RUSKA INSTRUMENT CORPORATION ◆ HOUSTON, TEXAS

MODEL 2450

PISTON PRESSURE GAGE

OPERATING INSTRUCTIONS

TABLE OF CONTENTS

MODEL 2450 DEAD WEIGHT GAGE

TYPES OF PISTON PRESSURE GAGES

The Dead Weight Tester or pressure balance is sometimes regarded as an absolute instrument because of the principle by which it measures pressure. An absolute instrument is defined here as one capable of measuring a quantity in the fundamental units of mass, length, time, etc. It may be suggested that only certain types of dead weight testers qualify in this category.

Figures 1, 2, and 3 illustrate the three most common type of cylinder arrangements.

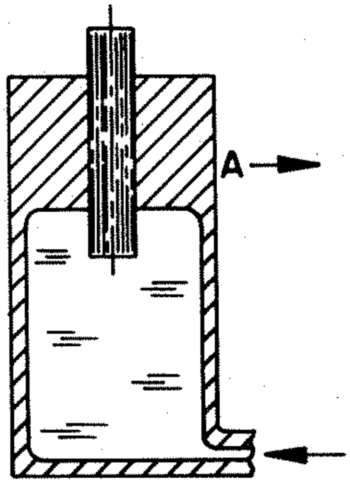


FIGURE 1

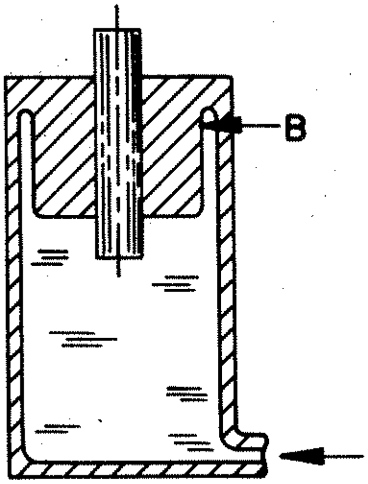


FIGURE 2

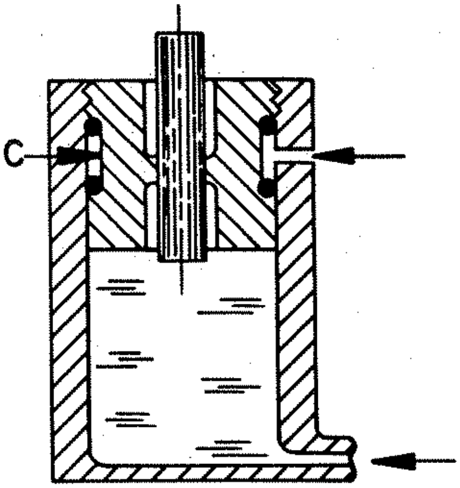


FIGURE 3

When the simple cylinder of Figure 1 is subjected to an increase in pressure, the fluid, exerting a relatively large total force, normal to the surface of confinement, expands the cylinder and thus increases its area. A pressure-drop appears across the cylinder wall near the point A and results in an elastic dilation of the cylinder bore.

It can be shown that the effective area of the piston and cylinder assembly is the mean of the individual areas of the piston and of the cylinder; therefore, as the pressure is increased, the cylinder expands and the effective area becomes greater. The rate of increase is usually but not always a linear function of the applied pressure. The piston also suffers distortion from the end-loading effects and from the pressure of the fluid but to a much less extent than the cylinder. It is evident, then, that the simple cylinder of Figure 1 would be inadequate for a primary dead weight tester unless some means of predicting the change in area were availabe.

The increase in the effective area of the simple cylinder is also accompanied by an increase in the leakage of the fluid past the piston. Indeed, the leakage becomes so great at some pressures that insufficient floating time can be maintained for a proper pressure measurement.

In Figure 2, the pressure fluid is allowed to surround the body of the cylinder. The pressure drop occurs across the cylinder wall near the top of the cylinder, at B, but in the opposite direction to that of the simple cylinder in Figure 1. In consequence, the elastic distortion is directed toward the piston, tending to decrease the area of the cylinder.

Again, the change in area with changing pressure places a limit on the usefulness of cylinder No. 2 as a primary instrument. But some benefit results from the use of cylinder No. 2 in the construction of a dead weight tester because higher pressures may be attained without a loss in float time. A small sacrifice is made in the float time at lower pressures because the total clearance between piston and cylinder must necessarily be greater at low pressure for cylinder No. 2 than for cylinder No. 1.

In the controlled-clearance design of Figure 3, the cylinder is surrounded by a jacket to which a secondary fluid pressure system is connected. Adjustment of the secondary, or jacket, pressure permits the operator to change the clearance between the cylinder and piston at will. A series of observations involving piston sink rates at various jacket pressures leads to the empirical determination of the effective area of the assembly. In the United States, the controlled-clearance piston gage is the accepted standard of pressure at levels higher than those that are practical for the mercury manometer.

Piston gages having very high resolutions may be made by using simple and re-entrant cylinders. A determination of the distortion coefficients of such gages may be made by direct comparison with a controlled-clearance gage. Most piston gages have some elastic distortion, but some, used in the very low pressures, have only small coefficients and, in some instances, correction for distortion may be neglected.

Measurement of pressure with the piston gage is subject to uncertainties resulting from effects other than those of elastic distortion. It is appropriate that the subject of elastic distortion be discussed first, since this characteristic is largely responsible for the various designs that have been developed.

Measurement processes proposed for high accuracy are disturbed by limitations in the performance of the equipment, by small changes in the environment and by operational procedures. The disturbances can be reduced to a degree by exercising control of the environment and development of skill in the operation of the apparatus. Some of the disturbances are difficult to control; it is easier to observe their magnitudes and apply corrections for their effects.

The factors that disturb a pressure measurement process when conducted with a piston pressure gage are described below. It is important that the operator acquaint himself with these factors and become accustomed to recognizing their presence. The success of the measurement will depend upon the degree to which control has been maintained or to the completeness by which corrections were applied for the disturbances.

Factors Affecting the Performance of the Piston Gage and the Measurement Process

Elastic Distortions of the piston and cylinder.

Temperature of the piston and cylinder.

Effects of gravity on the masses.

Buoyant effect of the atmosphere upon the masses.

Hydraulic and gaseous pressure gradients within the apparatus.

Surface tension effects of the liquids.

THE MEASUREMENT OF PRESSURE WITH THE PISTON GAGE

Pressure results from the application of a force which is distributed over an area of surface; it is defined as a force or thrust exerted over a surface divided by its area.

$$P = \frac{F}{A} \qquad \text{where}$$

P represents the pressure, F the force, and A the area.

Elastic Distortion of the Cylinder--

As the pressure is increased within a piston gage, the resulting stress produces a temporary deformation of the cylinder. The net effect is a change in the effective area of the piston. If the change in the area is a linear function of the applied pressure, the relationship may be described by the equality

$$A_e = A_o(1 + bp) \qquad \text{where}$$

A_e is the effective area at a pressure, p,

A_o is the area of the piston-cylinder assembly at a reference pressure level, and, b, a coefficient of elastic distortion that is determined experimentally. The value of b is the fractional change in area per unit of pressure.

TEMPERATURE

Dead Weight Gages are temperature sensitive and must, therefore, be corrected to a common temperature datum.

Variations in the indicated pressure resulting from changes in temperature arise from the expected change in effective area of the piston. Treatment, therefore, is a straightforward application of the thermal coefficients of the materials of the piston and cylinder. By substituting the difference in the working temperature from the reference temperature and the thermal coefficient of area expansion in the relation

$$A_o\ (t) = A_o\ (\text{Ref. } t)\ (1 + C\ \Delta t)$$

the area corresponding to the new temperature may be found.

In the equation above,

$A_o\ (t)$ = Area corrected to the working temperature.

$A_o\ (\text{Ref. } t)$ = Area of the piston at zero PSIG and at the selected reference temperature.

C = Coefficient of superficial expansion as indicated in the test report.

Δt = Difference between working temperature and reference temperature.

The magnitude of error resulting from a temperature change of 5°C for a tungsten carbide piston in an alloy-steel cylinder is approximately .008%.

For work of high precision, gage temperatures are read to the nearest 0.1°C.

THE EFFECTS OF GRAVITY

The confusion and ambiguity that has resulted from the carelessness with which the terms mass, weight, and force have been used is under severe and just attack by those who recognize the consequences in the continuation of such practice (see reference 8). The scientific community has long been careful in the use of terms involving units and dimensions. We are obligated to pay attention to what they have to say. We are at the threshold of international agreement on a unified system of weights and measures. It is important that, regardless of how inconvenient or mysterious these new units appear to us, we must quickly become acquainted with them and contribute our best effort toward a rapid and successful transition to the new system. The new units and their definitions leave little room for ambiquity. An understanding of the relationship between units of the International System will help us in correcting our habits with the use of our present units.

Objects familiar to us are attracted toward the earth by the action of gravity. We are interested in this attraction because it provides a way in which we can apply accurately-determined forces to the piston of a pressure gage. The force may be evaluated if we know the mass of the object to be placed on the gage piston. The quantity is expressed as

$$F = k\,Mg_{\ell} \qquad \text{(See reference 2)}$$

Where g_{ℓ} is the local acceleration due to gravity, M the mass of the object, and k a constant whose value depends upon the units of F, M, and g_{ℓ}:

$k = 1$ for F in Newtons, M in kilograms, and g_{ℓ} in Meter/Sec^2.

