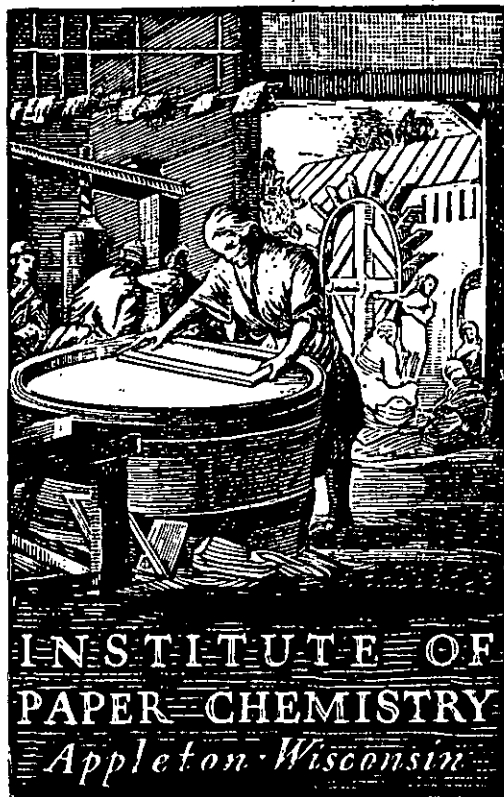


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THEORY, USE AND CALIBRATION OF BURSTING STRENGTH TESTERS

Project 2694-7

Report One

A Summary Report

to

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

January 12, 1972

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

THEORY, USE AND CALIBRATION OF
BURSTING STRENGTH TESTERS

SUMMARY

A review is given of the literature on the theory, use, and calibration of bursting strength testers for the last seventy years. The most widely used instruments for testing paperboard in the United States, the Mullen and Cady testers, have received the most attention in this review. A bibliography of the 78 most pertinent references are appended.

INTRODUCTION

In preparing this review, extensive use was made of the IPC bibliographic series on paper testing (1-4). These were supplemented by a search of the Abstract Bulletin of The Institute of Paper Chemistry for the more recent period through June 1971. Inasmuch as the literature is quite extensive and dates over sixty or more years, no claim is made for completeness, although it is believed the survey has included all of the more important recent articles.

Primary attention has been focused on the more widely used instruments for testing paperboard in the United States such as the various models of the Mullen tester made by the B. F. Perkins Division, Standard International Corporation, and the Cady testers made by the E. J. Cady Company. References in the foreign literature have been included where pertinent; however, it was deemed to be beyond the scope of this review to catalog the many types of bursting strength testers developed in this country and abroad over the past seventy or more years.

The invention of the Mullen tester by J. W. Mullen dates back to 1887. In 1907 a bursting strength specification was introduced into what is now the Uniform Freight Classification. An interesting account of this development has been written by Bettendorf (5).

A number of types of bursting strength testers are described in the literature, many of which are primarily of historical interest such as the Webb and Eddy testers (6,7). Additional references to these and other testers may be found in the bibliographies cited above. Many instruments for measurement of bursting strength have also been devised in Europe and elsewhere such as the Schopper-Dalen, Lhomargy, Lorentzen and Wettres, Stalybridge England air burst, and Frank testers. Comparisons of Mullen and Schopper-Dalen instruments have

been made by Sieber (8), Oliver (9), Underhay (10), Thoden (11), Michalik (12), and Mititelu (13). Hailer (14) has compared Frank and Mullen bursting strength testers having hydraulic clamping devices.

Instruments which are widely employed for testing the bursting strength of paperboard in the United States are the Model A and AH Mullen testers and to a lesser extent the Cady instruments. The Model A Mullen testers are available with hand clamping and Model AH with hydraulic clamping. A redesigned Cady tester is available which automatically clamps the sample and starts the burst cycle (15).

SPECIFICATIONS AND METHODS

Bursting strength specifications for corrugated and solid fiberboard are contained in the Common Carrier Classifications. These include the following:

- a. Uniform Freight Classification for railroad shipment
- b. National Motor Freight Classification for motor carrier shipment
- c. Coordinated Freight Classification for motor carrier shipments which originate and terminate in New England
- d. Official Express Classification for Railroad Express Agency shipment

The various classification documents specify similar bursting strength test procedures. For example, Rule 41 of the Uniform Freight Classification specifies the following bursting strength test procedure to be carried out after conditioning the board to equilibrium at 50% R.H., 73°F.:

Bursting Test Procedure

"Note 1. (a) Minimum test per square inch referred to in this rule, in separate descriptions of articles, or in descriptions of package numbers, except in the case of triple wall board, means the bursting strength of material in pounds per square inch, measured by tests made with the Cady or Mullen tester. The diaphragm used in this tester shall be such that a pressure of 23 to 30 pounds will distend it to a height of $\frac{3}{8}$ inch above the diaphragm plate. A motor-driven tester of the jumbo type operating at a constant speed of approximately 120 revolutions per minute shall be used.

"(b) In applying Cady or Mullen tests, a specimen of the board shall be clamped firmly in the machine to prevent slippage. If board slips during

tests, the results must be disregarded. In testing corrugated board, double-pop tests may be disregarded.

"(c) Six bursts must be made on unscored areas, 3 from each side of the board. Only one burst is permitted to fall below minimum test required. Board failing to pass foregoing test will be accepted if in a retest consisting of 24 bursts, 12 from each side of board, not over 4 bursts fall below the minimum test required. When individual bursts in a series are invalidated for reasons described under Paragraph (b), and disregarded, additional bursts shall be made until the total number of valid bursts required to complete the series (6 or 24, as the case may be) has been secured."

While Rule 41 specifies a diaphragm pressure tolerance and test speed, no procedures for determining compliance are prescribed. Other instrumental variables such as indicator calibration, platen condition, etc., which affect test results are not mentioned. The clamping pressure to be used is left to the discretion of the operator except that tests where visible slippage occur must be disregarded.

TAPPI Methods T 807 and T 810 describe procedures for evaluating the bursting strength of paperboard and corrugated board (including solid fiber-board), respectively. They differ primarily with regard to clamping pressure. Method T 807 specifies a clamping pressure of 100 p.s.i., whereas T 810 specifies that the clamping pressure should be sufficient to prevent slippage. ASTM Methods D2529 and D2738 correspond to the TAPPI methods mentioned above.

The literature concerned with the theory of the bursting strength test and the effects of instrumental variables on bursting strength are briefly reviewed in the following section.

THEORY OF BURSTING STRENGTH TEST

The bursting strength test involves application of increasing pressure through a rubber diaphragm to a circular area of the specimen which is firmly clamped around the periphery of the test area. The maximum pressure when the specimen ruptures is termed the bursting strength and includes the pressure contribution of the diaphragm in addition to that caused by the test specimen.

Thus, the bursting strength specimen corresponds to a clamped circular plate exposed to a lateral pressure. A comprehensive treatment of the behavior of such plates has been made by Timoshenko, et al. (16). As pressure is applied to the specimen, bending and shear stresses are induced in the specimen as well as direct tension stresses due to stretching in the middle plane of the specimen. Reference (16) indicates that, for thin sheets at relatively large deflections, the bending and shear stresses are small in comparison with the direct tension stresses and may be neglected. Hence, as developed in later pages, bursting strength is primarily dependent on the tensile strengths and stretches of the sheet in the machine- and cross-directions.

