During the month of March, a simple laboratory model will be constructed for use in verifying the theories used in the development of the third device described above. It is anticipated that the machining problems and tolerances encountered in the construction of this laboratory model will be applicable ultimately to the preparation of prototypes.

the variable spring variable orifice device.

The original appropriation on this Task Order was $18,550. As of March 1, 1957, the unexpended balance was approximately $14,200.

Sincerely,

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In Duplicate

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February 22, 1957

Dear Sir:

This summary letter report describes the work done under Work Order No. IX, Task Order No. A, during the period from November 8, 1956, through February 7, 1957. The objective of this research was to evolve and evaluate ideas which might lead to the successful development of a constant-temperature-environment device with the following characteristics:

(1) It should weigh no more than 1 pound and should be relatively inexpensive.

(2) It should maintain an internal temperature that would be within 10 F of some suitable mean temperature for a period of at least 12 hours in an ambient temperature of -65 F.

(3) It should be large enough to enclose various time-delay mechanisms which are available to the Sponsor and should be designed so that the enclosed mechanisms could operate related units in a normal fashion.

(4) It should have a shelf life of five years.

Summary

The results of this study have been very encouraging and it appears that a device that would satisfy all of these requirements could be developed.

The unit that is currently considered to be the most promising would consist of an aluminum-vacuum-bottle type of device in which the temperature would be held at some constant value by utilizing the heat generated

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on solidification of a selected fused chemical compound which has an appropriate heat of fusion and freezing point. Such a device using, for example, hydrated nickel nitrate, $Ni(NO_3)_2 \cdot 6H_2O$, could maintain a constant temperature of approximately 134 F for about 12 hours in an ambient temperature of -65 F, or for longer periods in higher ambient temperatures; if the temperature differential were only 40 F, the device would maintain a constant temperature of approximately 134 F for about 83 hours.

Engineering Activity

The following three approaches that might satisfy the requirements of the constant-temperature-environment unit were investigated:

(1) Holding the temperature inside of the unit at some level below the lowest ambient temperature of interest (-65 F).

(2) Holding the temperature inside of the unit at some level above the highest ambient temperature of interest (120 F).

(3) Holding the temperature inside of the unit at some intermediate temperature between the lowest and the highest ambient temperatures of interest.

Holding the Temperature of the Unit Below -65 F

Two methods of lowering the inside temperature of the unit below the lowest ambient temperature (-65 F) were considered. The first made use of a mixture of dry ice and alcohol. This would produce a temperature of -72 F, but maintaining a supply of dry ice in the field would be difficult.

The second method utilized a conventional refrigeration system. The complexity of a mechanical arrangement of this type, together with the probable high cost, makes this approach undesirable.

Holding the Temperature of the Unit Above 120 F

By mutual agreement with the Sponsor, the highest ambient temperature was chosen to be 120 F. The following methods were considered for maintaining the temperature inside of the unit above 120 F:

(1) Electrical heating
(2) Chemical heating
  (a) Combustion
  (b) Heat of reaction
  (c) Heat of fusion.

Electrical Heating

Electrical heating of the proposed unit could be done very simply with a heating element, a battery, and a control system. The heat losses for a typical unit with an inside temperature of 120 F and an outside temperature of -65 F for a 12-hour period could probably be held to less than 20 BTU. (The calculation of heat losses can be found below under <u>Vacuum-Bottle Heat-Loss Calculations</u>.) To supply the amount of heat needed, a 5-ampere-hour battery would be required. A silver chloride - zinc battery with a 5-ampere-hour capacity would weigh about 4-1/2 to 5 ounces. The cost of a battery of this type is about $1 per ampere hour, or $4.50 to $5. Control of the proposed unit could be accomplished with a small thermostatic switch.

It is estimated that an aluminum vacuum bottle that was large enough to contain the above-indicated mechanisms could be prepared so as to weigh less than 1/2 pound without the battery. This would indicate that an electrically powered unit would be feasible, although the cost of the battery would be rather high. Batteries with a shelf life of five years have to be stored dry; the electrolyte would be added when the proposed unit was to be activated. Because silver chloride - zinc batteries are very inefficient at very low temperatures, it would probably be necessary to activate battery-powered units at a temperature of 32 F or above.

Chemical Heating

Combustion and Heat of Reaction. Chemical heating could be accomplished either by a combustion process or by a noncombustion process utilizing the heat of reaction of chemical compounds. Processes based on combustion would be very efficient from the standpoint of heat per pound, but the heat lost with the products of combustion and maintenance of an adequate supply of oxygen would pose difficult problems. Processes utilizing a heat of reaction, for example, from mixing strong acid and water, would be difficult to control.

