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Techniques of Water-Resources Investigations
of the United States Geological Survey

Book 8 Chapter A2

INSTALLATION AND SERVICE MANUAL FOR U.S. GEOLOGICAL SURVEY MANOMETERS

By J. D. Craig

Book 8
Instrumentation

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PREFACE

The series of manuals on techniques describes procedures for planning and executing specialized work in water-resources investigations. The material is grouped under major subject headings called "Books" and further subdivided into sections and chapters. Section A of Book 8 is on instruments for measurement of water level.

The unit of publication, the Chapter, is limited to a narrow field of subject matter. This format permits flexibility in revision and publication as the need arises. Chapter A2 deals with installation and servicing of U.S. Geological Survey manometers.

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INSTALLATION AND SERVICE MANUAL FOR U.S. GEOLOGICAL SURVEY MANOMETERS

By J. D. Craig

ABSTRACT

The purpose of this manual is to describe the installation, operation, and maintenance of the bubble-gage manometers currently (1982) used by the U.S. Geological Survey. Other applications of these devices, such as the long manometer and differential manometer, are discussed, and accessories available for them are described.

The bubble gage (water-stage manometer with gas-purge system) described in the Installation and Service Manual, October 1962, has been extensively modified and developed into the STACOM (stabilized and temperature compensated) device. This chapter is the manual for the STACOM unit and an update of the manual for the screw-type bubble gage. A parts list is included for both units.[1/]

GENERAL DESCRIPTION OF THE MANOMETERS

The manometers operate on the principle that a difference in pressure between ends of the manometer displaces the free surface of a liquid-mercury column. Displacement of the liquid mercury develops a head sufficient to balance the pressure. The pressure-cup reservoir on the manometer is driven by a servo motor, actuated by a float switch, to a position that develops a sufficient height of mercury to balance the pressure. The float switch operates within a narrow lead band and actuates the motor until a null position is developed when the pressure is balanced. Activitation of the float switch is a direct consequence of movement of the free surface of mercury when pressures across the manometer change as a result of variations in stream level. A counter displays the stage (height), in feet of water, which is recorded on an analog or digital recorder or both. The manometer assembly converts the pressure in the sensing element of the gas-purge system to a shaft rotation, which drives the stage-indicating and recording mechanisms.

Pressure transmitted through the manometer tubing to the pressure-cup reservoir is developed at a bubble orifice placed in the stream. When a gas is supplied through the tubing and bubbles freely into the stream through an orifice at a fixed elevation, pressure in the tubing is equal to the pressure head at the bubble orifice. Minor differences due to variation in the weight of gas and friction of the flowing gas in the connecting tubing result in small errors in the pressure. The gas-purge system provides a means of transmitting the pressure head of water above the orifice to the manometer. The dynamic purge provided by the continuous formation of bubbles avoids discrepancies of locked-system temperature effects. This principal is utilized to transfer pressure head caused by stream stage to the recording equipment in the gaging station, which is installed at a location above expected flood levels.

The servo-control unit provides the amplification necessary for the sensitive float

1/ Part numbers in this manual refer to drawing dated Oct. 21, 1971, for STACOM, and Sept. 1, 1959, for screw type.

switch to control operation of the motor. Amplification is needed because pressure on the float-switch contacts otherwise is too light to provide enough electric current to operate the motor. Such sensitivity is required to detect changes in mercury level of only a few thousandths of an inch. The servo-control unit also provides a delay circuit to dampen pressure surges that often result from surface waves or water-velocity disturbances. The circuit locks the manometer drive during punching of the paper tape on the digital recorder. The delay circuit also eliminates undesirable "painting" of analog-recorder charts and contributes to longer periods of satisfactory operation.

Recording equipment used with the manometer can be any type of analog or digital water-stage recorder. Those units with suitable sprocket ratios or jack shafts can be chain driven by the manometer unit. The two drive sprockets regularly furnished are designed to permit coupling to the Leupold & Stevens digital recorder, the Leupold & Stevens continuous recorder Model A-71, and the Fischer & Porter digital recorder Series 1542.

THE STACOM MANOMETER

The U.S. Geological Survey manometer (bubble gage) was first introduced in 1956, but fewer than 100 were installed in the next several years. The manometer would have failed and been forgotten except for the men in a few field offices who were determined to make it work because it was the only viable alternative to a stilling well.

Frustration and disappointment prevailed until 1961, when a more reliable mercury-wetted servo control was introduced. Although far from perfect, this control improved operation and allowed more detailed analysis of other manometer problems. Thus, during 1961-67, several accessories for improved operation were offered, used, and subsequently required on procurements of new manometers.

During 1963-67, several commercial versions of all-solid-state servo controls were tried with fair to poor results. However, in 1968 an in-house-designed, ramp-start, solid-state servo control was introduced that significantly improved record collection. In fact, the new control unit avoided a decision to adopt a much more expensive and complicated pickup system that had been designed to eliminate nagging problems with "loss of sensitivity."

Through the development years, the hydrographers responsible for record collection suggested a multitude of devices or changes. Although many of these suggestions were not feasible or economical, the general tone of the complaints was considered very carefully. Consequently, design of a new manometer that would satisfy the complaints and further improve operation was begun in 1969, and testing was done in 1971.

The new U.S. Geological Survey STACOM manometer is the first significant model change since introduction of the bubble-gage manometer in 1956. The word STACOM is derived from the two words--STAbilized and temperature COMpensated. This title will also clearly distinguish it from the original screw-type manometer.

The threaded shaft has been replaced either with a cable belt and sprocket-drive system (earlier STACOM models) or a roller chain (later STACOM models). The motor-drive assembly is pivoted and can

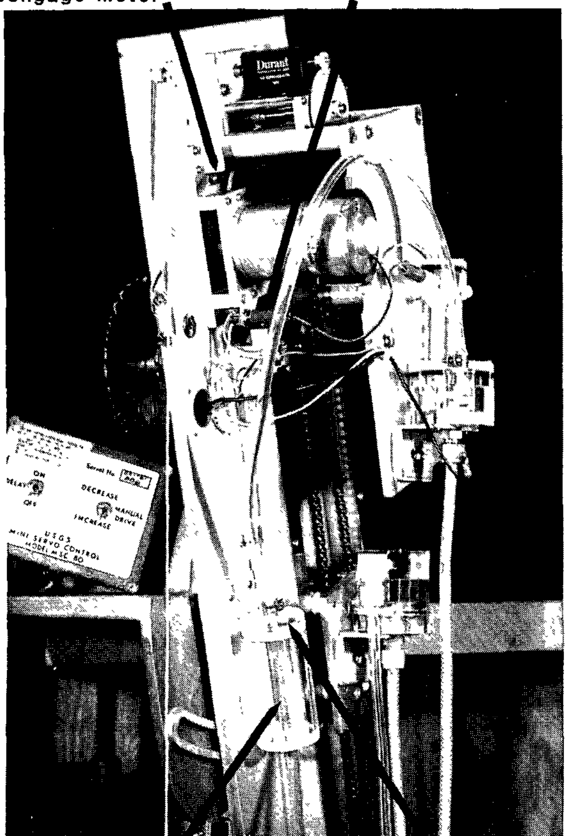

Figure 1.--STACOM manometer drive system.