Theoretical relationships between bursting strength and other properties of paper and paperboard have received much attention. However, due to the various simplifying assumptions inherent in most of the treatments, the theoretical results are most applicable to thin papers and less applicable to heavier paperboards and corrugated boards.

In 1924 Carson (17) suggested that an equation for the stress in the walls of a spherical pressure vessel could be used to relate bursting strength to tensile strength and stretch. The equation (taken from Marks Mechanical Engineering Handbook) is as follows:

$$PR = 2T$$

(1)

where

P = bursting strength

R = radius of curvature of the specimen at rupture

T = tensile strength

In Equation (1) the radius of curvature is related to the stretch of the specimen by the following expression (18,19)

$$(e/100) + 1 = (R/r) \text{ arc sin } r/R \quad (2)$$

where

e = breaking strain

R = radius of curvature

r = radius of orifice

Thus, the equation used by Carson indicates that bursting strength should be primarily related to tensile strength and stretch of the sheet.

Several years later, in 1930, Carson and Worthington (18,19) carried out extensive tests in which the deflection of the bulge at failure was measured. Analysis of the results in terms of Equations (1) and (2) indicated that the bursting strength of machine-made paper is fairly well related to M.D. tensile strength and stretch. [Note: This conclusion pertains to conventional machine-made papers where the M.D. stretch is normally less than the C.D. stretch.]

Campbell (20) found that the shape of the bulge prior to rupture was approximately spherical and deduced that approximately equal strains are induced in all directions in the plane of the sheet for both handsheets and machine-made papers. Later unpublished work at the IPC indicated that the sphericity of the

bulged specimen is a reasonable approximation within a few percent when analyzed in terms of vertical displacement of the specimen at a few selected points.

Clemens (21) also indicated that the specimen assumes the form of a sphere. Thus, there is good evidence that both isotropic and anisotropic specimens are distorted to a bulged shape which is essentially symmetrical with respect to the central axis of the specimen. Campbell (20) also observed that the $\frac{PR}{2T}$ ratio of Carson and Worthington (18,19) varied over a considerable range (0.98 to 2.19) for handsheets with isotropic properties in the plane of the sheet.

Strachan (22) disagreed with the derivation of Equation (1); however, Van den Akker (23) indicated that Strachan incorrectly analyzed the forces in the bursting strength test. Bierett and Schulze (24) developed the following formula for converting test results for one size of upper clamp opening to another:

$$\frac{P_m}{P_n} = \sqrt[x]{\frac{F_n}{F_m}} \quad (3)$$

where

\underline{P} = bursting strength

\underline{F} = area of opening of upper clamp

and \underline{m} and \underline{n} denote the two clamp conditions

Bierett suggested that \underline{x} should equal 2 for homogeneous materials but found values near 1.7 for various papers.

Other mathematical treatments have been carried out by Roberts (25), Cunane (26), and Yamaguchi (27).

Van den Akker (23) derived a more general expression which, after various simplifying assumptions were made, takes the form shown below:

$$P = (2\sqrt{6} \sqrt{e} T)/r \quad (4)$$

where

\underline{P} = bursting strength

\underline{e} = extension at rupture in tension of the specimen in its
least extensible direction, i.e., breaking strain

\underline{r} = radius of the orifice

\underline{T} = "average" of the M.D. and C.D. tensile strengths

Thus, as an approximation, bursting strength is proportional to the product of the "average" tensile strength and the square root of the breaking strain in the least extensible direction. This is normally the machine-direction.

While \underline{T} is defined as the "average" of the M.D. and C.D. tensile strengths Van den Akker pointed out that this should be regarded as an approximation for a number of reasons as follows:

1. As the pressure is increased in the bursting strength test nearly equal strains in all directions are induced in the specimen. Assuming failure occurs when the stretch in the least extensible direction is exceeded (normally the M.D.), the strain in the cross-direction at that instant will be less than the breaking stretch. Referring to Fig. 1 where M.D. and C.D. tensile load-elongation curves for conventional machine-made papers are shown, this means that the cross-direction tensile force at rupture in a burst test would be less than its maximum value in a tensile test - i.e., \underline{T}_{cf} rather than \underline{T}_c . Defining \underline{T} as the "average" of the M.D. and C.D. tensile strengths does not take this effect into account.

2. The above does not necessarily mean that the average tensile strength $(\underline{T}_m + \underline{T}_c)/2$ is greater than the average of \underline{T}_m and \underline{T}_{cf} . The bursting

strength test involves biaxial stresses, whereas the tensile tests involve only uniaxial stresses. While lateral contractions of the specimen can occur in the tensile test they are not permitted in the bursting strength test. As a result the force in a given direction to induce a given strain in the bursting strength test will be greater than the force required to induce that strain in the uniaxial tensile test. Thus, while the ultimate strength in the direction of greater stretch is not fully achieved in the bursting strength test the force in that direction will be greater than would be expected from the uniaxial tensile curve.

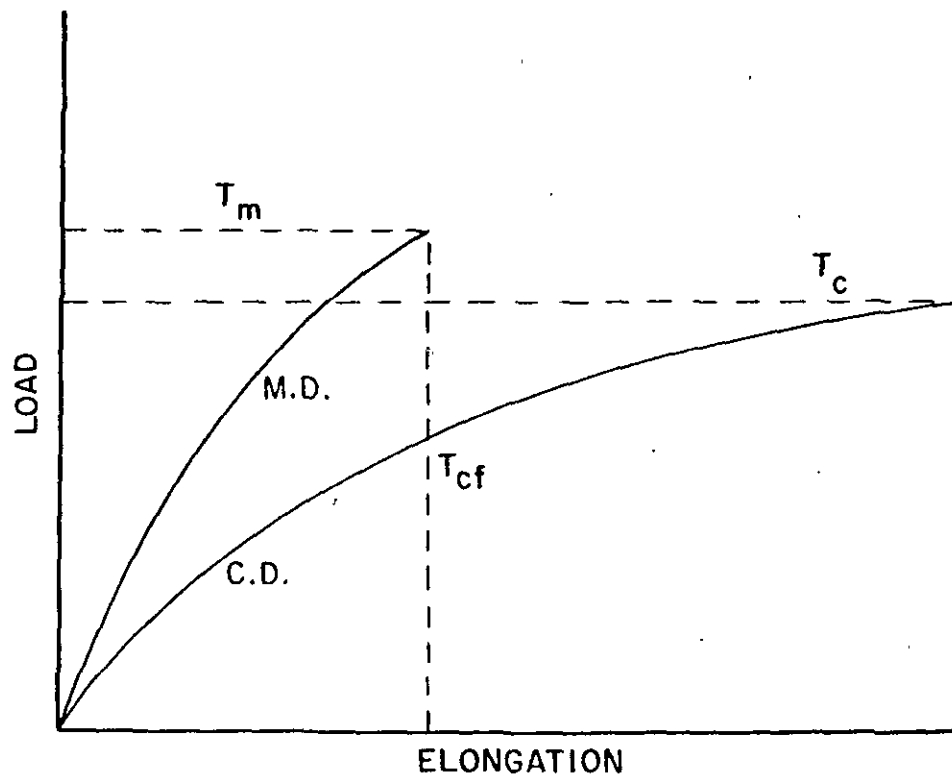


Figure 1. Tensile Load-Elongation Curves for Conventional Machine-Made Papers

3. Other factors such as edge and span effects also can lead to discrepancies between tensile and bursting strength tests.