$k = \frac{1}{980.665}$ for F in kilograms force, M in kilograms, g_ℓ in cm/sec^2.

$k = \frac{1}{980.665}$ for F in pounds force, M in pounds mass, and g_ℓ in cm/sec^2.

BUOYANT EFFECT OF THE AIR

According to Archimede's principle, the weight of a body in a fluid is diminished by an amount equal to the weight of the fluid displaced. The weight of an object (in air) that has had its mass corrected for the effects of local gravity is actually less than the corrected value indicates. The reduction in weight is equal to the weight of the quantity of air displaced by the object or the volume of the object multiplied by the density of the air. But the volume of an irregular shaped object is difficult to compute from direct measurement. Buoyancy corrections are usually made by using the density of the material from which the object is made. If the value of mass is reported in units of apparent mass vs brass standards rather than of true mass, the density of the brass standards must be used. Apparent mass is described as the value the mass appears to have as determined in air having a density of 0.0012 g/mℓ, against brass standards of a density of 8.4 g/cm^3, whose coefficient of cubical expansion is 5.4 x 10^{-5}/$^{\circ}$C, and whose value is based on true mass in vacua (see reference 4).

Although the trend is swinging toward the use of true mass in favor of apparent mass, there is a small advantage in the use of the latter. When making calculations for air buoyancy from values of apparent mass, it is unnecessary to know the density of the mass. If objects of different densities are included in the calculation, it is not necessary to distinguish the difference in the calculations. This advantage is obtained at a small sacrifice in accuracy and is probably not justified when considering the confusion that is likely to occur if it becomes necessary to alternate in the use of the two systems.

A satisfactory approximation of the force on a piston that is produced by the load is given by

$$F = M_a \left(1 - \frac{\rho_a}{\rho_b} \right) k \, g_\ell \qquad \text{where}$$

F = the force on the piston

M_a = Mass of the load, reported as "apparent mass vs brass standards".

ρ_a = Density of the air.

ρ_b = Density of brass (8.4 g/cm^3)

REFERENCE PLANE OF MEASUREMENT

The measurement of pressure is strongly linked to gravitational effects on the medium. Whether in a system containing a gas or a liquid, gravitational forces produce pressure gradients that are significant and must be evaluated. Fluid pressure gradients and buoyant forces on the piston of a pressure balance require the assignment of a definite position at which the relation $P = \frac{F}{A}$ exists. It is common practice to associate this position directly with the piston as the datum to which all measurements made with that piston are referenced. It is called the reference plane of measurement and its location is determined from the dimensions of the piston. If the submerged portion of the piston is of uniform cross section, the reference plane is found to lie conveniently at the lower extremity. If, however, the portion of the piston submerged is not uniform, the reference plane is chosen at a point where the piston, with its volume unchanged, would terminate if its diameter were uniform.

When a pressure for the dead weight gage is calculated, the value obtained is valid at the reference plane. The pressure at any other plane in the system may be obtained by multiplying the distance of the other plane from the reference plane by the pressure gradient and adding (or subtracting) this value to that observed at the piston reference plane.

For good work, a pressure gage should be provided with a fiducial mark for associating the reference of the piston with other planes of interest within a system. Not only does the mark serve to establish fixed values of pressure differences through a system, but it indicates a position of the piston with respect to the cylinder at which calibration and subsequent use should be conducted. If the piston is tapered, it is important to maintain a uniform float position for both calibration and use.

In normal operation, the system is pressurized until the piston is in a floating position slightly above the fiducial or index mark. After a short period, the piston and its load will sink to the line at which time the conditions within the system are stable. If there is a question as to the error that may be produced by accepting a float position that is too high or too low, the error will be equivalent to a fluid head of the same height as the error in the float position. This statement assumes, of course, that the piston is uniform in area over this length.

EFFECTS OF LIQUID SURFACE TENSION

One of the smaller disturbances that affect the performance of a piston gage is that resulting from the surface tension of the liquid. The strong meniscus that is formed around the piston as it enters the cylinder is visible evidence of a force acting on the surfaces. Numerically, the force on the piston that results from surface tension is

$$F_{st} = \gamma C$$

where

γ = Surface tension of the liquid in dynes/cm or pounds force/in.

C = Circumference of piston in centimeters or inches.

CONDITIONS FAVORABLE FOR A MEASUREMENT

THE BEGINNING--DETERMINATION OF THE ZERO PRESSURE.

A pressure measurement is no better than its beginning. All pressure measurements are made with respect to something. When a value of pressure is expressed, it is implied that the difference between two pressure levels is the value stated. In order to determine the difference between two pressures, each of the pressures must be measured. Furthermore, if a level of confidence is stipulated for the expressed value of pressure, the confidence figure must include the errors of each of the pressure measurements. This problem is not unique to pressure measurement and is brought to attention here to impress, by repetition, the importance of proper zero measurement at the start.

Errors in establishing a starting-point zero at the beginning of the test arise principally from uncertain oil heads in various parts of the equipment. In general, the vertical dimensions of a hydraulic calibrating system, such as would normally be connected to a laboratory dead weight gage, are small; therefore, the total head error is relatively small. If the pressure to be measured or generated is large, the small starting error may possibly be neglected. But if pressures in the low ranges are expected to be measured with high accuracies, small head errors at the beginning are quite significant.

When using the piston gage as a standard of pressure for the calibration of elastic-type sensors in the low ranges, the problem of establishing a datum for the sensor is one that requires attention. The sensor usually has a mechanical or electrical adjustment for setting the zero. Some adjustments may have a considerable range which enables the device to indicate zero although a rather large bias may be present at the time the zero is adjusted.

If a pressure reference plane is not stipulated in the documents for the sensor, one must be chosen. The choice may be an arbitrary one or it may be one based on obvious details of sensor geometry. All pressures must be thereafter referenced to this datum.

When calibrating gages or transducers with gas, using a diaphragm barrier between the oil and gas portions of the system, it is necessary that the readout mechanism of the diaphragm device be adjusted to zero when no pressure exists across the diaphragm. The diaphragm terminates the liquid portion of the system, thus it becomes the interface of the oil and gas media. Head corrections are computed for the difference in height of the piston gage reference and interface diaphragm for the oil and from the diaphragm to the transducer for the gas system. If the gas system is opened to atmosphere and the liquid system is also opened at a point of equal height of the diaphragm, the pressure across the diaphragm will be zero and the readout mechanism may be adjusted to zero. After the transducer is also carefully adjusted to zero, the gas system may be closed, and the calibration begun.

One source of error at low pressures is the presence of air in the system. If a quantity of air is present in the vertical section of a connecting tube, the assumed head correction will be in error. If air migrates to the dead weight gage, the reference plane may be shifted because the buoyancy of the oil upon the piston has been upset.

A quantitative measurement of the amount of air in the system may be made by taking note of the number of turns necessary on the hand pump handle to raise the bourdon gage pointer a perceptible amount. The dead weight gage must have a weight on the piston to make the test effective. When no air exists in the system, the pointer will move almost immediately as the pump handle is rotated slowly.

ESTABLISHING THE PRESSURE

Assuming the dead weight tester is to be used in the calibration of a pressure measuring device, and, assuming also that the device has been properly tested and exercised prior to calibration, the selection of weights is placed on the dead weight tester according to the results of the calculations. The pressure may be raised until the dead weight gage is floating in a rather high position.

For the first few moments, the weights on the dead weight tester may be observed to fall rather rapidly--more so than usual. The unusual descent rate is observed for three or more reasons: (1) the packing of the valves, pump plunger, and O-ring seals is compressible to some extent and reluctant to be squeezed into the packing gland. The movement of the packing is not instantaneous; (2) any air in the system is forced into solution by the increased pressure. Dissolution of the gas causes a reduction in the volume of the pressurized fluids which is manifested by an apparent increase in fall rate; (3) the greatest contribution to the increased sink rate is the contraction in fluid volume from the transfer of the heat to the apparatus. The increase of pressure is accompanied by a sharp rise in temperature of the oil and also a rather large volume expansion. As the vessels of the system absorb the heat, the oil contracts and thus causes an apparent increase in leakage in the dead weight tester.

The effects of the three causes are additive and serve to indicate an apparent high rate of leakage. The sink rate may be measured with a scale and watch. If measurements are plotted for each minute interval for several minutes, the curve will drop sharply the first few minutes and then level off to a constant value. After raising the pressure to values as high as 600 to 700 atmospheres, seven to eight minutes are required for the thermal effects to die out.

CROSSFLOATING

It was mentioned earlier that some dead weight gages must be calibrated against a standard gage. In the jargon of the laboratory, the process is called crossfloating. When crossfloating one gage against another, the two are connected together and brought to a common balance at various pressures. The balancing operation is identical with that employed on an equal-arm weight balance where the mass of one weight is compared to another. In each instance the operator must decide when the balance is complete. In a crossfloat, the two gages are considered to be in balance when the sink rate of each is normal for that particular pressure. At this condition there is no pressure drop in the connecting line and consequently no movement of the fluid. The condition can be difficult to recognize, particularly if there is no means of amplification in the method of observing. The precision of the comparison will depend directly upon the ability of the operator to judge the degree to which the balance is complete. This procedure is repeated for several pressures and the values of areas obtained are plotted against the nominal pressure for each point. A least-squares line is fitted to the plots as the most probable value of the area at any pressure.