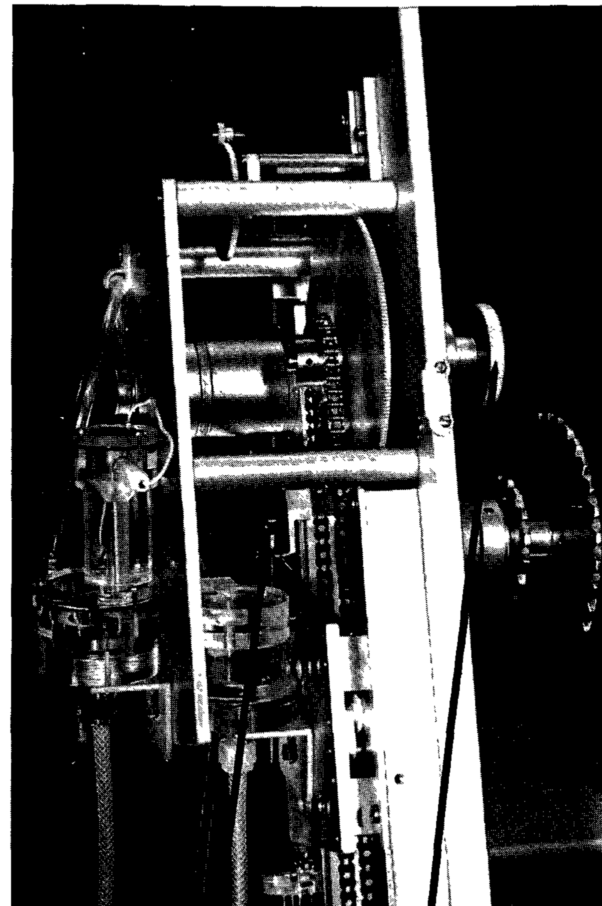

Figure 2.--Pressure reservoir traverse system.

be uncoupled by loosening one screw (fig. 1) and moving the platform to the left until the motor-drive gear is disengaged. The pressure reservoir (moving cup) can then be caused to traverse the entire vertical distance quickly with a few turns of the hand knob (fig. 2) at the rear of the manometer backplate.

The counter remains synchronized throughout this traverse, so any datum that had been established is not lost. Guide rails direct the path of the pressure reservoir. Less power is required by the new drive system to move the reservoir due to lower friction and, more importantly, less variation in friction.

Temperature Compensation

All uncorrected mercury manometers of the type used by the Geological Survey have an error of 0.01 percent per degree Fahrenheit change in temperature due to changes in specific gravity of the mercury with temperature. Unless high heads and rapid changes in temperature occur, this error is probably not noticed, as it is corrected for gradually during regular visits to the station when the manometer is reset to the outside gage reading. When a high degree of accuracy is required, the error can be reduced to less than 0.001 percent per degree Fahrenheit by adding an optional correcting device to the STACOM manometer.

The ambient-temperature-correcting device varies the angle of the manometer with the vertical in direct proportion to the temperature change. To prevent affecting the base datum, the two mercury reservoirs must be perfectly alined front to rear (fig. 2), so that both subscribe identical arcs about the pivot point at manometer zero. To check for accuracy of reservoir alinement, the counter must remain at zero throughout the full excursion of manometer-angle adjustment with the pressure reservoir open to the atmosphere. (This requirement prevents the original manometers from being modified in a practical way to compensate for temperature errors.)

The temperature-correcting device is a self-contained servo package (fig. 3) that samples the manometer backplate temperature each minute, corrects the manometer angle if necessary, and then shuts off until the next minute. The device has a visual counter readout in degrees Celsius and operates from two 6-volt lantern batteries for a year or more. The temperature-correcting device is recommended only for models designed for stage changes of 75 feet or more.

The preceding discussion reveals that manometer angle (when measuring water head with gas purge) is really a function of temperature; therefore, the most commonly used angle adjustment index should be engraved on the fold-out arm in degrees of temperature.

This angle determination is accomplished with a fold-out arm and plumb bob with string (fig. 4), both fastened at predetermined points on the manometer backplate. With the arm extended and the plumb bob in place, the string hangs across the temperature index (fig. 5), which is calibrated with marks at 5-degree-Fahrenheit intervals (degrees Celsius if automatic temperature correction is used). On a standard manometer, a manually adjusted screw is used (fig. 6) to set the angle to whatever the local average ambient temperature is estimated to be. Obviously one or more seasonal changes can be made to decrease errors due to extreme temperature changes. On 1981 later and models, a level bubble has been added to the upper left-hand corner on the backplate to set the gage (the same as the screw-type