In addition to the above the analysis neglected the pressure contribution of the diaphragm and considered only tension stresses — i.e., bending and shear stresses were assumed to be negligible. This latter assumption is appropriate for thin papers but results in error in the case of thicker paperboards and corrugated boards.

Despite these approximations, Equation (4) is generally accepted as a reasonable approximation for paper and predictions of bursting strength of paper based on the equation have been in good agreement with experiment.

Sommer (28) in 1941 derived an expression similar to that obtained by Carson. Winkler (29) indicated that the Sommer relationship was useful so long as the height of the distended bulge does not exceed approximately 0.4 times the radius of the orifice. Vollmer (30) derived an expression which was similar to that obtained by Van den Akker.

Further analyses relating bursting strength to tensile properties have been made by Fujiwara (31) and Böhmer (32). These analyses attempt to specify more precisely the effect of the machine- and cross-machine direction tensile strengths and elongations.

Fujiwara (31) assumed that the stress strain curve is approximately described by a parabola of the form

$$T = Ae^{0.5} \quad (5)$$

where:

\underline{T} = tensile strength

\underline{e} = tensile elongation

\underline{A} = constant

Following Van den Akker's approach but with this added assumption, Fujiwara obtained the following expression

$$P = K[T_m + T_c (e_m/e_c)^{0.5}] / R(e_m) \quad (6)$$

where

\underline{P} = bursting strength

$\underline{T}_m, \underline{T}_c$ = M.D. and C.D. tensile strengths

$\underline{e}_m, \underline{e}_c$ = breaking strain in M.D. and C.D. directions

$\underline{R}(\underline{e}_m)$ = radius of curvature at moment of burst

\underline{K} = constant

Fujiwara also showed an expression for $\underline{R}(\underline{e}_m)$ and Böhmer (32) expanded the expression in a Maclaurin series to obtain the following equation for anisotropic sheets

$$P = K[T_m + T_c (e_m/e_c)^{0.5}] \sqrt{e_m} / r(1 + e_m)^{1.5} \quad (7)$$

where \underline{r} is the radius of the orifice and the other symbols are defined as in Equation (6).

It was concluded that a proper balance of tensile and elongation values in the M.D. and C.D. directions is an important factor affecting bursting strength. It also may be remarked that the above assumption of a parabolic relation for the tensile stress-strain curve may be adequate for machine-made papers or boards having the usual M.D.:C.D. ratio of properties. Specially made papers such as extensible papers have much more complex stress-strain curves and the parabolic expression would not be suitable for such papers.

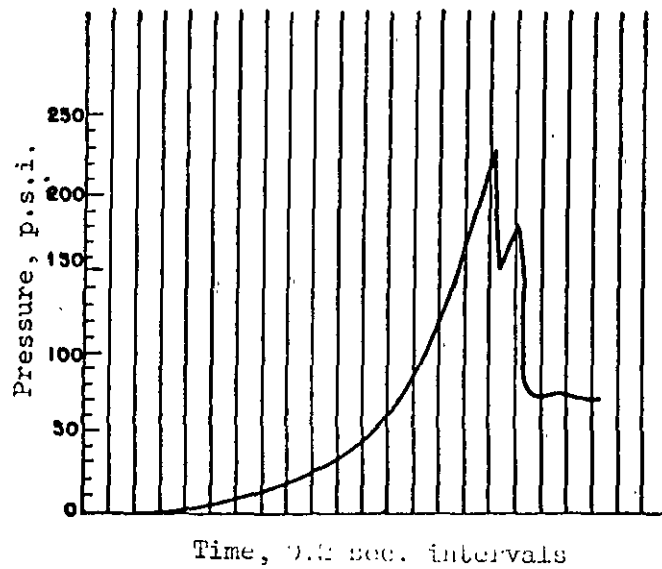
EFFECTS OF INSTRUMENTAL VARIABLES

INDICATOR CALIBRATION

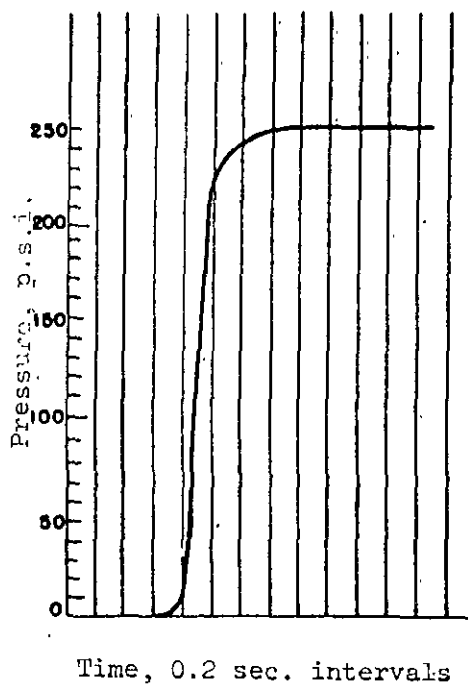
Correct calibration of the indicating mechanism is both an important and controversial subject. Maximum reading Bourdon tube pressure gages have been almost universally used to the present — primarily because of their low cost. However, with such gages the inertia of the moving parts affects the observed readings. The application of electronic pressure transducers coupled with suitable indicators has, however, received attention in the literature and a system based on this approach is commercially available.

Deadweight gage testers are generally used to calibrate the higher capacity Bourdon gages. Much thought and effort has been applied to devise procedures to simulate test rates in the bursting strength test during calibration so as to take into account the inertial effects mentioned above. Typical pressure vs. time curves obtained in (a) a bursting strength test and (b) gage calibration on a deadweight tester are shown in Fig. 2 (33). Figure 2A shows that in a bursting strength test the pressure rises at an increasing rate until the specimen ruptures. Just prior to rupture the rate may be approximately constant (34). After rupture there is a sudden decrease in pressure. Using the deadweight tester, Fig. 2B shows that the rate of pressure increase decreases as the final pressure is approached. This difference in behavior makes it difficult to account for gage inertial effects such as pointer overthrow in deadweight gage calibration.

Comments on the effect of the mass of the gage needle and gage calibration may be found in References (10,35). Carson and Worthington (19)



A - Bursting Strength Test on Corrugated Board



B - Deadweight Tester Gage Calibration

Figure 2. Pressure-Time Curves for Bursting Strength Test on Corrugated Board and Deadweight Tester Gage Calibration [Ref. (33)]

indicated that the gage should be calibrated in the same position in which it is to be used and recommended that a valve be used so as to permit applying pressure at about the rate prevailing during test. Clark (36-38), in a number of articles, discussed the need for taking into account gage inertia.