Of the different methods used in amplifying the signals that are generated by the crossfloat process, one is presently in use that is rapid and convenient. An electronic sensor, which indicates the floating position of the piston, is placed beneath the weights of each gage. The output signal from the sensor is processed and fed to an analog meter having a vertical scale, the value of which is adjusted to indicate units of displacement of the piston. Two meters -- one for each instrument -- are placed contiguously for simultaneous viewing. A constant-volume valve, inserted between the gages, supplements the sensors.

Other, less precise, methods of estimating the true balance, include:

a. Optical amplification of the sinking stack of weights of one of the gages while timing the descent with a stop watch and

b. Interposition of a sensitive null-pressure transducer which displays small pressure differences directly.

When using a suitable amplifying device, the scatter in the plotted areas from a good quality piston gage should not exceed one or two parts in 10^5.

BIBLIOGRAPHY

1. Bridgman, P. W., The Physics of High Pressure, G. Bell & Sons, London, 1952.

2. Cross, J. L., "Reduction of Data for Piston Gage Pressure Measurements". NBS Monograph 65 (1963).

3. Dadson, R. S., "The Accurate Measurement of High Pressures and the Precise Calibration of Pressure Balances", Proc. Conf. Thermodynamic and Transport Properties of Fluids, London, pp. 32-42, 1957, Institute of Mechanical Engineers.

4. "Design and Test of Standards of Mass", NBS Circular No. 3 (Dec., 1918), Included in NBS Handbook 77, Volume III.

5. Johnson, D. P. , J. L. Cross, J. D. Hill, and H. A. Bowman, "Elastic Distortion Error in the Dead Weight Piston Gage", Ind. Engineering Chem., 40, 2046 (Dec., 1957).

6. Johnson, D. P., and D. H. Newhall, "The Piston Gage as a Precise Measuring Instrument", Trans. of ASME, April, 1953.

7. Newhall, D. H. and L. H. Abbot, "Controlled-Clearance Piston Gage", Measurements and Data, Jan.-Feb. 1970.

8. "Pressure Measurement", Measurements & Data Home Study Course, No. 17, Measurements and Data. September-October, 1969.

9. Tate, D. R., Gravity Measurements and the Standards Laboratory, National Bureau of Standards Technical Note No. 491 (1969).

CALIBRATION OF AN ELASTIC PRESSURE SENSOR WITH REGARD TO THE FLUID PRESSURE GRADIENT WITHIN THE SYSTEM

Modern elastic pressure sensing devices have been developed into a class of highly sensitive mechanisms having remarkable performance. The accuracy with which they are capable of measuring a given pressure is, among other things, affected by their position with respect to other members of the system.

Liquid and gaseous pressure media have mass and are subject to pressure gradients within a pressurized system. The gradients arise from the influence of gravity on the mass. For convenience, they are sometimes referred to as heads. Although the head within a particular system may have a relatively large numerical value, the net effect is often small because of a condition in which the transducer is manually adjusted to zero output at a pressure level that is not really zero. The calibration is then conducted at a level having a constant value of pressure biasing all the transducer outputs, including its zero. A question arises as to how much bias may be tolerated before the process is affected significantly.

Since it is difficult to estimate the magnitude of a pressure bias that will affect the performance of a transducer, the process may be adjusted to remove the bias. The procedure to be described may be conducted with different degrees of care depending on the range, type, and accuracy of the transducer; the magnitude of the biasing head; and perhaps, other factors.

In general, the pressure gradients become significant in the low ranges of measurement--below 1000 pounds per square inch or about 70 atmospheres.

Q-0573-9

ARRANGEMENT OF THE APPRATUS

In Figure 1, a hydraulic-type pressure transducer, having a plane, B-B, at which the sensing occurs, is shown in its relationship to the pressure standard--a piston gage. The pressure reference plane of the standard is reported by the manufacturer as occupying the position A-A. The difference in height of the two planes is determined by measurement to be h. It is apparent that the internal pressure is less at B-B than at A-A--the difference being designated as ΔP and expressed as

$$\Delta P = hd \qquad \text{where}$$

d is the density of the fluid.

Integral values of pressure may be, or may have been, calculated for the piston gage pressure reference plane at A-A. Corrections for the unpredictable variations in the piston temperature are applied in the form of small metric weights having the appropriate accuracy. In a similar manner, the pressure at the reference plane at A-A may be shifted to B-B by the addition of more of the same type weights. The pressure at A-A must be increased by the amount ΔP for the conditions shown in the figure. The quantity of mass is determined by multiplying the value ΔP by the piston area and converting the product to convenient units of force. The value of mass thus obtained must then be placed on the piston for each pressure to be produced in the calibration of the instrument.

On most occasions, complete compensation for the existing head is not required because only a substantial reduction is necessary to satisfy the problem. Measurements in the elevation of the plane B-B over, or beneath, A-A are not critical. Furthermore, when calculating the mass required for compensation of the existing head, it is usually unnecessary to consider the change in piston

area as a function of pressure. Once a figure for the position of B-B with respect to A-A has been established, the usual care in operation of the equipment is necessary.

Pressure transducers are usually small in size and a plane of reference can be estimated with a fair degree of accuracy. Some bourdon tube pressure gages of the dial indicating type, however, are quite large and have no accepted or well-defined plane to which their indicated pressures refer. The bourdon tube may be coiled into a loop of 6 to 8 inches in diameter and will have an internal pressure difference from top to bottom of up to 0.25 psi (1700 Pa). Some manufacturers choose the end of the tube socket as the reference point. There appears to be no common plane from which fluids of all the densities normally encountered will produce the same indication on a bourdon-tube gage. The selection of a reference would, therefore, be a matter of choice. There is some merit in the selection of a position whose identifying features would be visible from the back as well as from the front.

In Figure 2, the reference plane position has been chosen to pass through the pinion carrying the pointer. The pivots are easily accessible for measurements of the vertical distance to other planes of interest within the system.

Establishing integral values of pressure at the plane B-B with the standard solves only a part of the problem. If this plane is chosen as that to which all pressures are referenced, the zero indication of the transducer must also be adjusted for the same plane. Regardless of whether the transducer must be calibrated to indicate a pressure with respect to absolute zero or with respect to the atmosphere, the procedure is the same.

A convenient way to make the adjustment is by the installation of an open-tube manometer having sufficient tube length to extend above the plane B-B. If the manometer valve is opened, the oil of the system may be forced by the pump to rise to the level B-B. With the oil standing at this level, the sensor may be adjusted to zero output. The measurement process will then refer all values of transducer output to the common datum, B-B. Transducers calibrated in absolute pressure values will have the atmospheric pressure at B-B subtracted from their stipulated calibration points for the pressures to be established by the piston gage.

The effects of liquid and gaseous head pressures are present in the equipment with which a transducer is intended to be used, as well as in the calibrating apparatus. It is just as important to pay attention to these effects in the field as it is in the laboratory. There is a need for uniform procedures in the calibration, installation and use of such devices or, in the absence of such procedures, for adequate communications between the calibrator and the user. At the least, the engineer performing the calibration should state on his calibration report the assumptions that were made during the test, the reference plane that was chosen, and the conditions under which the zero was adjusted. The user would then be able to establish the same conditions for operation of the instrument.

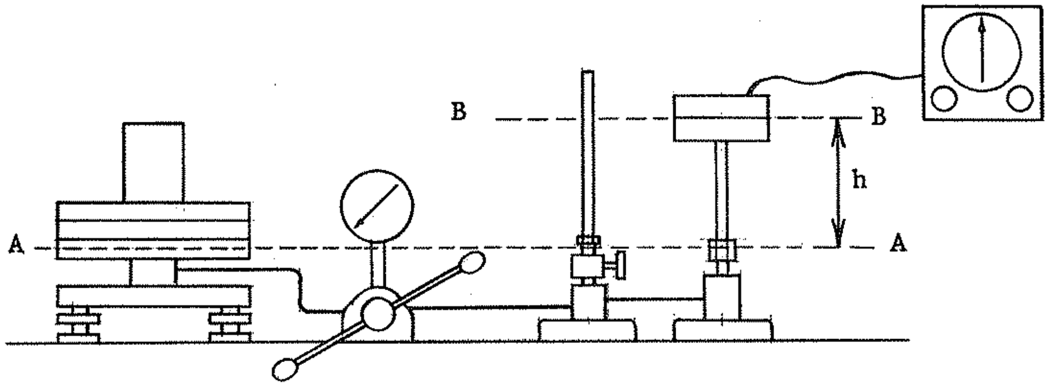


FIG. 1

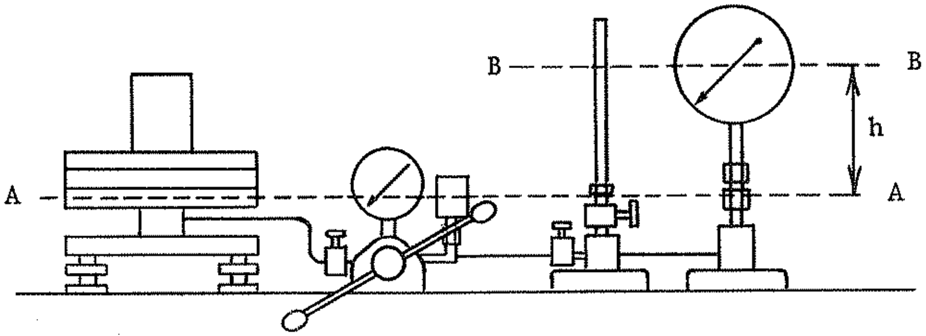


FIG. 2

STANDARD PRESSURE FOR PISTON GAGE NO. ______________

OPERATING AT g_ℓ = ______________ DATE: ______________

Piston No. ______________ Gravity and Buoyancy K = ______________

$A_o(23°C)$ ______________ in^2 Expected Temp. (t) ______ °C Weight Set ______________

b ______________ /psi Δt ________ 1 + CΔt ______________

C ______________ /°C Therm. No. ______________

$A_o(t)$ ______________ in^2 Piston Tare ______________ Pounds

1 Pressure*	2 1 + bp	3 A_e	4 $W=pA_e$	5 M = WK	6 Masses Used	7 Rem.lbs.	8 Gms

Expiration Date: ______________

* At the reference plane of the piston.

