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AUTHORITY
AGAD 312.1 security J/64, 8 Nov 1950; OTS index dtd Jun 1947

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Instruments

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Progress Report on "A Condenser Gage Apparatus for Measuring the Pressure and Thrust Characteristics of Jet Propulsion Motors"

from

Central Research Department, Monsanto Chemical Co., Dayton, Ohio
and
Explosives Research Laboratory, Bruceton, Pa.

Report OSRD No. 1678

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Section 8.1

Progress Report on "A Condenser Gage Apparatus for Measuring the Pressure and Thrust Characteristics of Jet Propulsion Motors"

Service Directive OD-14

Endorsement (1) From G. B. Kistiakowsky, Chief Division 8 to Dr. Irvin Stewart, Executive Secretary of the National Defense Research Committee. Forwarding report and noting:

> "The adaptation of the G. M. condenser pressure gage to the measurement of thrust and pressure in jet propulsion motors has given very satisfactory results and appears to have some advantages over other electrical systems developed for this purpose."

This is a progress report under Contracts OEMsr-639 with Monsanto Chemical Co. and OEMsr-202 with Carnegie Institute of Technology.

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PROGRESS REPORT

on

A Condenser Gage Apparatus for Measuring the Pressure and Thrust Characteristics of Jet Propulsion Motors

from

Monsanto Chemical Company, Central Research Laboratory
and
Explosives Research Laboratory, Bruceton, Pa.

Investigation Group:

John Eck) Supervision
F. A. Long)
Charles G. Sage
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Report Prepared by:
Charles G. Sage

Approved by:
C. A. Thomas, (Monsanto)
L. P. Hammett, (ERL)
July 20, 1943

SUMMARY

Following a suggestion of Dr. C. A. Thomas and with the cooperation of the General Motors Research Laboratory, a condenser type gage developed for use as a gas engine indicator has been applied as a reliable and relatively simple device for studying the pressure and thrust characteristics of jet propulsion motors. The equipment is in regular use at the composite propellant pilot plant of the Monsanto Chemical Company at Dayton, Ohio.

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This report describes the pressure and thrust measuring apparatus which has been installed at the pilot plant of the Monsanto Chemical Company in Dayton, Ohio.

Principle of Operation

The principle of operation is shown schematically in Figure 1. The pressure to be measured is applied to a condenser type gage developed by the Physics Instrumentation Division of the General Motors Research Laboratories in Detroit. (E. J. Martin, C. E. Grinstead and R. M. Frawley, "An Electrical Engine Indicator for Measuring Static and Dynamic Pressures", Trans. A.I.E.E., March, 1941.)

The pressure causes a change in the electrical capacity of the gage which affects the frequency response of a tuned radio frequency transformer thereby changing the output of the transformer. The output of the transformer is detected and lead to a bucking circuit which acts as a gain control and zero adjustor. The output from the bucking box is applied to an oscillograph and the deflection of the oscillograph beam is recorded by a synchronously driven continuous feed movie camera. For measuring thrust, the reaction force is applied to a piston acting in an oil filled cylinder. The pressure developed in the cylinder is then measured with the condenser gage.

The oscillograph, camera and control panel are shown in Figure 2.

Description of the Apparatus

1) Condenser Gages

Gages with 1000 and 3000 pounds per sq. in. pressure range have been obtained from the General Motors Research Laboratories. The gages are shown in Figure 3 and a representative diagram of their construction in Figure 1. The two tubes on the 3000 pound gage are water connections for temperature control but this feature has not been used. The water cooled gage was designed primarily for use in cylinders of internal combustion motors where extreme temperature changes would take place. The operation of the gage depends on the change in capacity produced by the deflection of the bottom diaphragm with respect to the inner central electrode. The gages are small, very rugged and may be obtained in any range up to 10,000 lbs. per sq. in.