A detailed treatment of many of the factors involved in gage calibration may be found in the work by McKee, et al. (33). A special recording pressure apparatus was used to check rate of response, needle throw, etc. It was concluded that if the gage is properly adjusted, it has sufficient response to correctly indicate the pressure at moment of rupture. The two main gage types are described and gage adjustments to correct for various types of error are discussed [see also Tuck and Mason (34)]. Several different methods of using deadweight gage testers were investigated. The authors (33) recommended insertion of a needle valve on the deadweight tester in the line to the gage. This permits control of the "average" rate of pressure increase in gage calibration, however the final pressure is still approached asymptotically. It was recommended that "the setting of the needle valve should be such that at the higher ranges of the gages the travel of the needle will approximate the rate encountered during a bursting strength determination which falls within the same range" - i.e., the maximum rate near or at rupture of the specimen. Figure 3 shows that as a consequence the rate of loading is lower at the lower pressures for a given gage; however, the authors (33) pointed out this approximates the conditions encountered in a bursting strength determination. Tuck and Mason (34) have shown that the rate of pressure increase at burst increases nearly linearly with the bursting strength level.

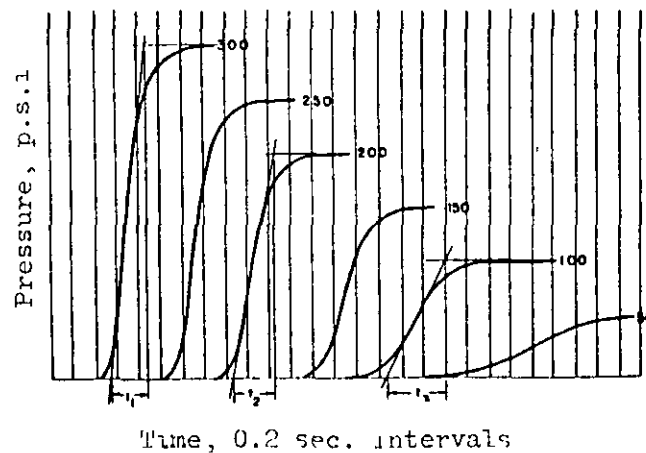


Figure 3 Pressure-Time Curves Showing Typical Calibration Data for a 300-lb. Gage [Ref (33)]

Tuck and Mason (34) measured the expansibility of various gages and found variations from 0.6×10^{-3} to 6.4×10^{-3} cc./p.s.i.g. The gage expansibility had a marked effect on the rate of straining during test and hence, some influence on the test result. A theoretical analysis was made of the dynamic errors arising from (1) friction, (2) vibration, and (3) gage needle overthrow. It was concluded that the cumulative dynamic error was near 2% - mainly due to overthrow. A dynamic method of gage calibration was suggested and a complete description of the method may be found in a later paper (39). Essentially, the method involved (1) coupling a deadweight tester to the bursting strength tester, (2) clamping a metal plate over the tester orifice, and (3) using the tester pump to apply pressure to lift the weights applied on the deadweight tester. A solenoid valve is used to release the pressure when the deadweight piston rises free of a spring inserted in the system. Corrections for switching time and for vibratory effects are required.

As another means for simulating the rate of pressure rise during test during calibration, Francis (40) suggested a modification of the technique described in Reference (33). In brief, a two-step opening operation of the needle valve was proposed. The degree of initial opening of the valve depends on the applied pressure. Then, as the gage needle approaches the final pressure, the needle valve is quickly opened so as to result in a faster rate of pressure increase in the final stages. While considerable skill is required of the operator, he indicated that trained operators should obtain agreement within ± 0.5 p.s.i.

Carson and Worthington (41) also measured gage expansibilities and suggested use of an apparatus constant which was primarily dependent on the sum of gage expansion and the compression of air "during the midhalf pressure change." Johansson and Jordansson (42) reported data on gage expansibilities both before and after evacuation to 99.5% vacuum. Marked differences in gage expansibility were obtained - apparently due to small amounts of air in the gages before the abovementioned evacuation. Evacuation reduced the gage expansion values to values lower than specified by the TAPPI method for paper bursting strength (T 403 m-53). Other authors discussing Bourdon gage calibration include Lhomme (43), Molieres (44), and Hailer (45).

In 1954, Brauns, et al. (46) used a strain gaged diaphragm-type transducer coupled to a high-speed Brown potentiometer to investigate the calibration of Bourdon tube bursting strength gages. The equipment was used to evaluate the tendency for pointer overthrow to allow more accurate calibration of Bourdon gages. Using the same apparatus, Johansson and Jordansson (42) reported results indicating the Bourdon-type gages gave higher results than the electronic indicator used. Decreasing the gage needle friction below 4 g.cm.

was shown to increase the difference between gage and electronic indicator. Francis (40) discussed application of a metal diaphragm device utilizing a capacitance measurement to determine displacement of the metal diaphragm at failure of the specimen. He commented that as the dilatancy of the diaphragm was reduced the readings from the device approached the gage reading. D'Altan (47), using a piezoelectric pressure transducer coupled to an oscilloscope reported fairly good agreement in pressure between Bourdon gage and pressure transducer readings. Quite recently, Maltenfort, et al. (48) summarized results obtained using a Statham pressure transducer connected to a suitable recorder. Among other things they concluded that "conventional Mullen gages overstate 'true' bursting pressures, due to pointer override, by as much as 6% on otherwise well-maintained and calibrated equipment." It was noted that the test repeatability was about the same for the two indicator systems. Despite the differences in results between indicator systems, they saw no reason to change the conventional test procedures or instruments or to attempt to redefine combined board specifications in Rule 41. The electronic indicator system was recommended, however, for use in referee situations.

CLAMPING PRESSURE AND PLATENS

The initial clamping pressure applied to the specimen is one of the more important test variables. Doughty (49), as early as 1910, reported that the bursting strength of paper decreased as the clamping pressure was increased and became sensibly constant at high torques (pressures). Using a Mullen tester for paper, Carson and Worthington (19) indicated that clamping forces ranging from 350 to 800 lb. were required to avoid slippage depending on the paper being tested. A clamping force of 1000 lb. was recommended. Further information on

the effects of clamping pressure on the bursting strength of paper and paperboard may be found in References (33,40,44,50-53).

For paper and paperboard the tendency for bursting strength to increase at low clamping pressures appears to be related to the amount of stretch which the specimen undergoes in the clamps (33). It may be explained in terms of the equation suggested by Carson (see Theoretical section). Assuming the actual tensile stress in the specimen at failure is constant, Carson's formula indicates the bursting strength should be inversely proportional to the radius of curvature. At lower clamping pressures the specimen stretches to a greater extent in the clamp area, causing a decrease in the radius of curvature and, hence, an increase in bursting strength.

While the bursting strength of paper and paperboards are affected by clamping pressure, the effect becomes small at high clamping pressures. As a result, the specification of a high clamping pressure tends to minimize variations in bursting strength due to this cause.

The bursting strength of corrugated board is markedly affected by clamping pressure (33,45,53-56) and the selection of suitable clamping pressures is a controversial problem. If the pressure is too low, slippage occurs and such results must be disregarded according to Rule 41. If the pressure is too high, the flutes under the platens are crushed and significantly lower results are obtained. To date no numerical level of clamping pressure is specified in the TAPPI method for corrugated board (T 810 su-66), Rule 41, etc.