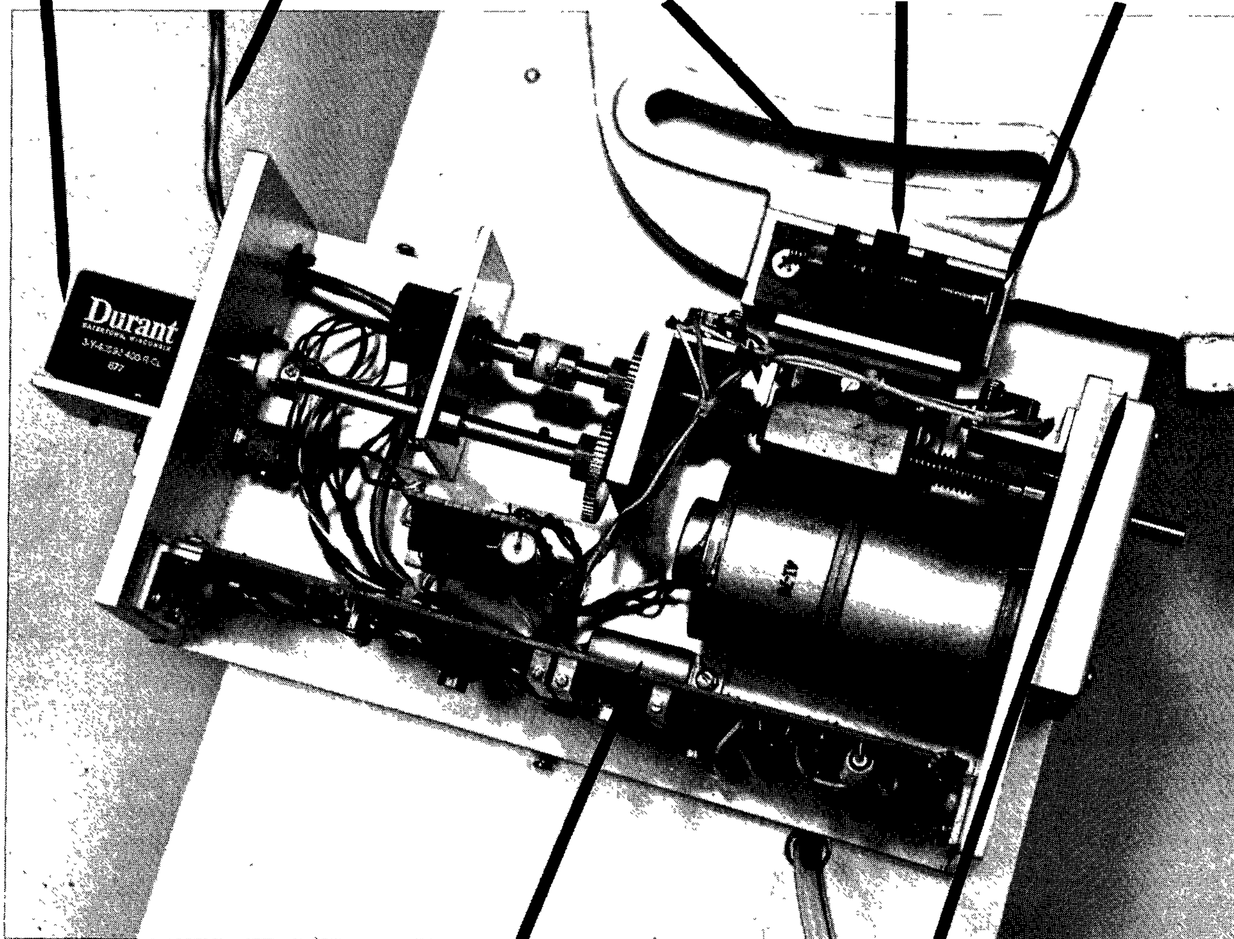

Figure 3.--Temperature servo with cover removed (rear view of manometer).

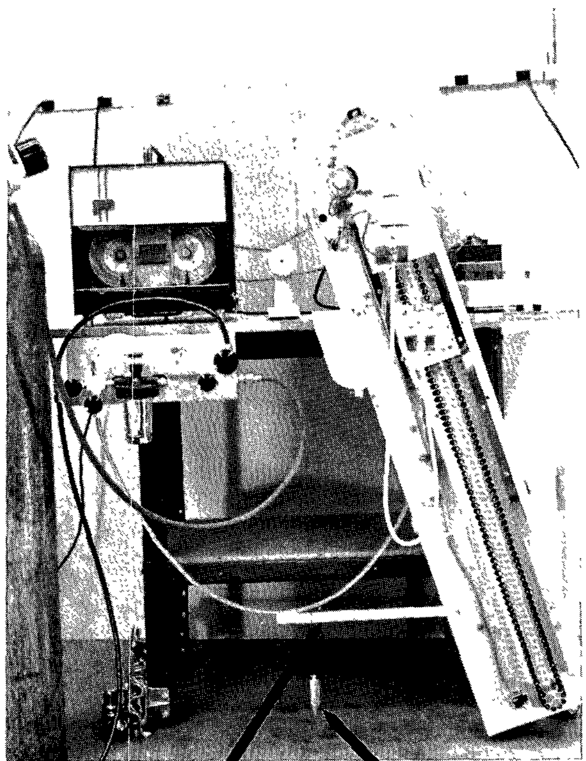

Figure 4.--Fold-out arm and plumb bob.

gage) at 17°40', which represents 67°F.

When the automatic angle-correcting device is installed, the angle is set to agree with the visual counter temperature reading of the unit, which should be the average ambient temperature at that time. On later visits, the angle can be checked occasionally to see that it continues to agree with the counter readout.

Float-Switch Reservoir and Mercury Overflow

In recognition of the mercury-contamination risk to the environment and to eliminate an aggravation, a method is provided for catching the mercury if the system is accidentally, or otherwise, purged. To accomplish this, it was first necessary to design the "O"-ring-sealed float-switch reservoir to provide an outlet for the mercury (fig. 7). Note that the float is smaller, the contact chamber is smaller, the contact spacing is adjustable externally, the mercury reservoir is smaller, and venting to the atmosphere is accomplished through the overflow reservoir. The rather devious inlet to the overflow reservoir prevents mercury droplets from splashing out during a sometimes violent purge. By removing this overflow reservoir (fig. 1) from the backplate and inverting in an elevated position, the mercury can be poured back into the system. The return path should be carefully examined and the tube or reservoir tapped as necessary to insure that all significant droplets have returned. Somewhat violent mercury purging may damage the pivots and bearings and, therefore, should always be avoided if possible. The straightin side contacts are purposely bent slightly to one side so that the effective contact spacing can be varied easily by turning the outside stainless-steel hex nut (fig. 7).

With the float switch sealed, a second gas-purge system can be attached at the reservoir outlet in place of the overflow reservoir, and the manometer can be used as a differential pressure device.