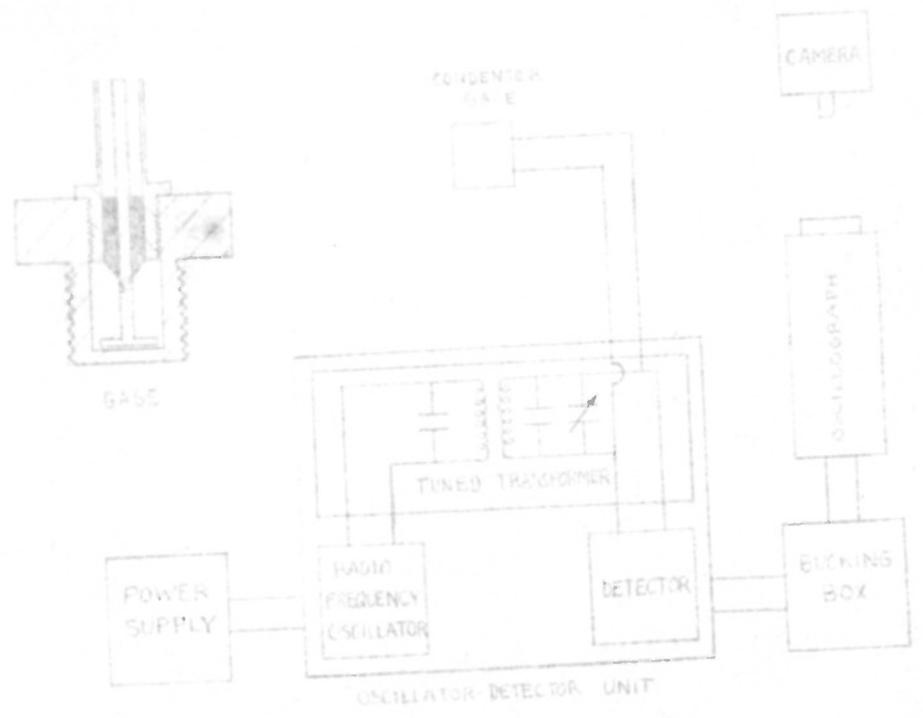
CAMERA
CONDENSER GAGE
OSCILLOGRAPH
GAGE
TUNED TRANSFORMER
POWER SUPPLY
RADIO FREQUENCY OSCILLATOR
DETECTOR
BUCKING BOX
OSCILLATOR-DETECTOR UNIT