Q-864-1 Rev. A

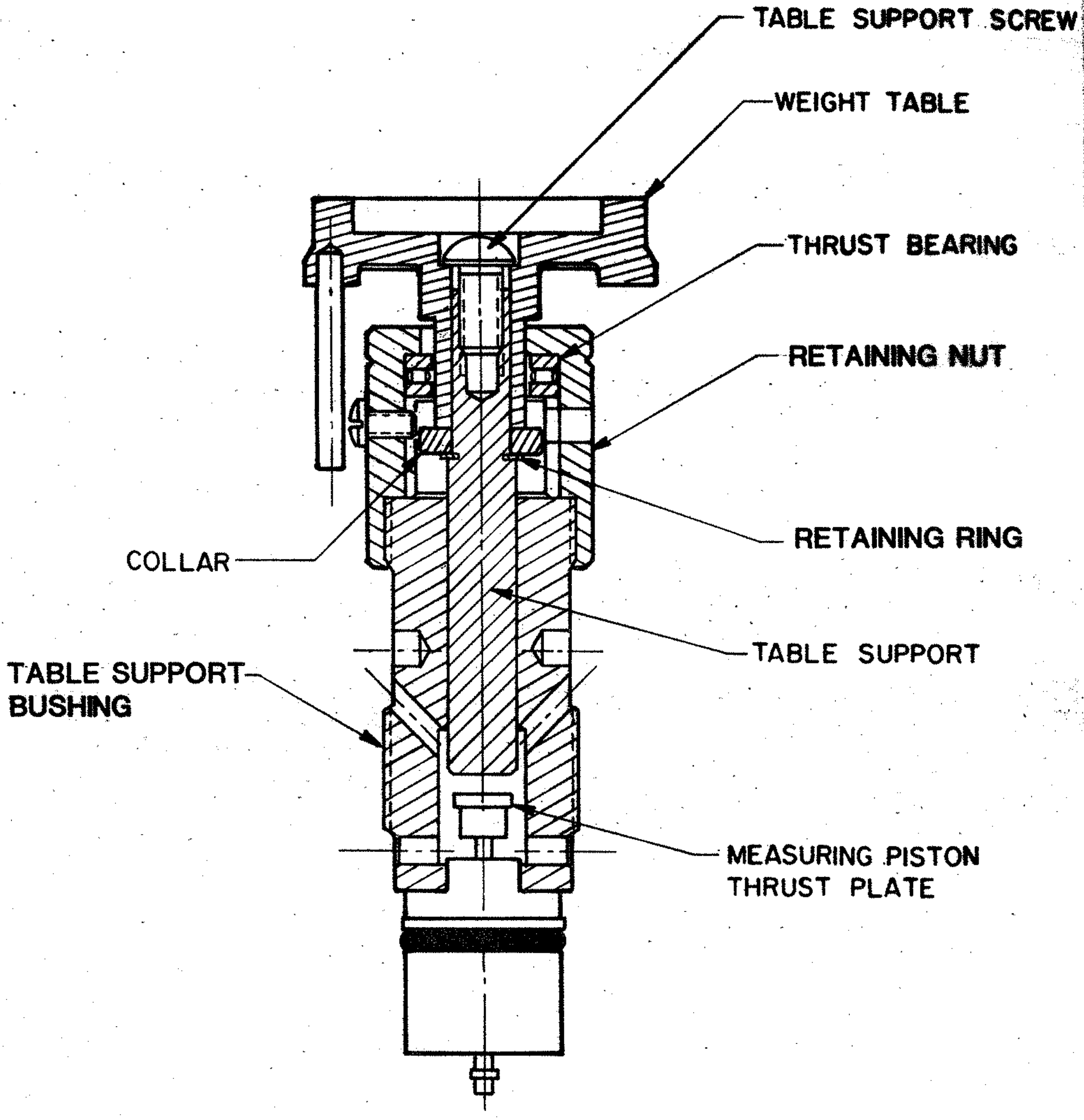


TABLE SUPPORT SCREW
WEIGHT TABLE
THRUST BEARING
RETAINING NUT
RETAINING RING
COLLAR
TABLE SUPPORT
TABLE SUPPORT BUSHING
MEASURING PISTON THRUST PLATE

FIGURE 1.1

DESCRIPTION OF THE RUSKA MODEL 2450
DEAD WEIGHT GAGE

The Ruska Model 2450 Dead Weight Gage was designed as a laboratory reference of pressure.

High operating range and mechanical durability are features that have been made possible by the use of a secondary piston of relatively large diameter. With this arrangement, the measuring piston may be made small in area without the hazard of damage from accidental misuse. A measuring piston whose area is small permits measurement of rather high pressures with weights of the size that may be conveniently handled by one person.

A circular table (termed "weight table"), on which the weights are placed, is attached to the secondary piston (table support). Referring to the accompanying cross sectional diagram of the Model 2450 Dead-Weight Gage, the table support (2450-002-9) rests directly on the upper end of the measuring piston and is guided axially by the bushing (2450-100-7).

Overranging load protection is accomplished by the use of an arrangement of ball thrust bearings located above the guide bushing. The gage may be safely operated with a full load of weights and with no pressure, or it may be fully pressurized without weights. The arrangement satisfies the condition necessary for performing hysteresis measurements in which the selected pressures are approached from below and above without appreciable overpressure.

Q-0973-3

The combined weight of the weight table assembly and piston assembly constitutes the tare weight of the gage. When the tare weight is divided by the effective area of the piston, the quotient is the tare pressure--the minimum pressure which the gage is capable of measuring and a pressure which is a part of every measurement made with the gage.

The cylinder is of re-entrant design and operates over the entire range of pressures without excessive leakage.

The Model 2450 gage is provided with a post carrying an index line which indicates a particular floating position of the piston. This position is usually near the center of the total displacement. The position of the pressure reference plane for each piston is reported with respect to the top surface of the weight-loading table. A line is cut in the periphery of the sleeve weight platter (No. 1 Weight) which, when placed in alignment with that of the index post, indicates the correct piston floating position. The true location of the pressure reference plane is determined by subtracting the distance shown on the test report from the dimension of the sleeve weight corresponding to the vertical distance from the peripheral line to the internal surface that rests on the weight-loading table.

A second index line is located on the main housing and weight table drive pin. When the pressure on the dead-weight gage is less than that requiring the sleeve weight, the position of the piston is determined by the second index mark.

The pressure at any point in the system may be determined by measuring the vertical distance of the point from the reference plane of the dead-weight gage. The pressure at the point, in psi, will be the vertical distance from the pressure reference plane, in inches, multiplied by the density of the oil in pounds per cubic inch.

When the piston gage is used as a standard of pressure for calibration of secondary pressure sensors, integral values of pressure are precalculated to the extent possible. These pressures are valid only at the pressure reference plane of the piston. A procedure for transferring these integral values to other positions within the system is described elsewhere in these instructions.

DESCRIPTION OF THE WEIGHTS

All weights are constructed of Type 303 stainless steel. They are entirely machined from rolled stock or forgings, and the removal of any metal is performed in such a way as to maintain balance about the centerline. Final adjustment is accomplished by drilling a symmetrical pattern of holes concentric with the axis.

INSTALLATION OF THE GAGE

The dead-weight gage must be erected on a pier or heavy table. The two leveling screws and the leg at the rear of the base casting are supported by the foot plates furnished with the instrument. The gage must be leveled and the leveling screws locked.

REMOVAL OF AIR FROM THE HYDRAULIC SYSTEM

Satisfactory performance of the hydraulic system may be obtained only when it is free of air. The presence of an air bubble in the vertical section of a measuring path will surely upset the assumed head that forms a part of the measurement. It is important, therefore, that the air be removed from the system. Once the apparatus is free of air, it is relatively easy to maintain that condition. Although an attempt is made to preserve the condition of the original test, some air may be present because of accidental admission or by liberation from solution during shipment. A procedure for removal of the air involves the gas absorption properties of the oil. Some of the traps in the system cannot be vented directly. A bubble will remain lodged in the trap even though a substantial flow of oil in the vicinity can be produced by the pump. Removal of the bubble can be accomplished by forcing the gas into solution and moving the solution out of the system. If the pressure of the liquid is raised to a few hundred atmospheres, the bubble will dissolve. After a slow leak has been created nearby, the pressure is maintained with the pump while the quantity of oil which includes the solution is forced out of the system. When the solution emerges, it frequently produces a spitting sound as the gas is liberated; at other times, the discharge may appear as a whitish foam.