Heat of Fusion. The heat of fusion of a chemical compound could be used to supply heat inside the proposed unit if the freezing point of the compound were above the highest ambient temperature and if a means were provided for supplying the initial heat required to melt the compound. For example, hydrated nickel nitrate, $Ni(NO_3)_2 \cdot 6H_2O$, has a melting point of 134 F and a heat of fusion of 65.5 BTU per pound; this means that 0.305 pound of molten nickel nitrate would be required to supply enough heat to maintain a temperature of approximately 134 F inside of the proposed unit for about 12 hours. The method of melting the nickel nitrate could consist of using a simple pyrotechnic device that would smolder and give off a relatively large amount of heat for a short period of time.

Holding the Temperature of the Unit at Some Level Between -65 and 120 F

Maintaining the temperature inside of the unit at some intermediate level between the highest and the lowest ambient temperatures could best be accomplished by utilizing the heat of fusion of a chemical compound whose melting point was in the proper range. The most efficient chemical for this purpose seems to be water, because of its high heat of fusion (144 BTU per pound). A mixture of water and ice would maintain a temperature of 32 F until either the ice melted completely or the water froze. At a meeting on November 27, 1956, the Sponsor indicated that an operating temperature of 32 F would be too low for the time-delay devices presently available and asked if some satisfactory compound with a higher melting point could be found. Hydrated calcium chloride, $CaCl_2 \cdot 6H_2O$, has a melting point of 84.2 F and a heat of fusion of 73 BTU per pound. To supply 20 BTU, 0.274 pound of calcium chloride would be required. Two other possibilities are hydrated sodium sulfate, $Na_2SO_4 \cdot 10H_2O$, melting at 88 F with a heat of fusion of 92 BTU per pound, and hydrated disodium phosphate, $Na_2HPO_4 \cdot 12H_2O$, melting at 97 F with a heat of fusion of 120 BTU per pound.

Provision of Heat to Melt Compounds

All of the proposed methods exploiting the heat of fusion require that the chemical compound involved be melted before or at the time that the constant-temperature-environment device is actually placed in service. Heat chemical pellets could be used to effect fusion of the compound. Then, a tab made of an alloy whose melting point was slightly above the melting point of the constant-temperature compound could be used as an indicator; when such a tab were exposed to the heat generated by fusion of the compound, melting of the tab would indicate that the unit was at the proper operating temperature. As soon as the desired temperature was reached in this manner, the constant-temperature-environment device could be capped and it would be ready for service.

To eliminate the need for a separate heat source to melt the compound, e.g., hydrated calcium chloride or nickel nitrate, the heat of formation of the compound might be used. For example, if 1 pound of anhydrous calcium chloride is mixed with the proper amount of water, the following reaction takes place:

$$CaCl_2(s) + 6H_2O(l) \longrightarrow CaCl_2 \cdot 6H_2O(s). \qquad (1)$$

Due to the heat of formation (370 BTU per pound of anhydrous salt), the resulting $CaCl_2 \cdot 6H_2O$ is molten. The compound thus formed has a freezing point of 84.2 F, and, under ambient temperatures lower than this, would maintain a temperature of about 84.2 F until it had frozen completely. A similar reaction using anhydrous nickel nitrate would release 190.3 BTU per pound of anhydrous salt.

Vacuum-Bottle Heat-Loss Calculations

In order to keep the energy requirements of the device as small as possible, the loss of heat energy must be kept to a minimum. The use of a vacuum bottle as the housing component of the proposed device would eliminate all heat losses due to convection and most of the losses due to conduction. Figure 1 shows a possible arrangement of a unit which could contain a time-delay device that was 3 inches in diameter and 3-1/2 inches in length or 1 inch in diameter and 6 inches in length. This unit consists of two vacuum containers, the smaller one of which slides into the other like a cork.

Heat may escape from such a vacuum bottle via three paths:

(1) Radiation

(2) Conduction through the rod that would operate an attached mechanism

(3) Conduction through the sliding surfaces.

Radiation Losses

Radiation losses are calculated from the formula[1]:

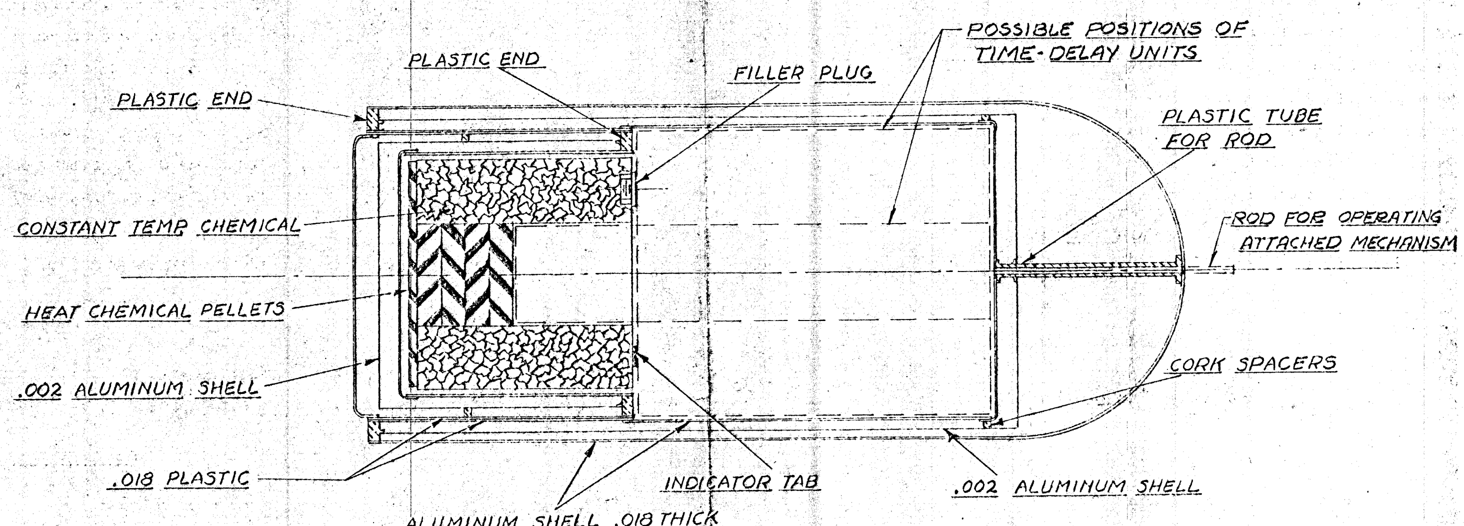
$$q = aF_eF_AA_1(T_1^4 - T_2^4) \quad (2)$$

where:

q = heat loss in BTU/hr

a = Stefan-Boltzmann constant = 0.173×10^{-8}

(1) Introduction to Heat Transfer, Brown and Marco, 1951, McGraw Hill Book Company, Inc., New York, New York, p 64.



FULL SCALE

FIGURE 1. PRELIMINARY DESIGN OF PROPOSED VACUUM-BOTTLE-TYPE DEVICE

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$$q = a F_e F_A A_1 (T_1^4 - T_2^4)$$

A_1 = area of inner shell in sq ft = 0.522

T_1 = inner-shell temperature in degrees F absolute (degrees Rankine)

T_2 = outer-shell temperature in degrees F absolute (degrees Rankine)

F_A = factor depending on configuration of the surfaces = 1

F_e = factor to allow for the departure of the two surfaces from complete blackness = 0.0238.

Assuming an inner-shell temperature of 134 F (593 degrees Rankine) and an outer-shell temperature of -65 F (394 degrees Rankine), the heat loss due to radiation for a container as shown in Figure 1 would be:

$$q = 0.173 \times 10^{-8} \times 0.0238 \times 1 \times 0.522 \times (593^4 - 394^4)$$
$$= 2.1 \text{ BTU/hr.}$$

The addition of an extra aluminum shell between the inner and outer shells of the two containers, as shown in Figure 1, will probably cut this loss by a factor of 2. Thus, the total heat loss from radiation for a 12-hour period would be approximately $\frac{2.1}{2} \times 12 = 12.6$ BTU.

Conduction Losses Through the Rod

why?

The heat lost by conduction through a 1/16-inch-diameter rod (assumed to be made of stainless steel) is calculated from the formula[(2)]:

$$q = \frac{Ak_m(t_1 - t_2)}{l} \qquad (3)$$

(2)Ibid, p 38.

where:

q = heat loss in BTU/hr

k_m = mean thermal conductivity in BTU/hr/ft^2/degree F/ft = 9.4

A = cross-section area of rod = 0.0000213 sq ft for a 1/16-inch-diameter rod

t_1 = temperature of inner shell in degrees F = 134

t_2 = temperature of outer shell in degrees F = -65

l = length of rod in ft = 0.125

Solving:

$$q = \frac{9.4 \times 0.0000213 \times \left[134 - (-65)\right]}{0.125}$$

$$= 0.32 \text{ BTU/hr.}$$

Thus, for a 12-hour period, the loss would be 3.8 BTU.

<u>Conduction Losses Through the Sliding Surfaces</u>

In order to lower the conduction losses, the sliding surfaces should be made of plastic. If k_m for the plastic used is equal to 0.027, the cross-section area of the plastic is 0.0007 sq ft, and the length of the plastic is 0.208 ft, then Equation (3) becomes:

$$q = \frac{0.027 \times 0.0007 \times \left[134 - (-65)\right]}{0.208} = 0.018 \text{ BTU/hr.}$$

Thus, for a 12-hour period, the loss would be 0.2 BTU.