FIGURE 1

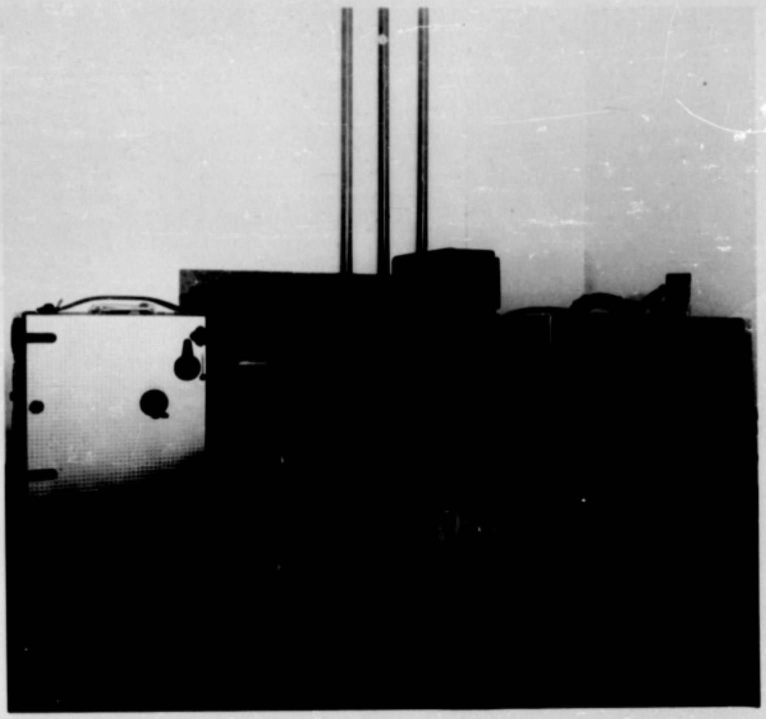

Fig 2

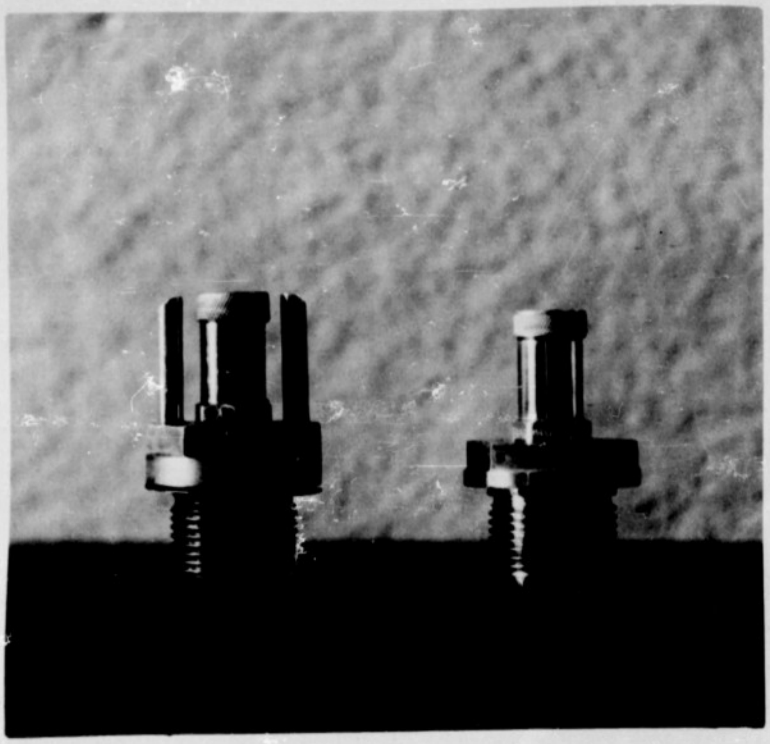

Fig. 3

2) Gage Adapter Couplings

Since the tension on the gage body threads can affect the spacing of the plates of the condenser, it was found advisable to insert the gage into a permanent adapter coupling in order to have constancy of calibration together with interchangeability of gages. The coupling is constructed so that the gage seats on the inner shoulder and is gasketed with a copper washer to prevent pressure getting up into the threads. The adapter fits directly into the thrust cylinder. In order to use the gage for pressure measurements in the motor, a second adapter is used. This adapter has a 3/8" pipe thread to fit the standard 3/8" tapped holes for crusher gages. To protect the gage from the hot gases, the adapter is filled with vaseline and plugged with modeling clay. Diagrams of the adapters are shown in Figure 4 a, b.

3) Thrust Cylinder

The thrust cylinder is shown in Figure 5. The piston has an area of one square inch and the cylinder and piston are honed to a 0.0005" fit. The back of the cylinder has three threaded openings, one for the gage, one for a blow out safety valve and one for filling with oil and removal of air bubbles. S.A.E. 30 oil is used.

4) Safety Valve

Because of the limited space between the diaphragm and the central electrode (0.002"), it is necessary to protect the gage from overload in those cases in which excessive thrusts are produced by blowing out of the orifice plate. For this purpose the diaphragm valve shown in Figure 4 c is inserted in the oil cylinder. Suitable blow out pressures can be obtained by using various thicknesses of shim brass or steel for the diaphragm.

5) Power supply, Oscillator-Detector and Bucking Box

The power supply, oscillator-detector and bucking box were obtained from the General Motors Research Laboratories and are described in the Trans. A.I.E.E. March, 1941.

The power supply is a regulated D.C. voltage source which can be varied from 200 to 500 volts. The normal operating voltage is around 270 volts. The power supply furnishes the necessary steady voltage to operate the oscillator in the oscillator-detector unit. It also furnishes the filament voltage for the tubes in the oscillator-detector.