Despite the regulatory disadvantages of high clamping pressures, McGee (54) recently suggested a clamping pressure of 50 p.s.i. be employed for corrugated board which may be sufficient to cause crushing of the flutes for many

corrugated board constructions. Hood (55) has also noted that lack of clamping pressure control may result in large differences in test results on corrugated board between laboratories and suggested that T 810 su-66 be revised to incorporate a minimum clamping pressure of 113 p.s.i. equivalent to approximately 1130 lb. clamp force. He commented that this change would bring the United States "in line with the testing procedures of other countries."

Various means for measuring clamping pressure have been employed over the years. With the older screw-type clamps, torque wrenches were sometimes employed (49,55,56). McKee, et al. (33) devised a mechanical strain indicator attachment for the Model A Mullen tester and the same principle has been used with Model C Mullen testers. More recently, pneumatic and hydraulic clamping systems have been made available. With regard to the latter, Hood (55) has noted the desirability of including a check valve in the hydraulic system so as to "lock" the upper platen in place after application of the initial clamping pressure. If there is no check valve in the clamping pressure system and too low an initial clamping pressure is used, the force exerted in the specimen during test may be sufficient to cause an upward displacement of the upper platen during test causing erroneous test results. By inserting a check valve in the hydraulic clamping system, the oil is prevented from flowing back out of the clamping cylinder during test. Consequently, the pressure exerted by the specimen on the upper clamp cannot displace the upper platen upwards. This gives essentially the same action as occurs in testers with hand clamps. A check valve is incorporated in current models of the Model AH Mullen tester.

Closely associated with the matter of clamping pressure is the condition of the clamping surfaces. If the platens are warped so as to concentrate the clamping pressure around the orifice, less stretch will occur in the clamped area and readings will be lowered (33,40,51,53,57). Conversely, if the clamping pressure is concentrated near the outer perimeter of the clamps, higher readings will usually be obtained. Uniformity is usually checked by clamping soft pencil carbon with a sheet of smooth paper or filter paper to obtain a pressure pattern. This technique will detect extremely unsatisfactory clamping conditions; however, as Francis (40) noted, many patterns are of intermediate quality and caution must be exercised in accepting such patterns.

The presence of oily or waxy substances on the platens is also known to affect test results. It may be conjectured that such substances affect the coefficient of friction between platen and specimen and, hence, affect the amount of stretch taking place in the clamps. Changes in smoothness of the platens may also affect test readings for much the same reason.

Many years ago bursting strength testers were equipped with rubber platens. Snyder (58,59) compared metal clamps with various surfaces with rubber clamps and concluded that the all-metal clamps resulted in superior clamping and permanence. Although this conclusion was questioned by Abrams (60), Carson and Worthington (18,19) confirmed Snyder's results and recommended metal clamps. This recommendation was followed by the manufacturer and metal clamps have been in almost universal use for many years.

As would be expected based on theory (see Theoretical section) the radius of the orifice affects the test results. Information on the effect of orifice size may be found in References (19,24,60). The greater the radius,

the greater will be the radius of curvature at rupture and, hence, the lower the bursting strength. Furthermore, the extent to which the edges of the orifice have been relieved of sharpness affects the test results (19,37).

AIR

The presence of air in the hydraulic system affects the rate of loading of the test specimen as noted by Carson and Worthington (19) and others. Based on the literature, its effect on test results appears to vary depending apparently on its location in the hydraulic system. For example, Clark (36) reported higher results with increasing quantities of air in the system. McKee, et al. (33) indicated if the air is located in such positions in the hydraulic system that appreciable flow of the fluid is required to transmit pressure to the gage - e.g., in the gage lines - lower test results are obtained. On the other hand, the presence of air under the diaphragm may have little or no effect on the test readings.

In this connection Tuck and Mason (34) noted that the percentage of fluid flowing into the gage at the moment of failure may range from about 4 to 32% of the total flow - depending on the gage expansibility. Thus, an appreciable flow of the fluid into the gage occurs and any air present will act to reduce the rate of straining of the specimen. They also indicated that a small but significant decrease in bursting strength occurs when air is introduced.

Pitman (61) introduced air in various amounts in the gage line. He concluded that small amounts of air produce widely erratic results. Larger amounts of air yield somewhat reduced test values and progressively retard the time to failure. Francis (40) commented on the importance of removing all air from the instrument.

DIAPHRAGM PRESSURE

The observed bursting strength includes the pressure exerted by the rubber diaphragm in addition to that caused by the test specimen. Thus, the pressure required to distend the diaphragm is both a significant and variable factor in the bursting strength test — particularly in the case of testers for paperboard such as the Model A and AH Mullen testers, Cady tester, etc.

In 1925 Abrams (60) observed that when a new diaphragm was substituted for one which had been in use for a considerable period of time, an increase in bursting strength of 14% was obtained. Quinn (53) commented on the need for diaphragm standardization.

McKee, et al. (33) cited results showing diaphragm contributions at rupture of about 13 and 26 p.s.i.g. for diaphragms exhibiting pressures of 26 and 51 p.s.i.g. at 1.8 cm. distention, respectively, using linerboard as the test material. They also noted that the caliper of diaphragms varied greatly and was not a reliable indication of the corresponding diaphragm pressure at 1.8 cm. distention. A diaphragm pressure specification of 40-45 p.s.i.g. at 1.8 cm. distention was suggested as a means for minimizing variations in bursting strength results due to differences in strength between diaphragms. Francis (40) confirmed the usefulness of this procedure but extended the allowable range to 40-50 p.s.i.g. at 1.8 cm. He commented that diaphragms passing this test were "invariably satisfactory while diaphragms not passing the test proved unsatisfactory."

When diaphragm specifications were introduced into Rule 41 the distention level was set at $3/8$ inch with an allowable pressure range of 23-30 p.s.i.g. There appears to be no published information relating this tolerance to

bursting strength variations. However, unpublished work at the IPC sponsored by the FKBI in cooperation with B. F. Perkins suggest that the 23 to 30 p.s.i.g. tolerance may permit about 2 p.s.i.g. differences in bursting strength of kraft linerboard.

Variations in diaphragm characteristics also affect results obtained on the Cady instrument though there is little or no information in the literature. In one unpublished study at the IPC some years ago it was found that a diaphragm exhibiting a pressure of 41 p.s.i.g. at full extension contributed about 6% at a bursting strength level of 200 p.s.i., whereas a diaphragm exhibiting a pressure of 24 p.s.i. contributed about 2%.

In Europe, diaphragms from several different sources are apparently available. Windaus and Herrmann (62) compared four different types using a Model AH Mullen tester. The four types were as follows:

1. thin diaphragms of the British Calibration Service
(thickness 0.4 mm.);
2. thick diaphragms of the British Calibration Service
(thickness 1.0 mm.);
3. diaphragms from Firma Frank, Weinheim (reinforced center, maximum thickness 2.47 mm.); and
4. B. F. Perkins diaphragms (reinforced center, maximum thickness 2.40 mm.).