Total Heat Loss From Vacuum Bottle

The total heat loss from the vacuum bottle, shown in Figure 1, for a 12-hour period would be approximately 12.6 + 3.8 + 0.2 = 16.6 BTU.

The calculations above were based on a 199 degrees F temperature differential. If the temperature differential were decreased to about 40 degrees, the operational life of the proposed unit would be increased. For example, if the temperature of the inner shell were held at 84 F and the ambient temperature were 44 F, the heat lost per hour would be about 0.24 BTU. With a 20-BTU heat source, the proposed unit should maintain a constant temperature for about 83 hours, or more than 3 days.

Recommendations

From the research conducted on this project, we believe that a constant-temperature-environment device could be built to satisfy the specifications as set forth in the introduction to this report.

Both electrically and chemically heated units seem feasible. However, the cost of a chemically heated unit utilizing the heat of fusion of a suitable chemical compound would be much less than that of an electrically heated unit. For this reason, we recommend that work be carried on to include further investigation into reactions involving the heat of fusion of chemical compounds to supply heat and into the preparation and evaluation of engineering prototype units. A proposal covering this activity is being prepared and will be sent to you in the near future.

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February 22, 1957

We would appreciate any comments that you or your associates might care to make with regard to the research.

Sincerely,

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Timing Device, Silicone Delay

February 19, 1957

Dear Sir:

This is the first letter report on Task Order No. J, and it describes the activity during the period from January 8 to February 8, 1957.

During the past several years, many organizations have been searching for a cheap, reliable, and reasonably accurate timing device. The Sponsor has had developed a time-delay device which is different from the conventional, expensive mechanical or electronic systems. This device utilizes the fluid flow of silicone putty; the volume of the putty extruded through an orifice is related to the time period involved in the extrusion. However, because the viscosity and volume of the putty change considerably with temperature and pressure, the range of operating conditions of this device is limited.

We believe that suitable temperature and pressure compensators can be devised to widen the operating range of the above-mentioned unit. Consequently, Task Order No. J was established to provide for the modification of the existing unit, particularly of the timing head.

To obtain pertinent basic-type information on silicone putty, we consulted the Engineering Index 1939-1956, Chemical Abstracts 1947-1956, and our Subject File and Catalogue. An article, "Silicone Putty as an Engineering Material", by L. W. Spooner, General Electric Company, gave considerable pertinent data showing the effect of temperature and pressure on the viscosity and density at various temperatures. To supplement this information, we contacted the Technical Inquiry Section, General Electric Company,

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Waterford, New York. To the best of their knowledge, the data in Mr. Spooner's article are still applicable to their current product, SS-91 Silicone Putty, and no additional information is available.

General Electric suggested that Viscasil 100,000, a new high-viscosity silicone fluid, might be equally suitable for our application. When compared to silicone putty, Viscasil has a number of advantages. Its viscosity does not change so drastically with temperature; it is fluid down to -50 C (-60 F); it is not corrosive to metals; and it has excellent high-temperature stability. A quantity of Viscasil 100,000 has been ordered for inclusion in our investigation.

Two other organizations, Canadian General Electric, Toronto, Ontario, and Dow Chemical Company, Midland, Michigan, were asked about silicone putty, but neither could supply any additional information.

We searched our facilities for suitable test equipment, but, because of space limitations, security, and economy, we have decided to fabricate our own test chambers from refrigerators. A used refrigerator was modified to operate at maximum output. By isolation of the freezer section with insulation, -20 F was reached, but the working volume was reduced to less than 1 cubic foot. Since extensive modifications would be necessary to achieve -20 F in an adequate working volume, we decided to use this refrigerator for the high-temperature (120 F) studies. Also, if possible, the internal volume of this unit will be divided so as to include an intermediate-temperature (50 F) compartment. If this proves unsatisfactory, another used refrigerator will be purchased for use in the intermediate-temperature studies.

February 19, 1957

For the low-temperature studies, a used 2-cubic-foot freezer was purchased and tested without any modifications. The lowest temperature reached after 24 hours of continuous operation was 8 F. The installation of a better refrigeration unit, at a nominal cost, will enable us to obtain -20 F in this freezer; this modification is being made currently.

We plan to have all of the modifications of the temperature chambers completed during February. Performance tests on the present time-delay unit will be made at the three temperatures. The design of an improved time-delay device of this type will be started, with particular emphasis on temperature and pressure compensators, for use in the existing device.

The original appropriation on this Task Order was $18,550. As of February 1, 1957, the unexpended balance was approximately $16,300.

Sincerely,

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In Duplicate