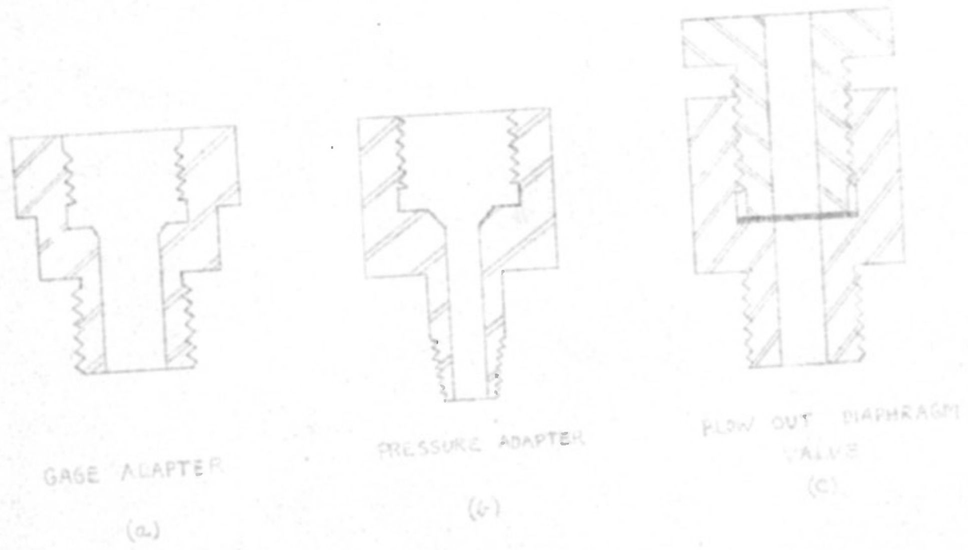
GAGE ADAPTER
(a)
PRESSURE ADAPTER
(b)
FLOW OUT DIAPHRAGM VALVE
(c)

FIGURE 4

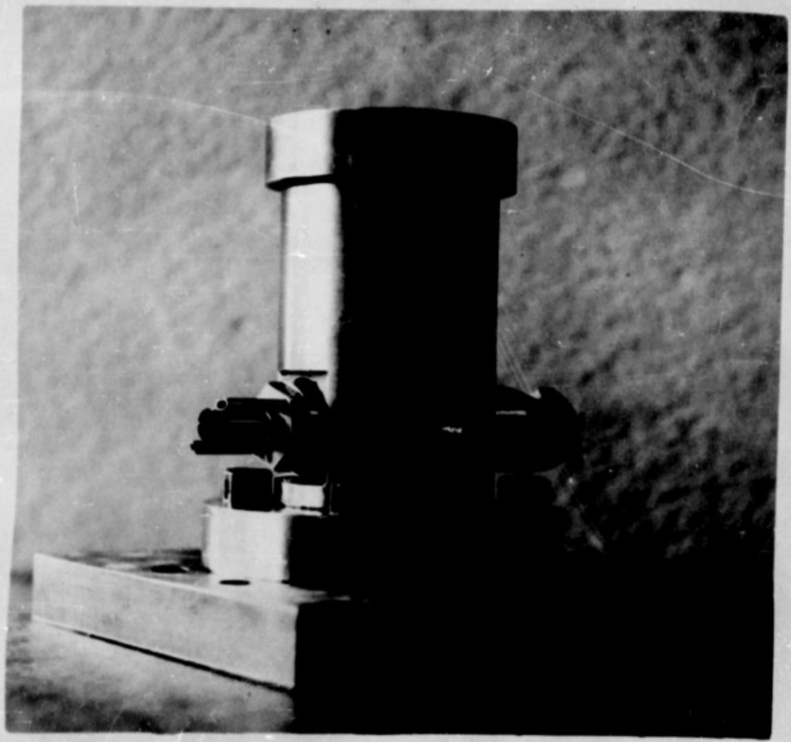

Fig. 5

The oscillator-detector unit contains a radio frequency oscillator, a tuned radio frequency transformer and a diode detector. In order to increase the stability to mechanical shock, the 140 $\mu\mu f$ midget tuning condenser was replaced with a 35 $\mu\mu f$ double spaced midget tuning condenser and fixed condensers. The 35 $\mu\mu f$ tuning condenser gives sufficient range to cover most of the resonance curve and is free from mechanical vibration effects.

The bucking box consists of a 10 tap 500,000 ohm resistor, a potentiometer and a 90 volt battery. The output voltage from the detector is applied across the tapped resistor which is then used as a gain control. The tapped-off voltage is bucked by the battery and potentiometer so that the output to the oscillograph is zero volts when no pressure is on the gage.