Using aluminum foil as the test media, they concluded that differences in type of diaphragm may cause variations of up to 100% in test data under unfavorable conditions. It was also observed that diaphragms from different lots made by the same supplier could also vary appreciably in quality.

Takishima and Arai (63) have also commented on the need for diaphragm standardization in the case of the various instruments used for testing paperboards.

In the case of instruments for evaluating the bursting strength of papers, a number of investigators have discussed the effect of the diaphragm (18,19,41,64,65). Reference (41) indicates that the diaphragm error can be minimized by "(1) selecting the rubber diaphragm material no thicker than is necessary for the range of papers to be tested, (2) bringing the diaphragm as close as practicable to the paper, and (3) installing it with adequate slack."

RATE OF LOADING

The earliest bursting strength testers were hand-operated and it was quickly found that bursting strength values could be varied slightly by increasing or decreasing the speed of operation of the hand wheel. A number of references in the early literature to this effect may be found in the first mentioned bibliography (1). Motor driven bursting strength testers were introduced to minimize the variation resulting from differences in pumping speed.

Underhay (66) has reported variations in test results of from 6.2 to 9.6% when increasing the rate of loading from 75 to 225 r.p.m. Carson and Worthington (18,19) indicated that the bursting strength of paper increases somewhat as the rate increases. McKee, et al. (33), using a Model A Mullen tester found that "...in the normal range of testing, it requires a variation of 30 to 35 cc./min. to produce approximately a 1% change in the test results." An unpublished study at the IPC on the Cady tester some years ago indicated that a change in pumping rate of 20 cc./min. could cause a 1% change in test results.

Lhomme (43) obtained a limited amount of data on test rate. Thompson (67) has also shown that changes in test rate have only a slight effect on the bursting strength of paper. Hailer (45), using board testers made by Karl Frank GmbH. and B. F. Perkins, indicated that the effect of test rate is very small. Francis (40) presented a limited comparison which indicated that little or no decrease in test results for paper occurred with decrease in pumping rate if the gage was calibrated for the lower pumping rate.

To summarize briefly, the evidence in the literature indicates that pumping rate exerts a small effect on the bursting strength for either paper or board testers. It may be noted, however, that Carson and Worthington (41) pointed out that the volume change during test is absorbed in several parts of the system such as the gage, compression of any air in the system, and initial distention of the diaphragm in addition to the test specimen. They commented that "it is the relation of the last mentioned part to the whole that determines the effective test rate for a given rate of displacement of liquid in the pressure chamber."

HYDRAULIC FLUID

Glycerin is commonly used as the hydraulic fluid because it is compatible with the natural rubber diaphragms employed for bursting strength tests. It is, however, a relatively viscous fluid and complicates the removal of air from the tester. Carson and Worthington (18,19) carried out tests comparing the effect of the following fluids on the bursting strength of paper: glycerin, ethylene glycol, and water. Essentially the same test results were obtained with all three fluids. During World War II experiments were carried out in Great Britain to substitute a dextrose liquor for glycerin due to shortage of

the latter fluid (68). Results obtained with the substitute fluid were comparable to those obtained with glycerin.

Because of the difficulties in removing air when glycerin is used, Tuck and Mason (34) recommended using ethylene glycol. It may be noted that the TAPPI method for paper bursting strength recommends the use of purified 96% glycerin but also permits the use of purified ethylene glycol.

VARIABILITY AND STANDARDIZATION

Numerous studies of bursting strength variability have been made. A recent comprehensive study by Randall and Lashof (69) analyzed results from more than 175 laboratories using several models of bursting strength testers (including Perkins' Model A testers). An excellent survey of the literature in this area is also included and is not repeated here. They confirmed the well-known fact that Perkins' Model A instruments give appreciably higher test results than the Model C. For Model C instruments they reported values of repeatability (within laboratory), comparability (between materials), and reproducibility (between laboratories) of 5.4, 9.5, and 14.3%.

Many investigators have considered the use of aluminum foil as a test media for checking calibration (63,69-74). However, in the opinion of some recent investigators, aluminum foils are of doubtful value for this purpose because testers may agree on foil yet differ on papers and vice versa. This apparently occurs because the stress-strain characteristics of the foil and its compressibility, surface characteristics, etc., are markedly different from that of paper.

Statistical control chart procedures using various paper and paperboard materials as reference standards have been used by a number of laboratories in the industry for checking instrument calibration for many years. One of the earliest published discussions concerning the application of this approach to bursting strength testers for board may be found in an article by Odium (75). Procedures followed in initiating control charts are mentioned and the merits of random and stratified sampling plans are discussed. The latter was deemed to

be preferable to better allow for cross-direction variations. Procedures in use at the IPC in 1955 are discussed in Reference (76). Knight (77) described application of control chart techniques on a Perkins' board Mullen tester. Certain fluctuations in test results were apparently traceable to uncontrolled fluctuations in temperature in the test atmosphere. Reid and Chase (78) discussed the application of control chart procedures to board Mullen testers using 42-lb. kraft liner as the standard sample. They indicated that it appeared to give more satisfactory results than either aluminum foil or pouncing paper. Forty specimens were tested on a given tester every other day. Corrective actions were required if (a) an average fell outside two-sigma limits, or (b) two successive averages fell outside a one-sigma limit.

In general, most investigators indicate that the control chart procedure is a valuable way of checking the adjustment and calibration of bursting strength testers. It should also be mentioned that the National Bureau of Standards in conjunction with FKBI conducts a collaborative reference program using 26, 42, and 69-lb. liners as the test media.

DOUBLE-POPS

When making bursting strength determinations on corrugated board, it is occasionally possible to audibly detect more than a single rupture of the test specimen. This is normally referred to as a "double-pop" or "double-burst" and is caused by the two facings rupturing at different times. Generally, a lower bursting strength value is obtained when an audible double-pop occurs. TAPPI, ASTM, and Rule 41 test procedures allow disregarding readings where audible double-pops occur. In Reference (33) it was concluded, based on pressure vs. time recordings, that the two facings of corrugated board rarely break simultaneously even when the ear does not detect a double-pop. In general, the pressure builds up an increasing rate until the first rupture is obtained, decreases momentarily, and then rises again to a second peak. The two (or more) peaks were often of similar magnitude and either might be greater in magnitude than the other. Audibility appeared to be related to the time interval between ruptures - i.e., for small time intervals between ruptures it appeared that double-pops could not be audibly detected.

Hailer (45) commented that double-pops increase with decreasing pumping rates which is in accord with the above. Casey (56) commented that the incident of double-pops did not appear to be influenced by clamping pressure; however, unpublished work at the IPC has suggested fewer double-pops are detected at high clamping pressures. Maltenfort, et al. (48) have recently indicated that the use of an electronic pressure recording system may be helpful in distinguishing between "good" bursts and double-pops.

MAINTENANCE AND CALIBRATION

As mentioned previously, the appropriate TAPPI or ASTM methods specify various instrumental tolerances and procedures for instrument adjustment and calibration. The following discussion repeats some of the information contained in the methods but also contains supplementary information from Ref. (33) intended to facilitate instrument calibration.