The hand pump, being the source of pressure, must be cleared of air first. The pump also serves for testing the system for residual air. When making the test, the plunger is advanced by one or two revolutions of the turnstile handle while the inlet valve is open. This operation removes the backlash from the spindle nut threads and bearings. The valve is then closed and the handle turned slowly while the operator watches the bourdon tube gage. If air is present in the system, there will be a lag in the indication of pressure as the pump handle is rotated. An acceptable test is one in which the gage pointer moves a perceptible amount for 1/4 turn of the handle.

Usually, most of the air that is present in the pump accumulates in the gage bourdon tube. The C- or helical-shaped tube forms an ideal trap for capture of a bubble. A suitable funnel or flume may be fashioned from a piece of paper and fastened beneath the bleed port with tape. The escaping oil should not be permitted to flow over the gage movement. After pressurizing the pump, the bleed screw is adjusted for a slow leak of approximately 10 to 15 drops per minute.* The pressure is maintained for the full stroke of the plunger, after which the pump is recharged and the test repeated. It is not necessary to reseal the tip screw during recharging. The new test should show an improvement but will, in some instances, reach a limit. When this condition occurs, the remaining air is usually trapped in the nipples and valves. The process is repeated for each of the outlet valves.

If the process reaches a limit beyond which no improvement is evident--even though there is still substantial remaining air--the next component may be attacked. At the conclusion of the process, the residual air may be dissolved by pressurizing the entire system and leaving it under pressure for several hours or overnight. The concentrated solutions, in the vicinity of the traps, will diffuse to the extent that, upon release of the pressure, the entire system will be unsaturated. There will be no further liberation of air. During the dwell period, the piston gage will, of course, be isolated.

---

*See "Notes on Operation of High-Pressure Systems".

Residual air in the piston gage is not a problem, because the leaking piston automatically allows the dissolved gas to escape. It is necessary only to pressurize the gage and allow it to operate for a period before beginning a measurement.

EXCHANGING PISTONS IN THE DEAD-WEIGHT GAGE

When it is necessary to exchange the piston assemblies, the dead-weight gage must be partially disassembled and some of the components laid by until later. Upon removal of the internal components, a degree of hazard is involved because of the possibility of exposing the parts to harmful dirt, corrosive fingerprints, and being dropped to the table or floor. Needless to say, the small, brittle carbide measuring piston will not survive an accidental drop. The remainder of the components, if dropped, will surely be damaged to the extent of sustaining raised burrs and will require the attention of a mechanic before reassembly.

Each manual operation that is performed on a mechanical device is accompanied by a finite degree of damage. The damage, however small it may be for the individual operations, is cumulative. It results from the imperfect execution of each manual operation. After a given length of time, the device may be expected to fail because of performance deterioration beyond the level of tolerance. It is important, therefore, to perform the manual operations with the greatest possible skill in order to keep the harmful side effects at a minimum.

There are two types of contamination that affect not only the performance of a piston pressure gage but also the mechanical state of the critical components. One contaminant is the ordinary hard particle of matter that scratches and abrades the finely-finished surfaces as it becomes entrapped between the closely-fitting members. The scratches invariably result in raised edges from the displacement of the metal and spoil

the original relationship of the members. The second type of contaminant is of a chemical nature and produces harmful effects by attacking the finished metallic surfaces in a corrosive manner. Ordinary fingerprints contain water-soluble, acidic salts, having extremely high corrosive activity with the metals of the critical instrument parts. Since these parts must necessarily be handled in making a piston exchange, they may be protected from exposure to both types of contaminants by the use of clean paper wipers. Even though the parts may be completely covered with oil, salts will be deposited on the metal surfaces if they are handled with bare fingers.

There are a number of industrial paper wipers available that are relatively free of lint. After a little practice, the corrosion-sensitive parts may be safely handled with these wipers instead of with the bare fingers. Even when using the wipers as insulators, the hands should first be washed and thoroughly dried before commencing the disassembly.

The space allotted to the discussion of cleanliness is not intended to imply to the technician the impossibility of performing the job correctly, but rather to give him reassurance that the results will be quite satisfactory if he follows a common-sense procedure of eliminating contaminations by technique alone.

Being forewarned of the hazards, the technician should wipe the bench and all instrument surfaces in the vicinity of the dead-weight gage before starting disassembly operations. A wad of wipers slightly wetted with a mild, non-toxic solvent will help to pick up the heavy oil film that invariably accumulates near the gage. Because of its tackiness, a wad so treated gathers and retains most of the accumulated dust and lint that has settled in the area.

DISASSEMBLY

The drive belt is removed from the motor pulley and is pulled toward the forward part of the gage. To insure that the belt has not been left off after the gage has been loaded with weights, it is advisable to leave the drive belt encircling the housing, Part 2450-100-6.

With the belt forward and out of the way, the area between the housing and motor drive serves as a space to lay the parts as they are removed from the housing. A new, clean piece of paper is placed on the base surface to keep the parts clean. The heavier type industrial wipers serve for this purpose.

After preparing the gage and bench for removal of the piston assembly, the operator should wash and thoroughly dry his hands.

Referring to the diagram for Model 2450, the weight table, Part 2450-008-1, is constructed of Type 303 stainless steel and may be safely handled with the bare fingers. The table support, Part 2450-002-9, to which the table is securely attached, is made of heat-treated alloy steel and should not be touched with the fingers.

It may be seen from the drawing that the weight table rests on the thrust bearing (05-400-0627-004) when in the down position. The bearing is designed to accommodate the load of all the weights smaller than the sleeve weight when there is no pressure in the gage. Since the table support (9) does not rest on the measuring piston thrust plate when in this position, the piston is protected from damage by an impact upon the weight-loading table. The thrust bearing is protected from overload by the stack of large weights by the drive-sleeve thrust bearing (05-400-3002-004). With no pressure in the housing, the sleeve weight rests on a shoulder of the driving sleeve and stands clear of the weight-loading table. The accidental loss of pressure will not result in an impact on the measuring piston but on the drive sleeve thrust bearing.

In changing piston assemblies, it is necessary only to remove the bushing (2450-100-7) from the pressure housing and force the installed cylinder out with the oil pump. Spanner Wrench No. 453 is used to unlock the bushing from the housing, after which the entire bushing and weight table assembly may be unscrewed with the fingers. The knurl on the cap (2450-002-11) is provided for this purpose. It is advisable to avoid touching the bushing (7) more than necessary with the bare fingers because of the possibility of transferring corrosive fingerprints to the alloy steel. When withdrawing the assembly, it should first be lifted carefully above the housing to expose the lower end of the bushing. Occasionally, the cylinder will cling to the lower surface of the bushing as the assembly is being removed. On such occasions, the free hand should be held under the assembly to catch the cylinder in the event it should fall during transfer to the table top. In the event it does not cling to the bushing, the cylinder may be forced out of the housing by pumping in a quantity of oil with the hand pump.

As the pumping is started, and, before the cylinder begins to move, the piston will rise to its upper limit. The small thrust plate may be grasped with the fingers, which are insulated with a wiper. The pumping must be continued until the cylinder is free of the housing bore, at which time the assembly may be lifted out and immediately wrapped with a wiper.

REASSEMBLY OF THE GAGE

Assuming that a different piston assembly is to be placed in the gage, the second piston is removed from its container, in much the same way that the first one was removed from the housing. Since the second piston is covered with oil, the assembly will be a little more difficult to remove from the container. The assembly must be moved from side-to-side in the container while gently lifting by the upper thrust plate in order that the air may enter beneath the cylinder.

Before installing the replacement piston-cylinder assembly, the top mating faces of the cylinder and piston should be wiped free of lint. Lint which clings to the outside diameter of the cylinder is not objectionable, since it will be pushed aside during assembly. The replacement assembly is inserted into the housing while being suspended by the piston thrust plate. These assemblies are always handled with paper wipers as insulators against contamination by fingerprints. With the valve to the reservoir open, the assembly may be pushed into the housing by pressing on the piston thrust plate. After a final wipe across the thrust plate with a wiper, the loading table and bushing assembly is replaced.