6) Oscillograph

The oscillograph is a standard Du Mont type 208 with a 5" blue phosphor short persistence screen. The oscillograph is modified, as described in the Du Mont instruction manual, so that the input goes to the D. C. portion of the vertical amplifier and the connections to the vertical and horizontal deflection plates are interchanged so that the deflections on the screen can be photographed with a camera having vertical film motion. A further modification is made to bring out a separate external beam switch which can be synchronized with the firing to prevent excessive burning of the screen by the high intensity spot.

7) Camera

The camera used is a Burke and James Universal 35 mm. movie camera. The camera is modified for continuous film movement by removing the shutter, claw movement and fade out mechanism. The film sprocket wheel is driven by an 1800 R.P.M. synchronous motor coupled through spur gears to a Boston gear reductor. No trouble has been experienced due to delay in reaching synchronous speed. Various film speeds from 0.75 to 6 inches per second can be obtained with proper choice of gear box and spur gears. Since most tests are of 0.5 second duration, a film speed of 3 inches per second has been used. A 4-1/4" focal length lens with f: 4.5 aperture was adapted to the camera in order to get full film coverage with a minimum of error due to screen curvature. Eastman Type 1301 Release Positive film is used. This film has a very clear base, excellent contrast and good sensitivity in the blue.

8) Timer

Time marks are placed on the film by photographing the flashes from a R.C.A. Type 901 glow discharge tube. The tube is operated with half wave rectified 60 cycle voltage giving 60 flashes per second. The light from the tube is brought into the angle of view of the camera by means of a mirror. Although time marks are put on all the records, the time of burning is calculated from the linear film speed. The time marks are used only to check irregularities.

9) Ignition Timer

In order to get a measure of ignition delay, a short duration pulse is put on the base line trace at the instant the firing switch is closed. The pulse is applied by charging a condenser through a low resistance inserted at the grounded end of the bucking box gain control. The voltage developed across the resistance appears as a pulse of a few milliseconds duration. The firing circuit and the pulse circuit are synchronized by using a double pole relay to close the two circuits.

10) Shot Numberer

An identification number is placed on each record by reflecting a set of illuminated stenciled numbers into the view of the camera.

11) Control Switch

A multiple switch was constructed to control the sequence of operations involved in the firing of a shot. The switch consists of a box containing six roller leaf micro switches activated by a sliding contact plate. The contact plate has adjustable cams for obtaining the desired sequence of switching. At present the sequence is as follows: numberer light on, numberer light off, camera on, oscillograph beam on, timer on and firing circuit on.

12) Motor Support

The mounted motor is shown in Figure 6. The motor rests on two V supports made of angle iron and is held in place with yokes made of roller chain. For thrust measurements the front of the motor rests against the piston of the thrust cylinder which is bolted to the back plate of the bomb shelter.

Operation of the Apparatus

In adjusting the apparatus, the tuning condenser of the oscillator-detector unit is set for maximum output as read on the milliammeter. The power supply voltage is then adjusted