Miscellaneous

There are four tapped holes on the right-side track of the movable mercury reservoir that are to be used if accessory rail sections (fig. 8) are to be installed for mounting adjustable-stage microswitches or a peak-detection slider. The reservoir

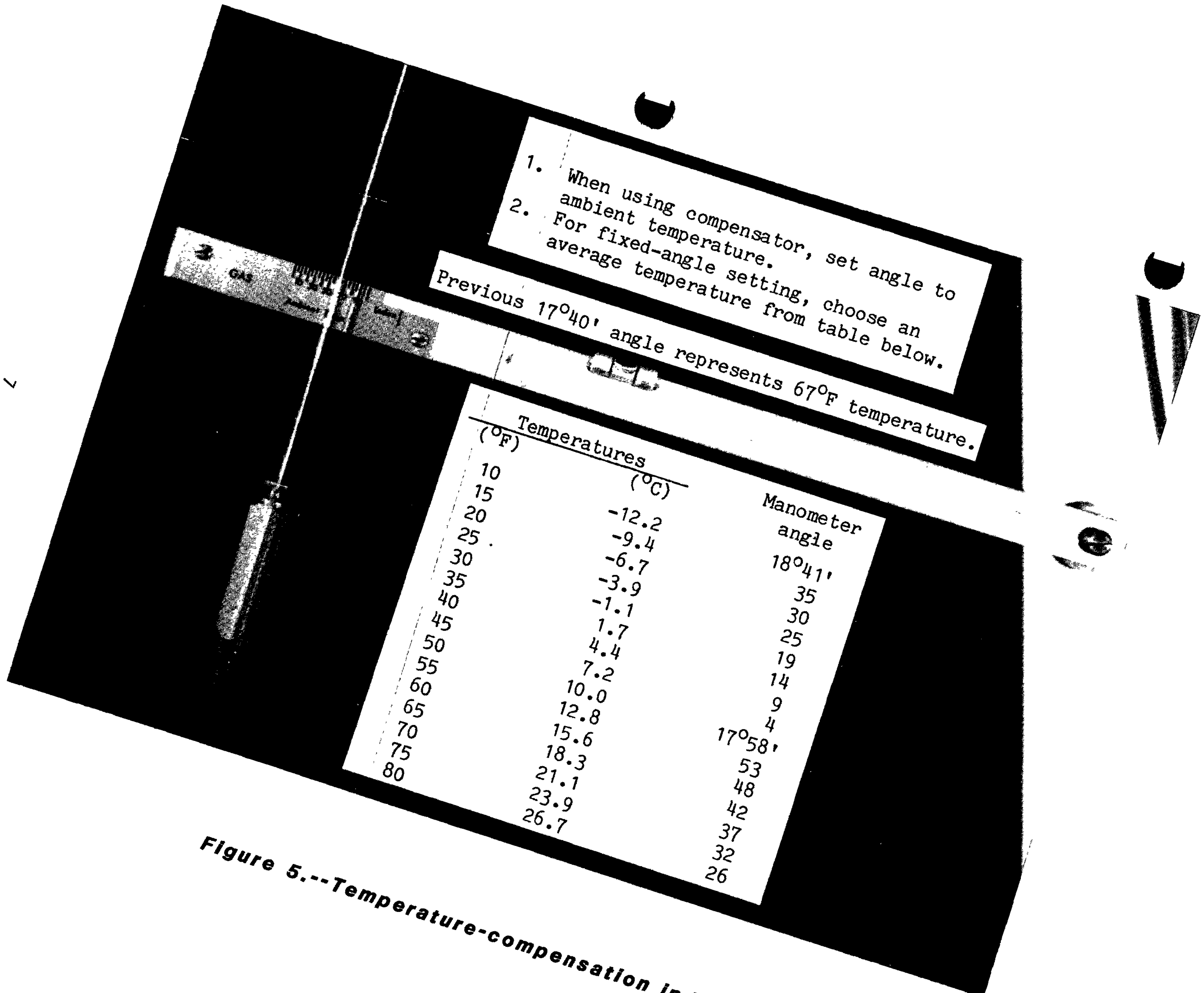

Figure 5.--Temperature-compensation index.