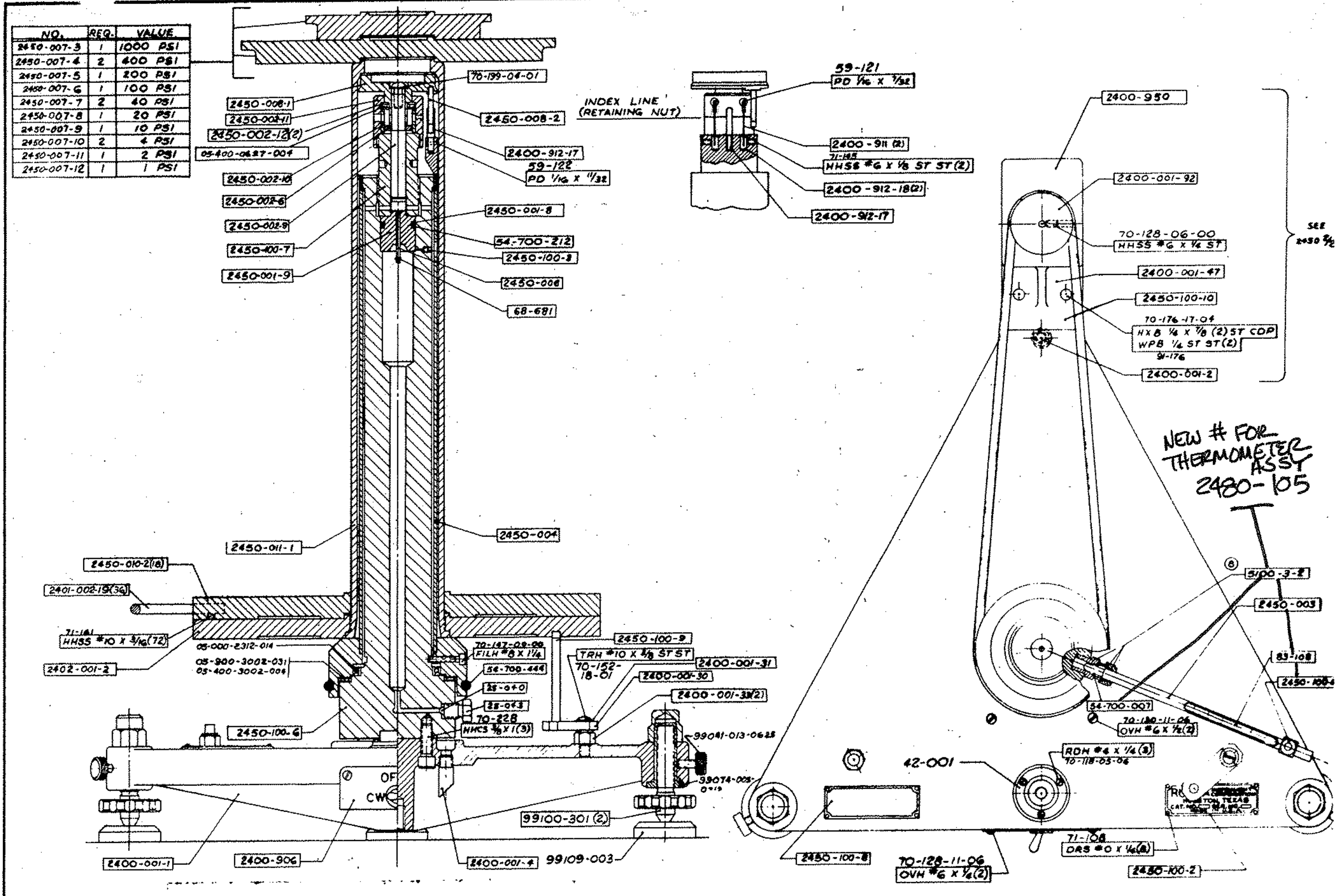
Upon completion of the assembly, the drive sleeve is rotated so as to expose the vent screw (2450-100-3). The screw is removed with a 3/32 hex key and the drive sleeve rotated until the port is covered but is still visible. Oil is pumped into the housing until bubbles cease to appear in the vent port, after which the screw is replaced.

NOTES ON THE OPERATION OF HIGH-PRESSURE SYSTEMS

During the initial installation of the apparatus or, perhaps, while making a measurement, a quantity of air, inadvertently, may be permitted to enter the bourdon tube monitor gages. The bourdon tube has a tip-bleed assembly in which a ball (5 mm) is forced into a seat by a socket-head setscrew. The screw has an inverted conical section in contact with the ball which, after having been tightened, makes a circular impression. When the setscrew is loosened, for removal of air, the ball may rotate and the impression may cross the seal line of the tube seat. The tube will then leak and no amount of torque on the screw will seal it. It is important, therefore, to maintain control of the hex key when loosening the setscrew for the venting operation.

The 1/8-inch hex key is inserted and a 7/16-inch open-end wrench is placed on the hexagon coupling such that the fingers of one hand may be used to break the screw loose and, at the same time, oppose the applied torque with the wrench. The setscrew will break loose with a sharp snap which, if uncontrolled, will allow the ball to become free and, perhaps, rotate. The idea is to prevent the setscrew from becoming loose enough to free the ball entirely. It is also important to prevent violent disturbance of the gage movement during the screw adjustment process. The ball is then reseated with only sufficient torque to create the high-pressure leak.

There are several places on the apparatus that permit trapped air to be released. On each of the hand pump cylinders, the plug, stopping off the top port, may be loosened to vent the cylinders at their uppermost points. The hex-head plug in the bypass valve may be removed for venting the valve.



NO.	REQ.	VALUE
2450-007-3	1	1000 PSI
2450-007-4	2	400 PSI
2450-007-5	1	200 PSI
2450-007-6	1	100 PSI
2450-007-7	2	40 PSI
2450-007-8	1	20 PSI
2450-007-9	1	10 PSI
2450-007-10	2	4 PSI
2450-007-11	1	2 PSI
2450-007-12	1	1 PSI

NEW # FOR THERMOMETER ASSY 2480-105

1	ASSEMBLY		
DWN. EAB DATE 2-14-64 CKD SH DATE 2-14-64	MAIN ASSEMBLY LAB. DEAD WEIGHT GAGE	A DCN 611 B DCN 663 C REVISED D	
	SUB-ASSEMBLY		
	RUSKA INSTRUMENT CORPORATION HOUSTON, TEXAS	SCALE 1/2" = 1"	NO. 2450 (1/2)

RUSKA MODEL 2400 PISTON GAGE

PREPARATION AND SHIPMENT FOR RECALIBRATION

When submitting a Ruska Model 2400 Piston Gage for recalibration or repair, the components and parts listed below should be shipped.

1. Items to be submitted--Refer to Drawing No. 2400.

   a. Instrument Base, P/N 1, with complete pressure housing assembly, P/N 2400-006-0.

   b. Piston assembly, 901, and weight-loading table, 903, assembled to pressure housing as in normal use.

   c. Extra piston assembly, 902, in container, 907, and weight-loading table, 904.

   d. Complete weight set, 2401 (Metric) or 2402 (English).

2. Preparation for shipment.

   a. Check that the round-head #10 x 1/4"-long retaining screw is securely in place in the lower section of the rotating drive sleeve, P/N 8. With a piston assembly and weight-loading table in place within the pressure housing, invert a small but strong plastic bag over the weight-loading table and wrap it tightly around the drive sleeve. Secure the bag with several turns of masking tape or reinforced binding tape. Insulate the top portion of the housing and weight-loading table with 1/2-inch or more of foam or other suitable material. Bind the insulation in place.

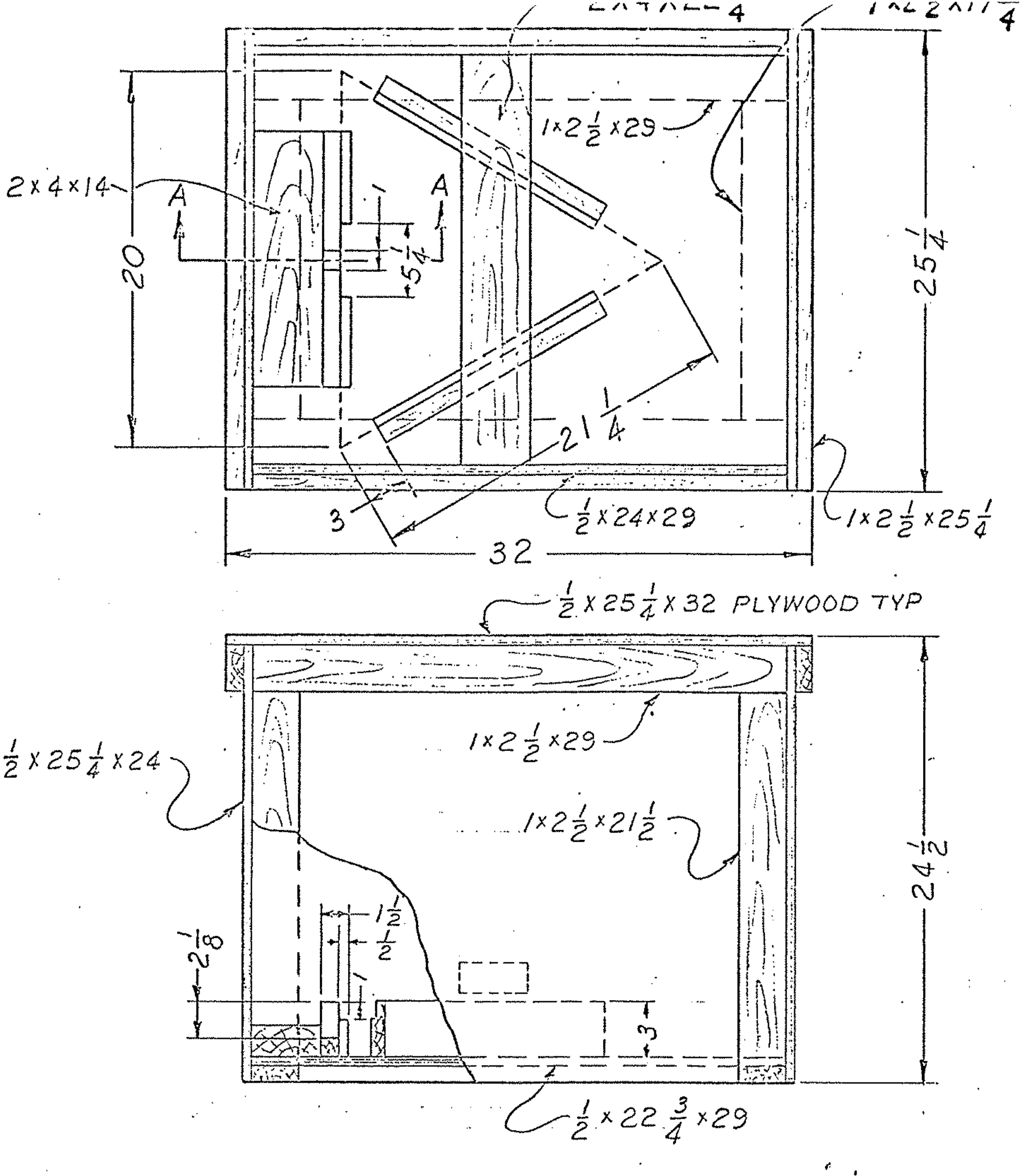
   b. When shipping the extra piston assembly in the 907 container, make certain the aluminum ring is in place above the cylinder before the cover is screwed down. This ring will limit the freedom of the cylinder within the container.