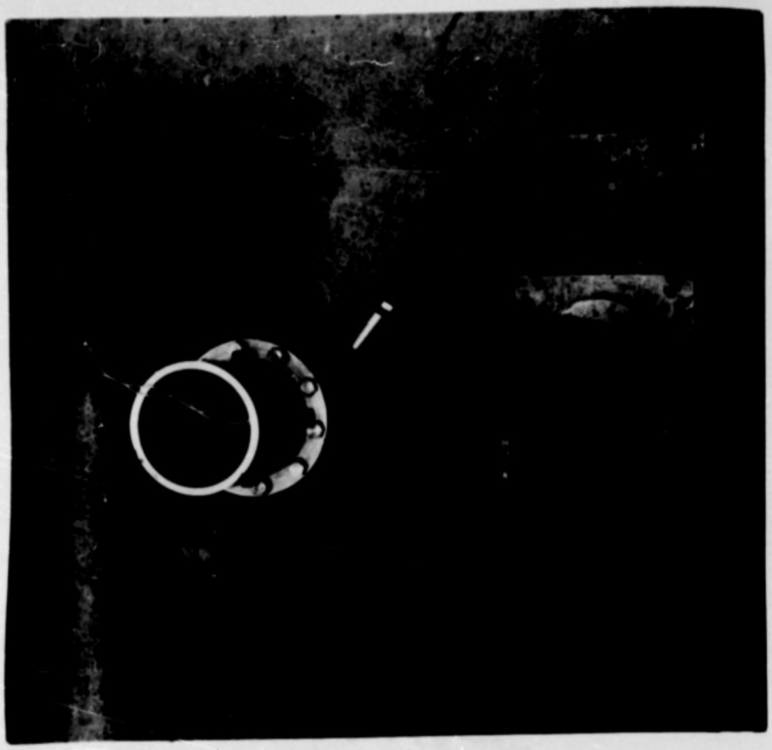

Fig. 6

so that the maximum output is 1.00 m.a. The capacity of the tuning condenser is then increased until the reading is 0.82 m.a. This tunes the transformer to the portion of the resonance curve near the point of inflection and gives the position of maximum sensitivity to capacity changes. The bucking box gain control is then set to the desired gain and the potentiometer adjusted to bring the oscillograph beam to the zero position. All other operations are then performed by throwing the multiple switch.

Figure 7 shows some representative pressure and thrust curves; c) and d) are pressure records and a) and b) are thrust records. The oscillations at the beginning of the thrust records are probably due to the high inertia of the motor, impact phenomena due to imperfect contact of motor and piston and residual air bubbles in the hydraulic system.

Calibration

The gage is calibrated against a calibrated Bourdon test gage using an oil pressure system and a Blackhawk hand pump. Figure 8 shows the output voltage, as measured from the bucking box with a vacuum tube voltmeter, as a function of pressure. Since the gain control is turned down, the actual output from the oscillator-detector is five times the plotted values. The maximum sensitivity is therefore 3.25 volts per 1000 pounds per sq. in.

Figure 9 shows the voltage sensitivity of the D.C. channel of the oscillograph as recorded with the camera. Figure 10 shows the calibration curve of the gage as recorded by the camera. The observed sensitivity of the gage is 211 pounds per square inch per millimeter deflection on the film. The sensitivity as calculated from Figures 8 and 9 is 208 pounds per square inch per millimeter deflection.

Despite the excellent calibration shown in Figures 8, 9 and 10, we have experienced some difficulties in obtaining reliable calibration values. In particular there have been erratic changes in the calibration value and gradual changes with change in temperature. The first difficulty is attributed to the use of beaded coaxial cable to connect the gage to the oscillator-detector unit. This type of cable has unsatisfactory mechanical stability and is subject to humidity and temperature effects. A new type solid dielectric coaxial cable is being obtained to replace the beaded cable. The second difficulty appears to be due to the use of ordinary steel for the gage adapters. The gages are made of low expansion coefficient invar steel and the differential expansion of the two materials effects the thread tension on the gage and defeats the purpose of the adapter. New adapters of invar are being obtained.

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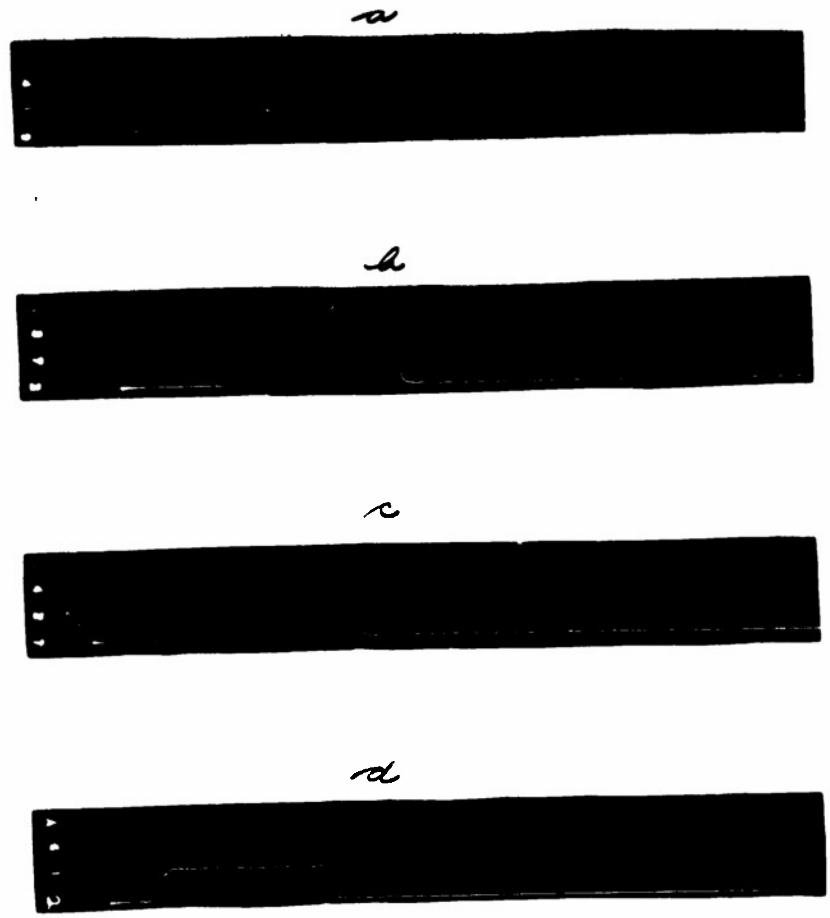