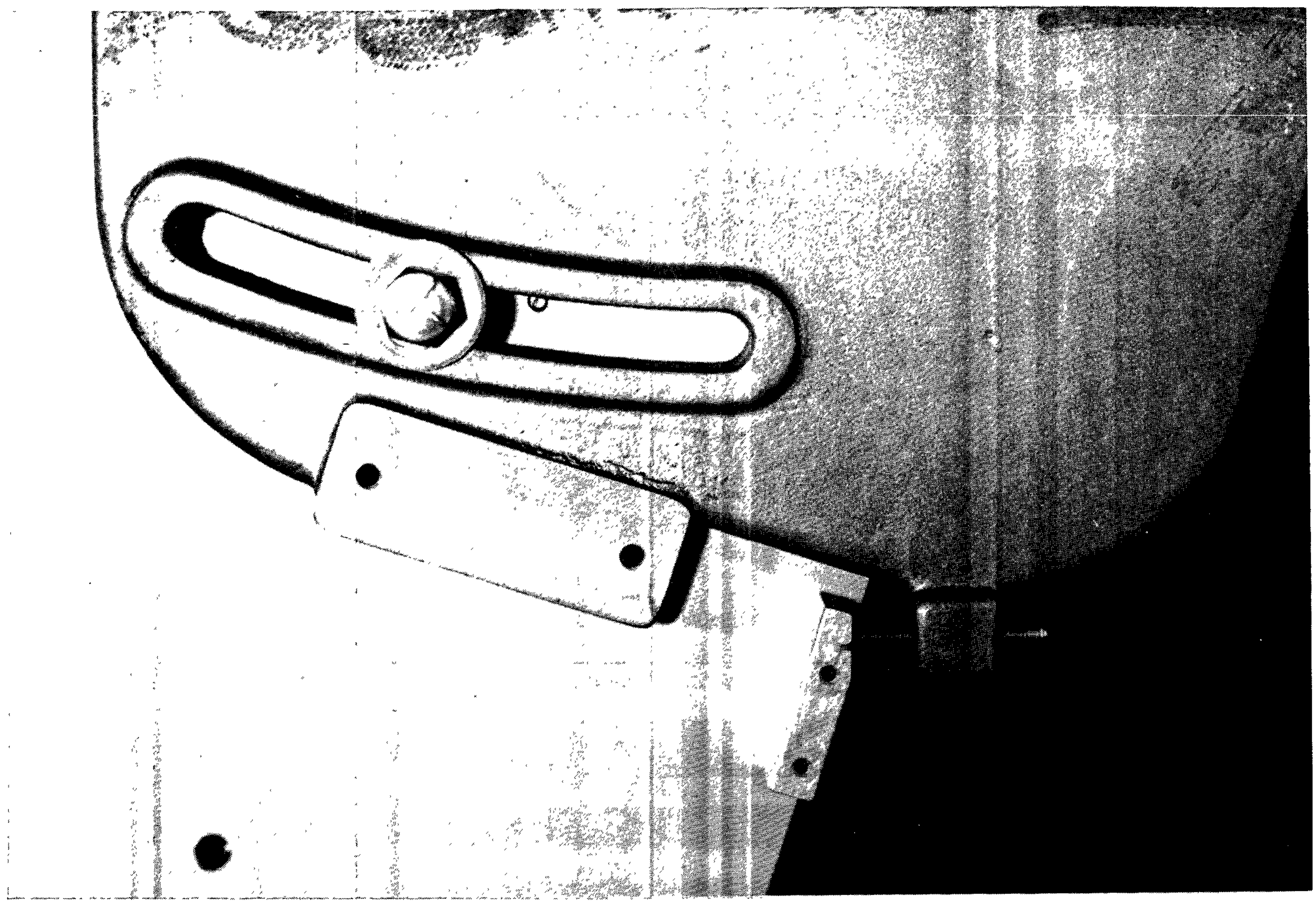

Figure 6.--Manual angle-adjustment screw.

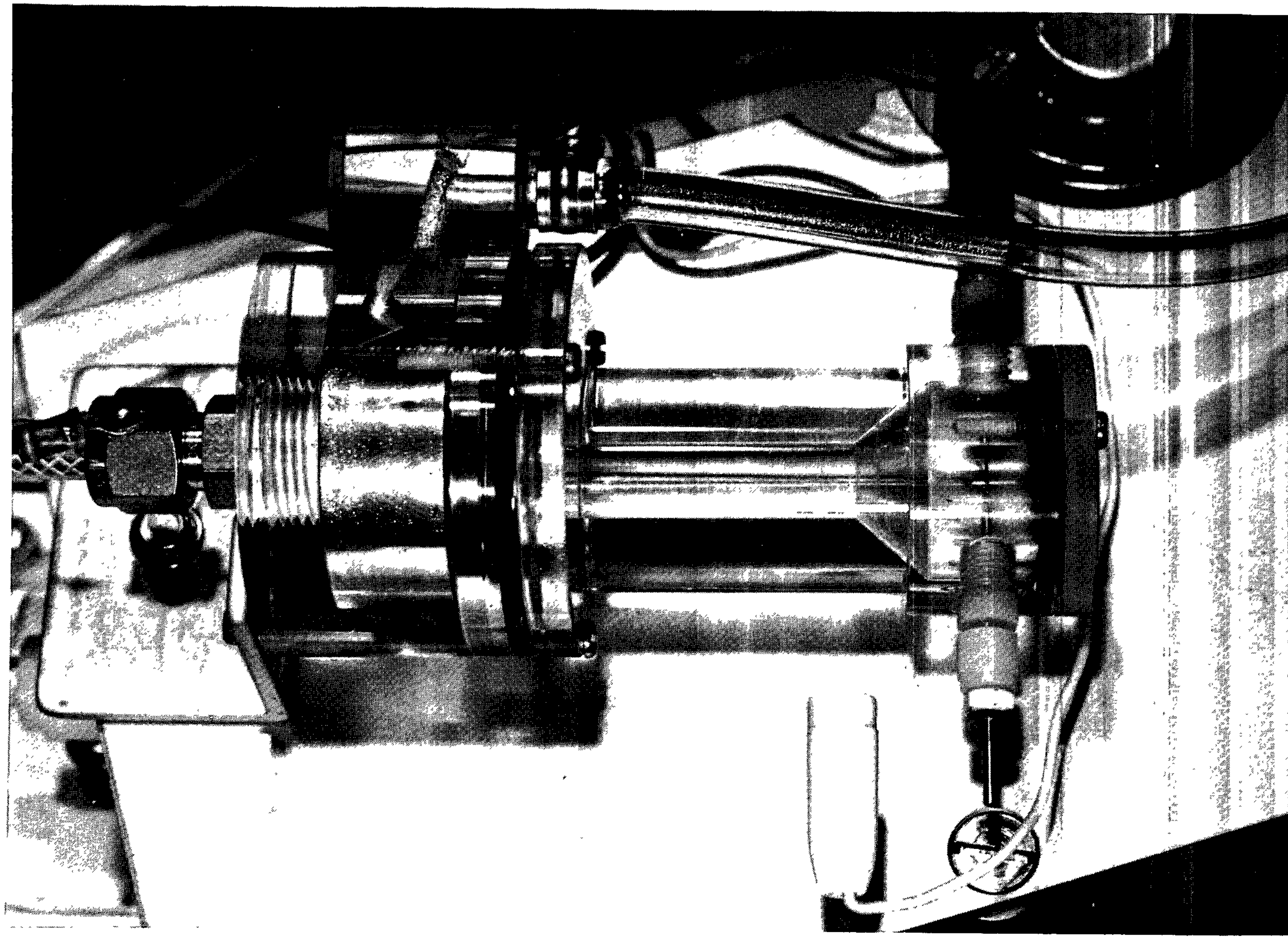

Figure 7.--Float-switch reservoir.