c. Wrap the extra weight-loading table in clean, heavy plastic film. Do not touch the spindle with bare fingers or scratch it during handling, as it is a highly functional part and is subject to severe corrosion. Insulate the entire assembly against impact damage and secure the insulation with additional wrappings of plastic and tape.

d. Prepare a shipping box as shown on the Drawing 2400-205. Use cushioning material around the edges of the triangular base when anchoring the instrument in the box. The extra parts may be taped to the housing or packed in a separate package and secured inside the box.

e. The weights should not be permitted to chafe against the slots in the shipping box. Insulate the weights with strips of corrugated paper folded so as to take up the clearance. Bind the boxes with steel banding ribbon for additional strength.

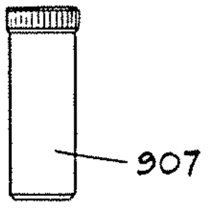
Shipment by motor freight is entirely satisfactory.

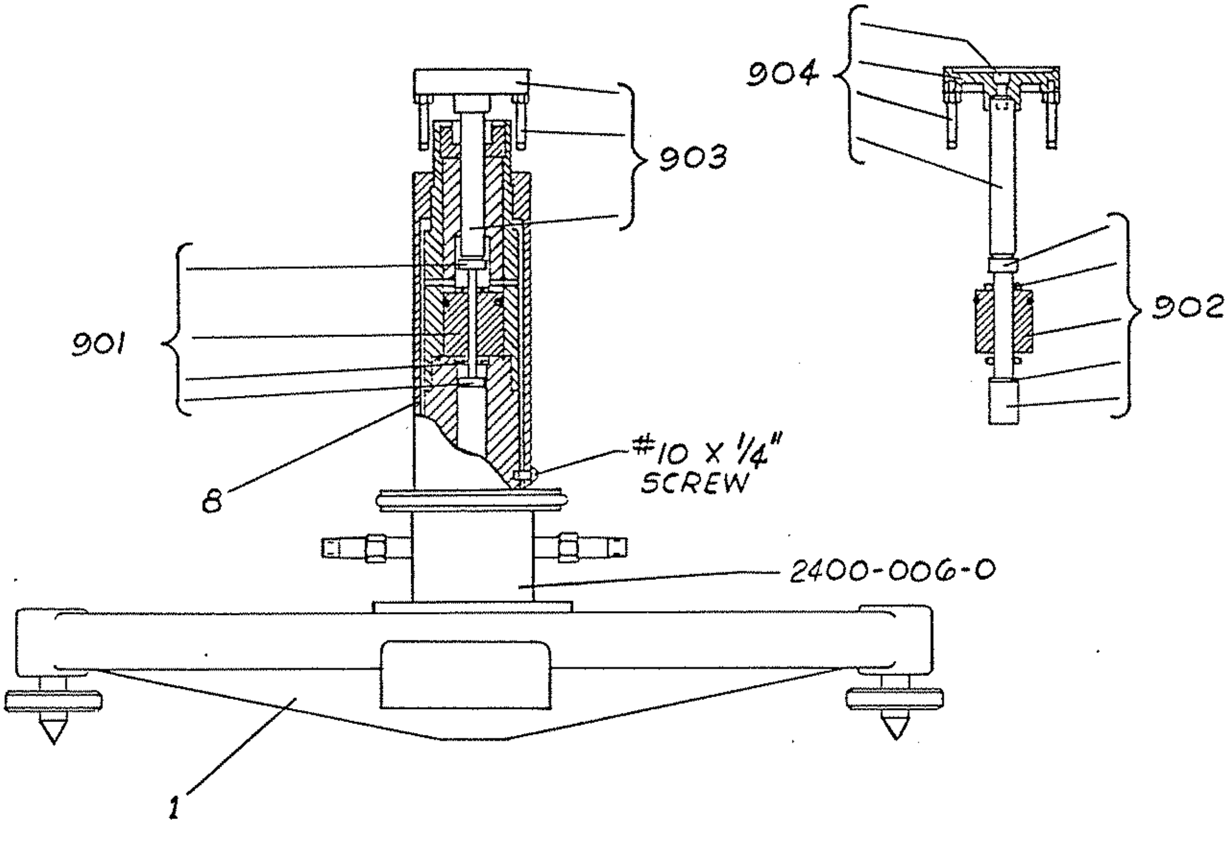


	SHIPPING BOX		SEE ABOVE	
REQ'D	DESCRIPTION		MATERIAL	

TOLERANCES NOT SPECIFIED	DWN. SK		REVISIONS	BY	DATE
	DATE 5-9-68	DEAD WEIGHT GAGE	A		
.X ±.030	C'KD		B		
.XX ±.010	DATE		C		
.XXX ±.005	PROD.		D		
FINISH	DATE		SCALE	NO.	
	APP'D	RUSKA INSTRUMENT CORPORATION	⅛" = 1"	2400-205	
	DATE	HOUSTON, TEXAS			
	TOOL				

1500 175H 12-67





Q-1171-3 3/4 RUSKA MODEL 2400 PISTON GAGE

4/4 USE 2400-205

SOME PRECAUTIONS TO OBSERVE DURING THE OPERATION OF A DEAD WEIGHT GAGE CALIBRATING SYSTEM

Hydraulic or pneumatic pressures should not be admitted to or released from a system by quickly opening or closing a valve. In most instances at least one of the components of the system contains a sensitive measuring element which may be damaged by a sudden change in pressure. For instance, if a dead weight gage is in a floating position and a valve is quickly opened, permitting the pressure to escape rapidly, the gage could possibly be damaged when the weights, fall freely against the lower stop. Indeed, in some instances it is possible to break a measuring piston. The pressure must be reduced by means of the hand pump until the piston mechanism is resting on its thrust bearings, after which a valve may be opened slowly, releasing the remainder of the pressure. A large and sudden change in pressure in the form of a shock may also damage the sensing unit in the Differential Pressure Indicator.

Before various devices are calibrated against a dead weight gage or other pressure reference, there should be pressure tested at a value somewhat greater than the top working pressure if possible. As outlined above, failure of one of these devices on the calibrating bench can result in considerable stress in the calibrating equipment.

When large changes in pressure are made with the dead weight gage, sufficient time must be allowed after the change for various elements of the system to become stabilized to the change in stresses. For very precise measurements, in pressure, a waiting period of 30 minutes may be necessary.

MODELS 2450 AND 2451 DEAD WEIGHT GAGE

WEIGHT-LOADING TABLE SUBASSEMBLY

Instructions for Reassembly

Note: These instructions are valid for Models 2450 and 2451 Dead Weight Gages having serial numbers higher than, and including No. 16092.

In the Models 2450 and 2451, the stops that limit the axial movement of the piston are located in the weight-loading table subassembly. In this position, the stops may be made stronger than those which are usually attached to the measuring piston. The piston is afforded virtually complete protection from a shock which is transmitted through the weight table assembly.

The elements that make up the weight table subassembly are keyed together in order that their correct relative alignment will be assured. When it is found necessary to disassemble the unit, as on the occasion of periodic redetermination of the mass, the reassembly should be undertaken with care that the alignment keys are properly positioned. If the reassembly is completed according to the instructions which follow, there should be little question about the success of the operation.

Assembly Procedure

Assuming the parts have been thoroughly cleaned with a volatile degreasing solvent and that the mass has been determined, proceed as indicated while referring to the diagram for part numbers and nomenclature. The parts should be handled by whatever means is convenient that will avoid transferring fingerprints to the surfaces. Industrial paper wipers are satisfactory.

1. Invert the table (2450-008) on a clean piece of paper.
2. Place the retaining nut (2450-002-11) in position over the neck of the table.
3. Place the collar (2450-002-6) on the face of the table neck while guiding the small pin into the blind hole in the collar.
4. Insert the table support (2400-002-9) through the collar and into the bore of the table. Rotate the table support until the keyway is in alignment with the key of the table. When in this position, the table support may be inserted to its full depth. The pins and keys are small and may be easily damaged; do not use force.