Fig. 7

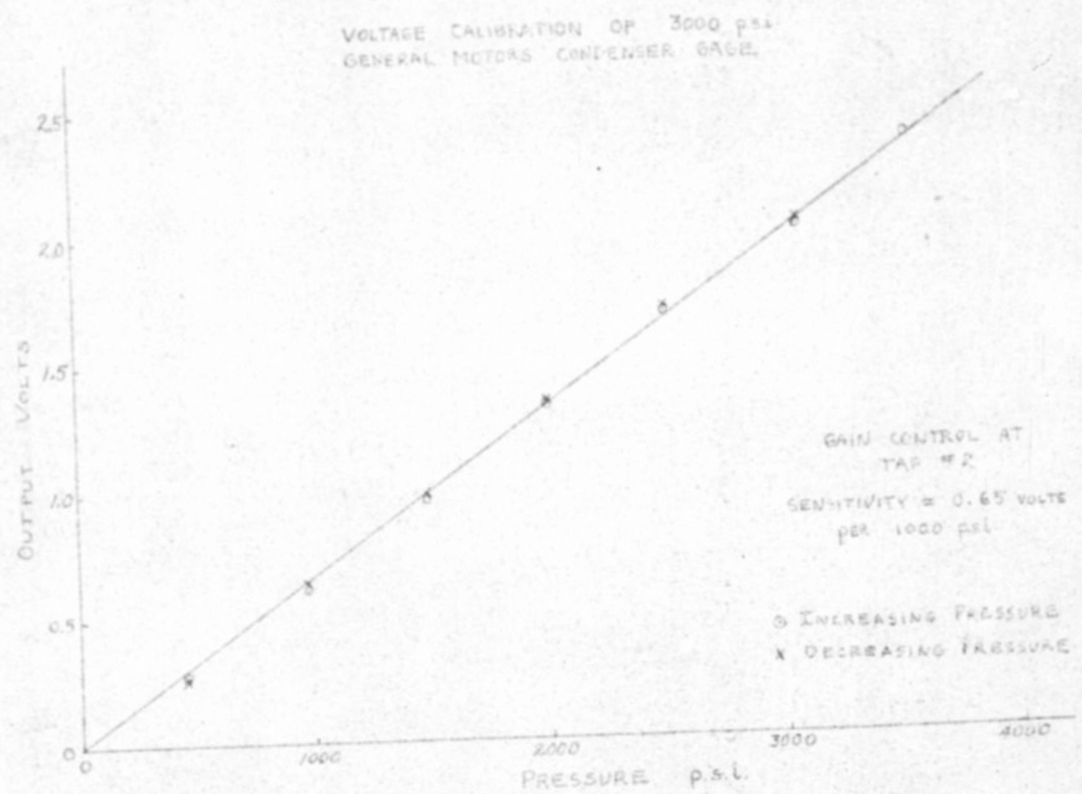
VOLTAGE CALIBRATION OF 3000 psi
GENERAL MOTORS CONDENSER GAGE
OUTPUT VOLTS
0
0.5
1.0
1.5
2.0
2.5
0
1000
2000
3000
4000
PRESSURE p.s.i.
GAIN CONTROL AT
TAP #2
SENSITIVITY = 0.65 VOLTS
PER 1000 psi
⊙ INCREASING PRESSURE
x DECREASING PRESSURE