CLAMPING PRESSURE

One model of the tester which employs a disk-shaped diaphragm is equipped with hydraulic clamping devices to measure the initial clamping pressure. For these testers the clamping pressure gage should be checked at periodic intervals using a deadweight tester. The piston on the hydraulic clamp testers has an area of 5 sq. in.; therefore, the total clamping force is obtained by multiplying the gage reading by the piston area. For example, a clamping pressure gage reading of 200 p.s.i. corresponds to a clamping force of 1000 lb. The area of the upper platen is 10 sq. in., hence the initial clamping pressure on the specimen would be 100 p.s.i. for a clamping pressure gage reading of 200 p.s.i.

In equation form this would be as follows:

$$P_{cp} = P_g (A_c / A_p) \quad (8)$$

$$P_{cp} = P_g / 2 \quad (9)$$

where

P_{cp} = clamping pressure on specimen

P_g = clamping pressure gage reading

$A_{\underline{c}}$ = clamping pressure piston area (5 in.²)

$A_{\underline{p}}$ = platen area (10 in.²)

The diameter of the upper clamping platen of the instrument using the hat-shaped diaphragm is 88.9 mm. (3.50 in.). This results in a clamping area of approximately 54 cm.² (8.4 in.²).

Clamping pressures for testers with disk-shaped diaphragms not equipped with the hydraulic device may be determined using an attachment to the tester as described in Reference (33), or by means of a torque wrench such as described in Reference (56). The attachment described in Reference (33) is schematically illustrated in Fig. 4.

The clamping force is applied by means of the conventional handwheel and screw assembly. This force strains the heavy arm of Yoke A of the Mullen tester (see Fig. 4), and the resulting strain is employed to indicate the clamping pressure. A length of steel keystick (B) is bolted to the upper part of the yoke, as shown, and serves to transmit the deflection to a dial strain gage. Another auxiliary member (C) is welded to a split ring (D) and serves to support an adjustable foot (E); E, in turn, engages the anvil of the strain gage. This arrangement amplifies the deflection or strain and results in a substantial displacement on the gage when a specimen is subjected to normal clamping pressures.

The deflection gage is calibrated by straining the yoke with known loads and recording the corresponding deflection. A similar calibration would be required for the torque wrench approach. Strains of the necessary magnitude and direction are obtained by loading the arm with deadweights through a proving lever, as shown in Fig. 5 [Ref. (33)], or by using a suitable force measuring

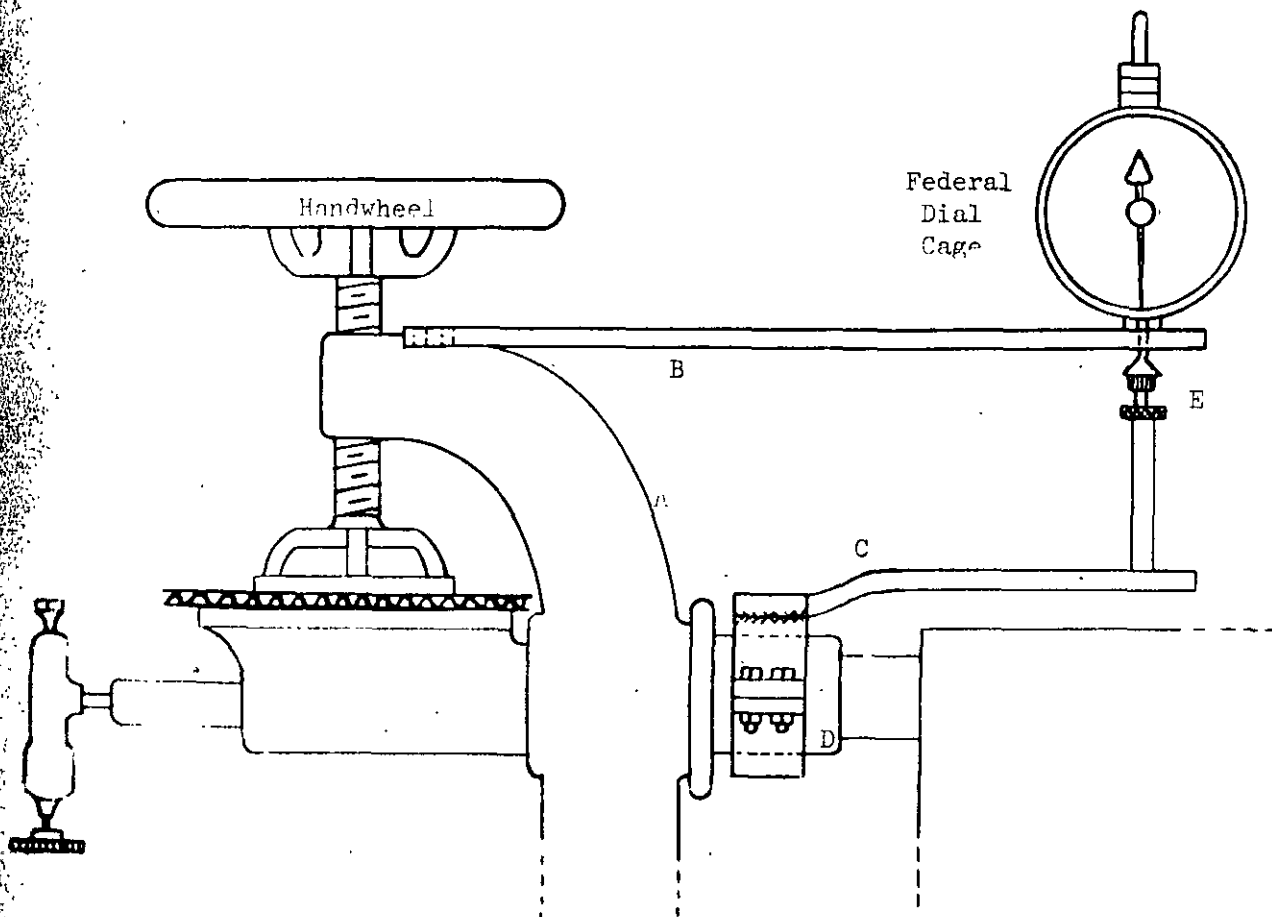
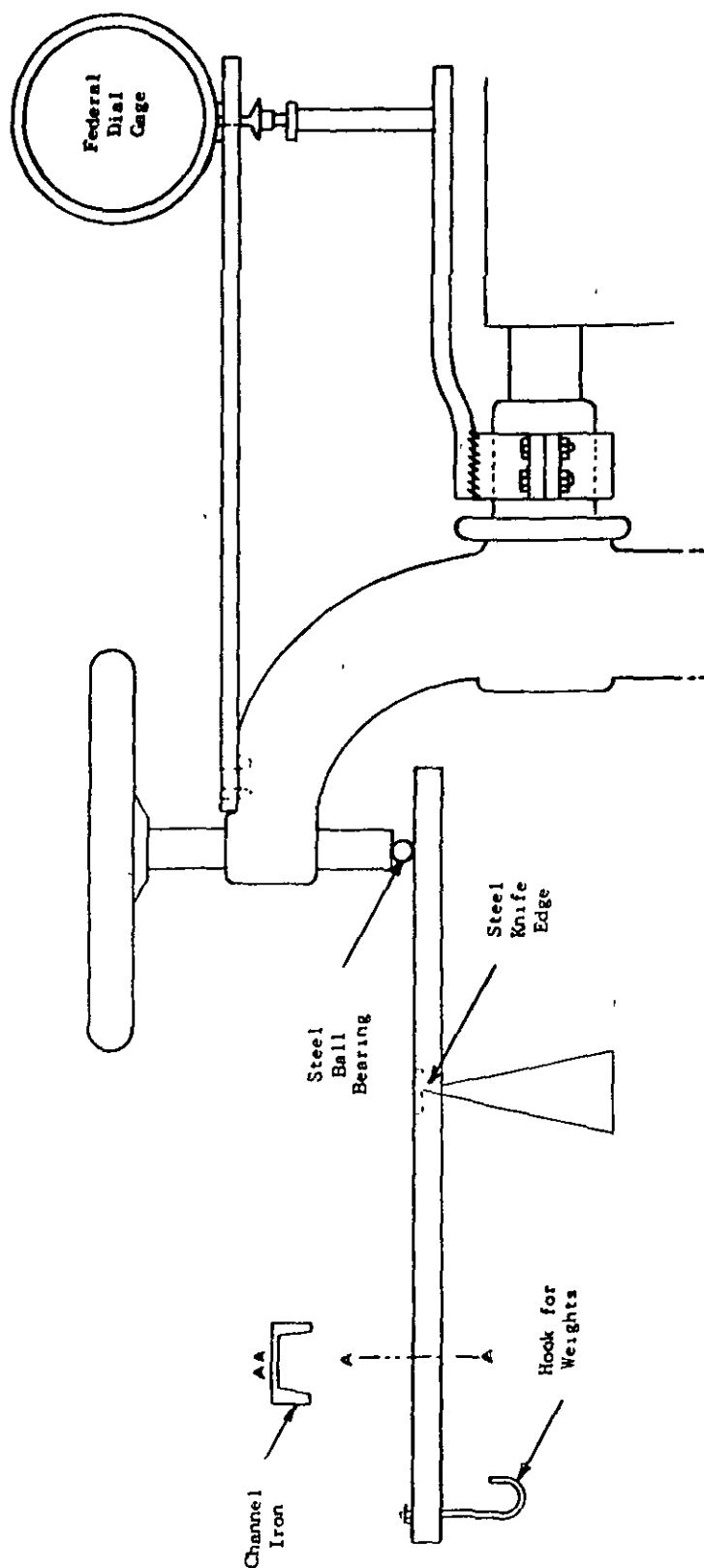