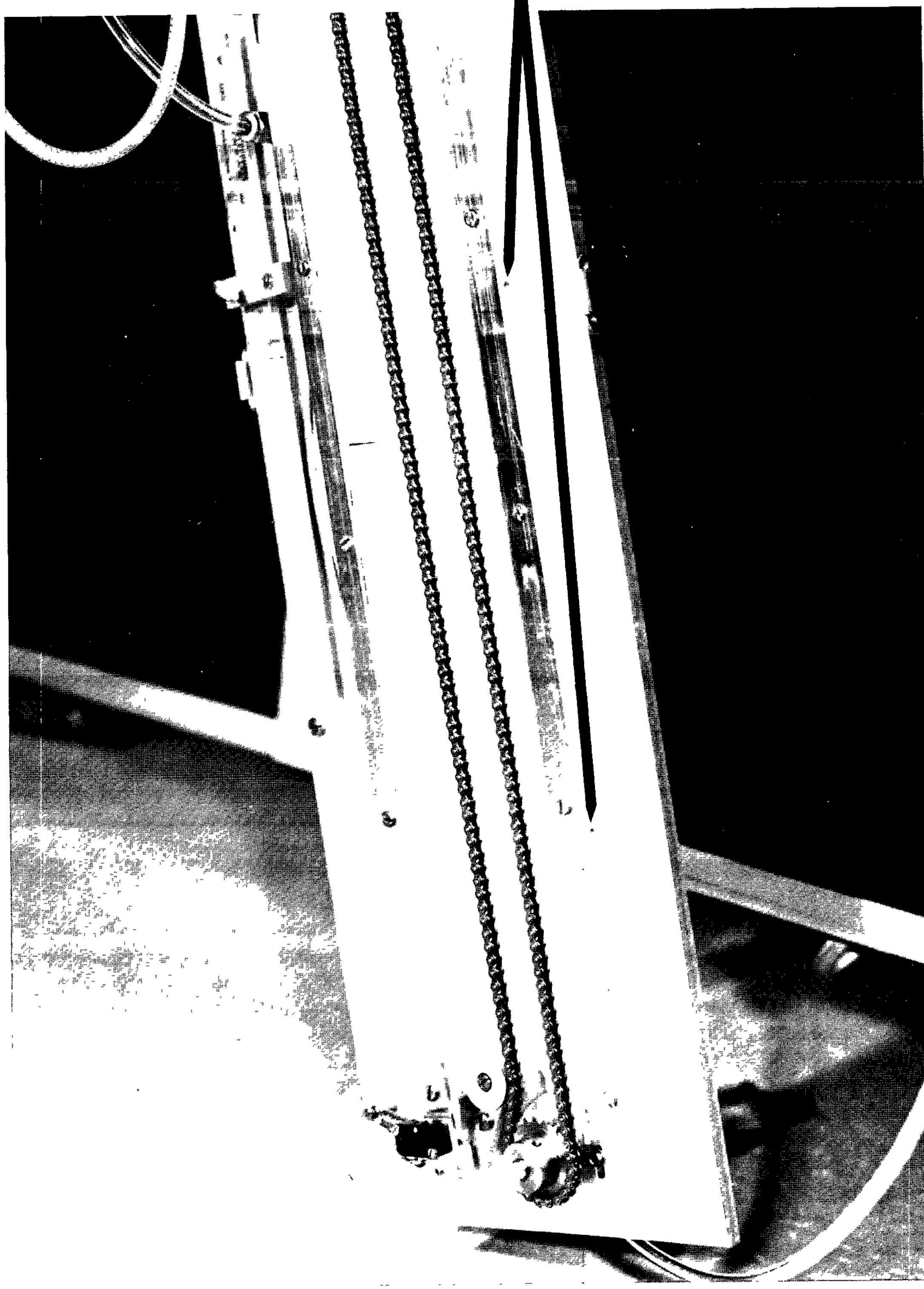

Figure 8.--Accessory switch rail section.

carriage plate also has tapped holes for mounting the switch-activator arm of whatever length or configuration is necessary. The regular left-hand-track limit switches are also adjustable (fig. 2), which means that the manometer can control its own travel and can also control any external device on-off at any predetermined stage.

The electrical connector on the manometer backplate is attached to an adaptor plate, which, in turn, covers a through hole large enough to accommodate the next larger size fitting. Tapped holes to attach such a fitting provide for field conversion to a more complex system in the future, if needed. Other through holes with hole plugs allow the passing of switch leads at any time. The motor connect is now a prepolarized single phone plug (fig. 1), which simplifies phasing of motor rotation.

The manometer cover is now a two-piece arrangement (fig. 9), and normally only the top half needs to be removed for servicing. Large viewing windows are on the front and side for cursory inspection of the condition of the float-switch reservoir, and a topside window is provided for counter readout.

It is possible to convert screw-type manometers to catch purged mercury as with the new manometer.

The above description of equipment shows that there are three subsystems:

1. The Gas-Purge System (fig. 10)
2. The Manometer Assembly (fig. 10)
3. The Servo-Control Unit (fig. 11)

The complete installation also includes a suitable recorder unit. To properly diagnose malfunction of the stage-measuring device, symptoms should be isolated into one of the three (or four) subsystems.

Purging Gas

Nitrogen is used as purging gas because it is cheap and readily available in most localities, it will not freeze and clog tubes, it is completely inert and safe, and it has very nearly the same weight as air. Compensation for weight variations that result from pressure are necessary for the recorder to follow variations in stage accurately. The density of river water also varies with temperature and with chemical and silt content, which causes errors in any pressure-sensing equipment used to record water levels.

Under standard conditions, water is approximately 900 times as heavy as nitrogen; therefore, errors due to variations in weight of the gas will be small. The manometer assembly can be adjusted to compensate for all errors that vary linearly with stage. The only other error due to variation in the weight of the gas is caused by temperature. Because nitrogen at atmospheric pressure has very nearly the same weight as air and because the weight of the atmosphere also varies with temperature, it is only the effect of a difference in average temperature of nitrogen in the bubble tube and temperature of the air that needs be considered.

For example, if the recording equipment is mounted 100 feet above the bubble orifice in the river with 2 feet of water over the orifice and if the average temperature of the gas in the bubble tube is constant at 40°F. While the air temperature increases from 40° to 70°F then the