FIGURE 8

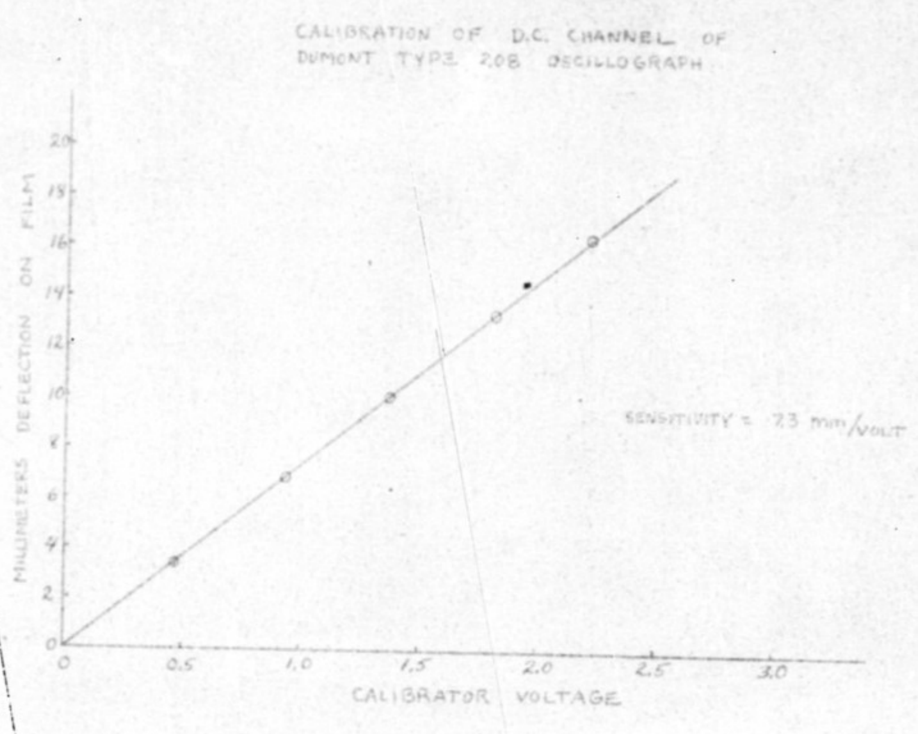
CALIBRATION OF D.C. CHANNEL OF
DUMONT TYPE 208 OSCILLOGRAPH
MILLIMETERS DEFLECTION ON FILM
0
2
4
6
8
10
12
14
16
18
20
0
0.5
1.0
1.5
2.0
2.5
3.0
CALIBRATOR VOLTAGE
SENSITIVITY = 7.3 mm/VOLT

FIGURE 9

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TSDIN FORM C D (10 FEB 47) C-5-17-2

ATI- 12574

ORIG. AGENCY NUMBER

O.S.R.D.-1678

REVISION

AUTHOR(S)

Sage, Charles G.

DIVISION: Power Plants, Jet and Turbine (5)

SECTION: Testing (17)

CROSS REFERENCES: Engines, Jet propulsion - Test equipment (33686); Thrust measurement (94100); Pressure - Measurement (73564)

AMER. TITLE: A condenser gage apparatus for measuring the pressure and thrust characteristics of jet propulsion motors

FORG'N. TITLE:

ORIGINATING AGENCY: O.S.R.D., N.D.R.C., Div. 8, Washington, D. C.

TRANSLATION:

COUNTRY	LANGUAGE	FORG'N.CLASS	U. S.CLASS.	DATE	PAGES	ILLUS.	FEATURES
U.S.	Eng.		[illegible]	Aug '43	18	10	photos, diagrs, graphs

ABSTRACT

Pressure to be measured is applied to condenser type gage. Pressure causes change in electrical capacity of gage which affects frequency response of tuned radio frequency transformer thereby changing output of transformer. This is detected and leads to bucking circuit which acts as gain control and zero adjuster. Output from bucking box is applied to oscillograph, and deflection of oscillograph beam is photographically recorded. For measuring thrust, reaction force is applied to piston acting in oil-filled cylinder.

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BY John D. Moore USCG

DATE 15 Feb. 1951

23 Pressure Gages