5. Pick up the entire assembly and hold it in a horizontal position. The assembly can be held in one hand with one finger (insulated with a wiper) pressing the table support firmly in position. With the other hand, move the retaining nut so that the junction of the collar and the neck of the table may be inspected through the breather hole in the retaining nut. If the parts are not properly seated, repeat operations 1 through 4. If they are seated, insert the retaining screw (2450-002-7) and tighten it, at first, only slightly. As the screw is tightened, it should pull up abruptly. If there is a soft or spongy feeling in the tightening action of the screw, the small pin may have slipped out of the hole in the collar.

   Reinspect the junction through the breather hole in the retaining nut or repeat the whole operation. When the screw is felt to tighten firmly without softness, pull the screw up tight.

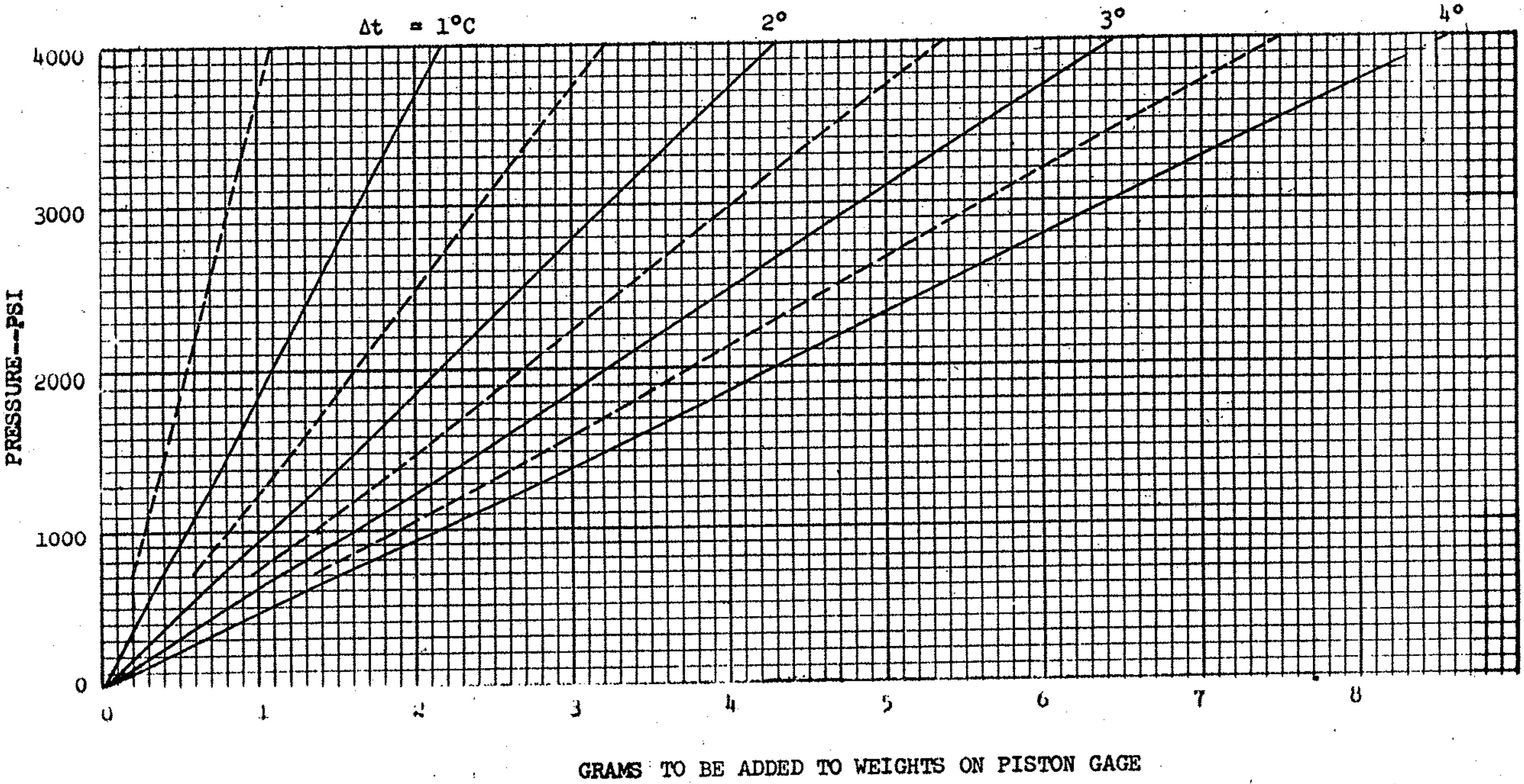
USING THE TEMPERATURE CORRECTION CURVES FOR RUSKA DEAD WEIGHT GAGES

When the dead weight gage is used as a standard of pressure in the calibration of elastic pressure sensors, it is economical to make corrections for the variables in advance. Usually, the corrections are applied for the fundamental values of pressure that occur repeatedly. A confusing point in the procedure is the necessity for the operating temperature of the gage to be predicted. The gage temperature, of course, fluctuates between certain limits, depending on the environment and the nature of the calibration so that an accurate prediction is not always possible.

If the advance calculations for pressure correction are made for a temperature that is lower than the expected operating temperature, the weight load on the piston would then be too small. During operation, the piston area would be larger than that used in the calculations. It would then be possible to add weight in some convenient form that would compensate for the deficit. Standard Class S laboratory metric weights are entirely suitable for this purpose. The accompanying chart indicates the quantity of weight to be added to the piston for several values of Δt--the difference between the observed temperature and the computed temperatures--and for the working pressure.

TEMPERATURE CORRECTION CURVES FOR RUSKA MODEL 2450/2451 DEAD WEIGHT GAGE FOR TUNGSTEN CARBIDE PISTON AND TUNGSTEN CARBIDE CYLINDER HAVING A NOMINAL AREA COEFFICIENT OF EXPANSION OF 9.1×10^{-6}/°C AND A NOMINAL EFFECTIVE AREA OF 0.130 IN^2

CHANGE IN MASS ON PISTON VERSUS MEASURED PRESSURE FOR VALUES OF Δt TO 4°C



0.130 IN^2-4000 PSI

Q-868-4
USE WITH Q-868-5

RUSKA INSTRUMENT CORPORATION ◆ HOUSTON, TEXAS

RUSKA HAND PUMP

40,000 PSI WORKING PRESSURE

CAT. NO. 2427

PACKING

The Ruska 40,000 psi hand pump uses teflon packing. When replacing packing, the following procedure should be followed:

1. Bleed cylinder (2) to atmosphere.
2. Advance plunger until its shoulder bears against follower ring (9). Compress packing by turning handle (23) until nut (8) can be backed off.
3. Unscrew packing retainer nut (8) and cylinder retaining nut (4) completely. Slide packing follower ring (9) back on plunger and withdraw plunger by cranking counter-clockwise.
4. Cylinder may now be withdrawn from pump base (10). It is sometimes beneficial to "pump" the cylinder out by cranking the plunger in. This helps to break loose the old packing from the packing chamber.
5. With the cylinder removed, the old packing set (5, 6, 7) is easily withdrawn. The rear anti-extrusion ring (3) should also be removed for cleaning.
6. Clean packing chamber and plunger.
7. Slide anti-extrusion rings and packing set (in order shown on drawing) onto plunger.
8. Replace cylinder, noting proper position of outlet holes.
9. Tighten cylinder retaining nut in place
10. Slide anti-extrusion rings and packing into the packing chamber, making sure that each piece seats into the bottom of the chamber.
11. Slide packing follower ring up against packing, and tighten packing retainer nut hand tight.
12. Crank pump closed until the shoulder of the plunger bears on the packing follower ring. The packing may now be further compressed by forcing the follower into the packing box with the plunger. When the packing has been sufficiently compressed, the packing nut is pulled tight.

PARTS LIST

RUSKA HAND PUMP, CAT. NO. 2427

No.	Name	No. Req'd	Ruska Stock No.	
1	Spanner Wrench	1	94-617	
2	Cylinder	1	2427-1-10	
3	Anti-Extrusion Ring	2	2427-1-9	
4	Cylinder Retaining Nut	1	2426-1-4	
5	Teflon Packing	3	2427-4-2	
6	Teflon Packing	2	2427-4-3	2427-004 (Set)
7	Teflon Packing	2	2427-4-1	
8	Packing Retainer Nut	1	2426-1-10	
9	Packing Follower Ring	1	2427-1-2	
10	Base	1	2426-1-1	
11	Plunger	1	2427-1-1	
12	Non-Rotation Pin	1	2426-1-8	
13	Stop Collar	1	2427-1-6	
14	Socket Set Screw	3	71-140	
15	Drive Nut	1	2426-1-2	
16	Thrust Washer	4	05-900-0877-033	
17	Thrust Bearing	2	05-400-0877-004	
18	Square Felt	2	99371-043	
19	Bearing	1	08-341	
20	Oil Cup	1	55-584	
21	Square Key	1	99056-006	
22	Handle Hub	1	2426-1-7	
23	Handle	2	2426-1-9	
24	Handle Knob	2	39-008	
25	Socket Set Screw	2	71-139	
26	Thread Cover	1	2427-1-7	
27	Drive Screw	2	71-108	
28	Number Plate	1	99236-225	