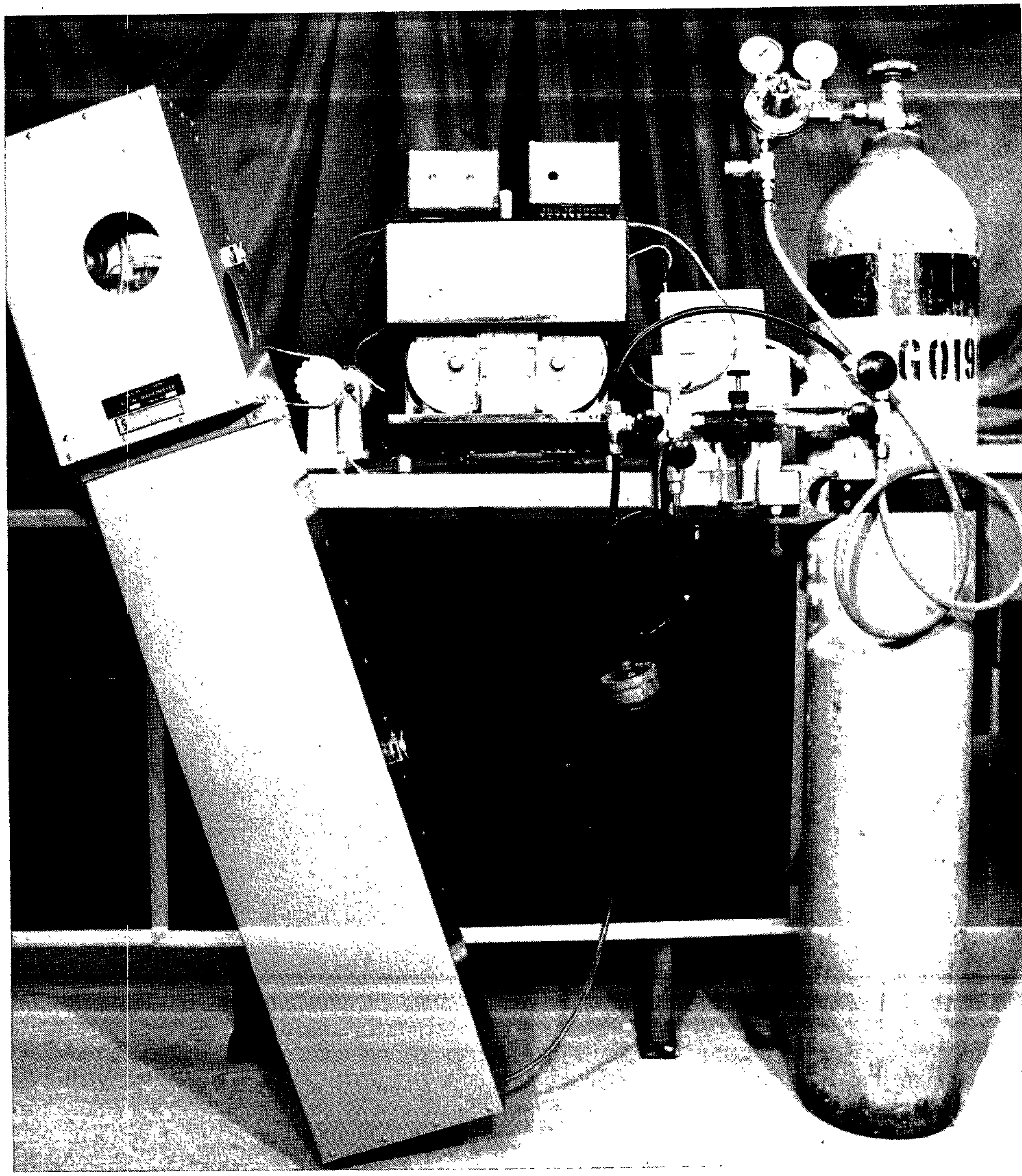

Figure 9.--Two-piece cover.

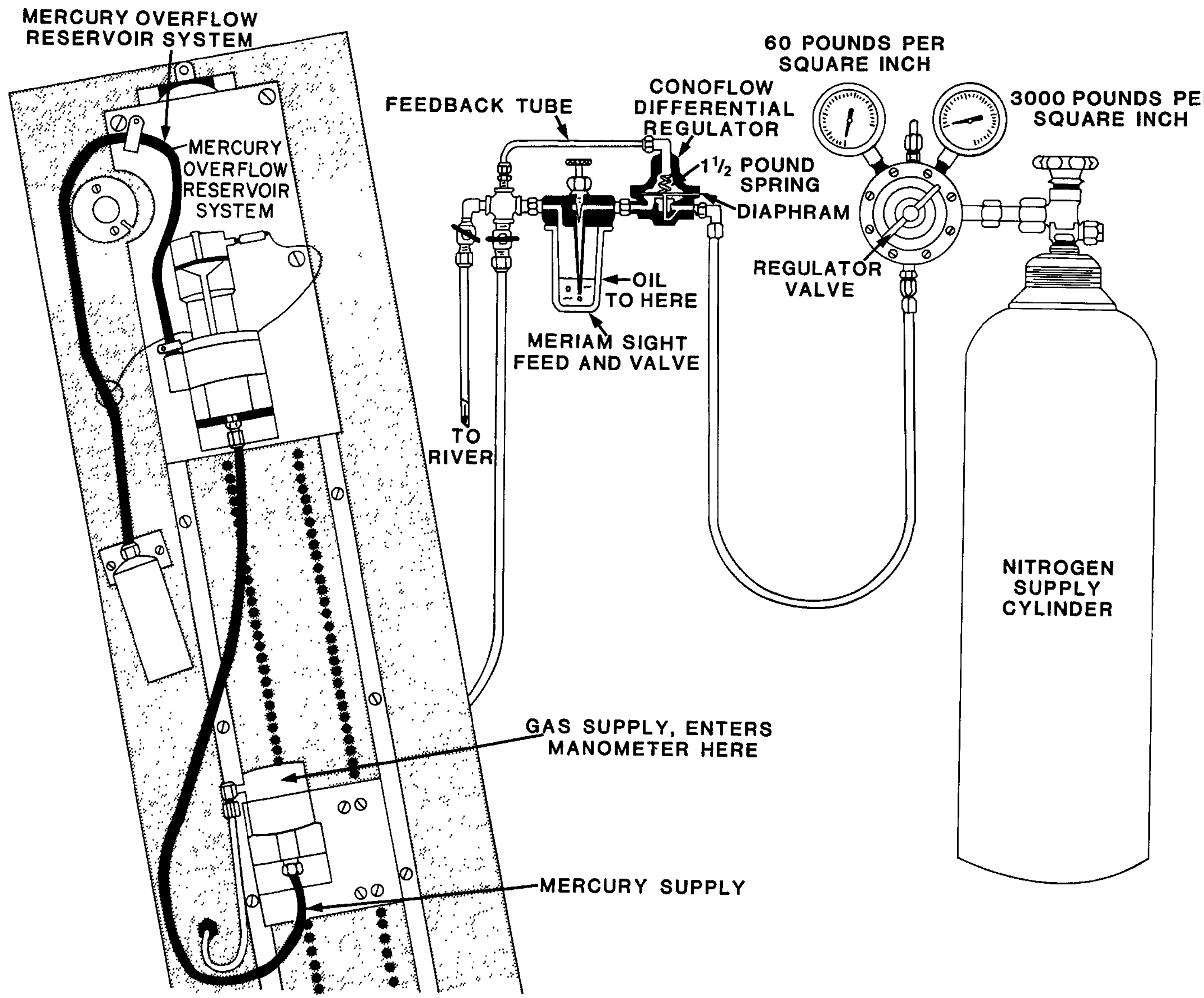

Figure 10.--Manometer assembly and gas-purge system.

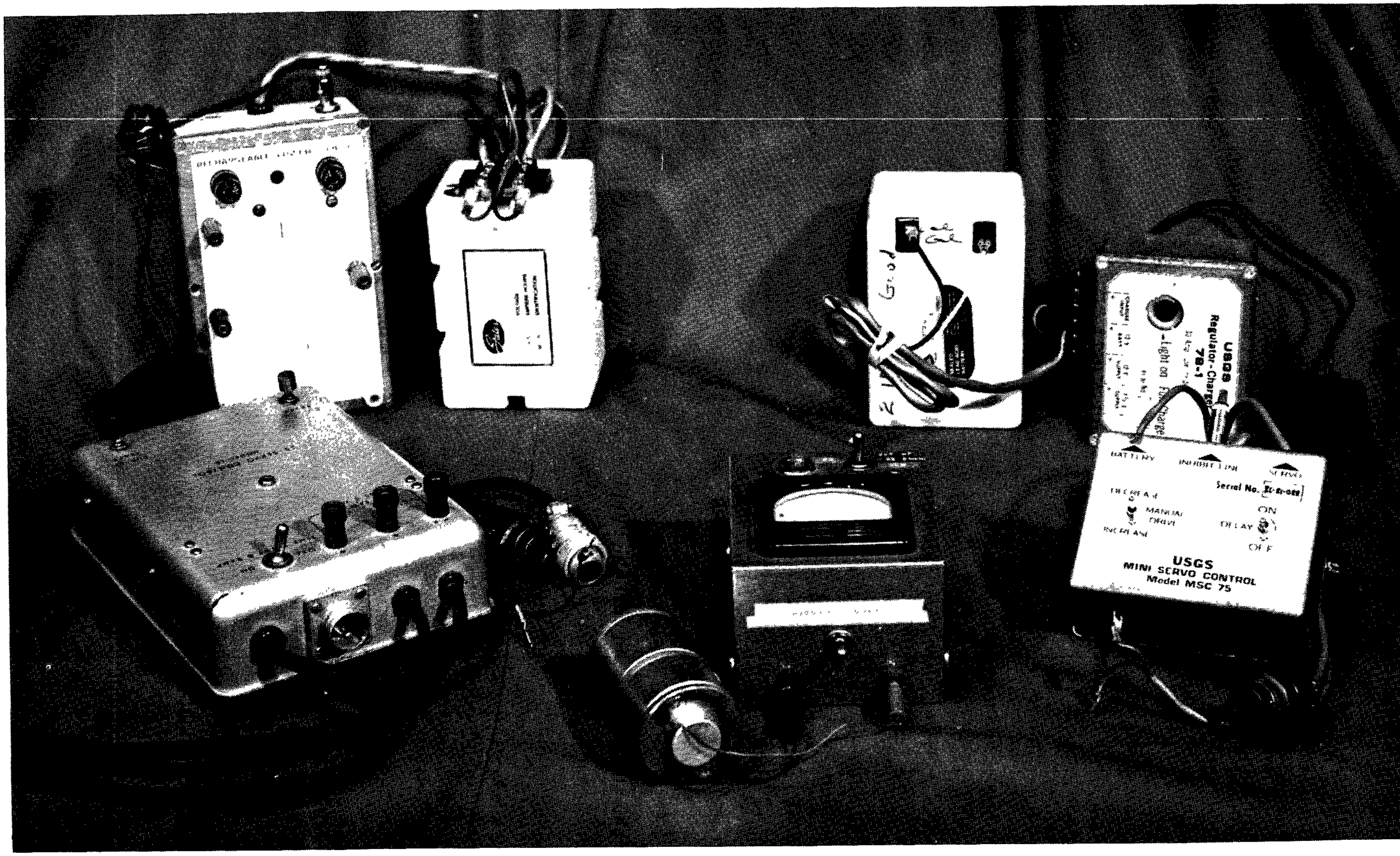

Figure 11.--Servocontrol unit.

error in the recorded level would be less than 0.01 foot. This error would decrease with the river stage and with the height of the equipment. For the usual height of equipment, this would not seriously affect the accuracy at low water, where greater accuracy is desired.

Density Effects

Any pressure-sensing system for recording water levels will be subject to errors due to variations in the density of water with temperature and with chemical and silt content. Stilling wells are not completely free of these effects because the water in the well may not have the same temperature or silt content as water in the river. Density-produced errors are usually quite small and, as they are proportional to stage, are, therefore, negligible at low water. The manometer can be adjusted for the effect of average silt concentrations, insofar as silt content varies directly with stage. The density of water does not vary appreciably with temperature from the freezing point to 60°F, but above 60°F, the variation is more rapid. At 90°F, for example, the relative density of water is 0.995. Density variations with chemical content in freshwater streams are not large enough to be significant.

Mercury, the heaviest liquid suitable for manometers, is used to keep manometers as short as possible. As the specific gravity of mercury is approximately 13.6, the effective vertical height of the manometer is 1/13.6 times the head of water to be measured. Thus, the manometer must be 13.6 times as sensitive to the mercury level as the accuracy desired in recording the water level (0.005 foot of water is equivalent to 0.0044 inch of mercury).

Manometer Angle

The manometer is installed at an angle of 17°40′ from the vertical at a temperature of 67°F. The angle is adjustable to compensate for temperature effects by use of the built-in index calibrated in degrees. From tests, the error caused by temperature change was empirically determined to be less than 0.01 percent per degree Fahrenheit. Angular adjustment may be made to compensate for an average, say seasonal, temperature that is different from 67°F. An automatic temperature correcting servo package is recommended as an accessory on long manometers to minimize errors due to temperature variations (fig. 3).

Power Consumption

Because this equipment usually must operate for long periods from dry batteries, the power consumption has been held to a minimum. At 6 volts (or 7 1/2 volts) the reversible motor draws about 200 milliamperes (1.2 watts) only while repositioning the manometer and recorder. The sensing and delay circuits draw currents of only a few milliamperes, and, with contacts open, the current is only a few microamperes.

DETAILED DESCRIPTION

Gas-Purge System

The gas-purge system (fig. 12) is the most complex and critical subsystem of the STACOM manometer. An understanding of its