Figure 4. Schematic Drawing of Clamping Pressure Attachment
for Jumbo Mullen Tester [Ref. (33)]

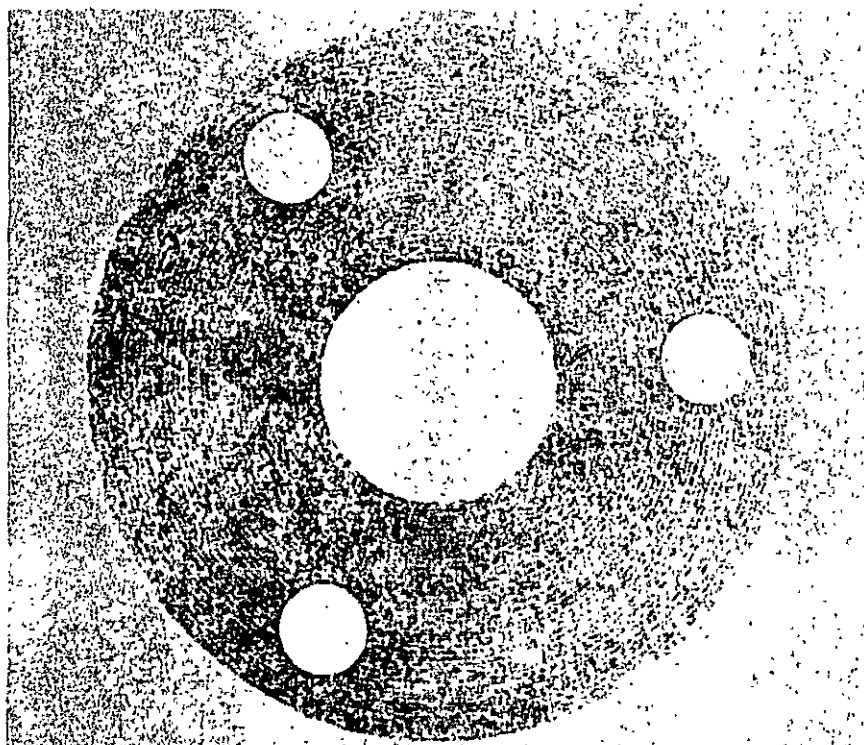
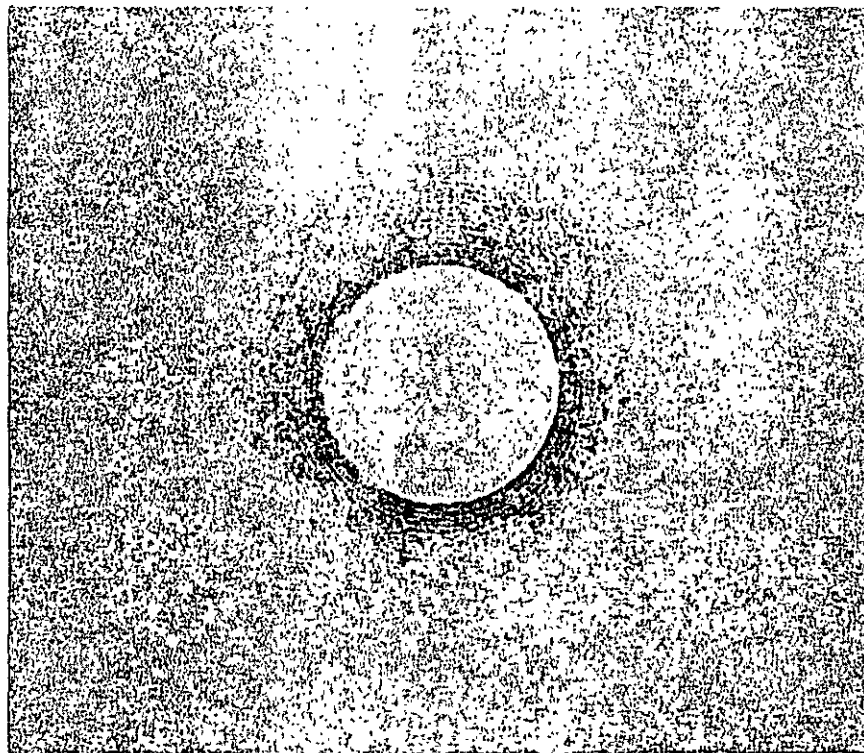


instrument. It is important to strain the yoke in the direction actually stressed when in use because Yoke A is not symmetrical in cross section. The force can be conveniently transmitted to the yoke by removing the upper specimen clamp and inserting a steel ball, such as used in a ball bearing assembly, between the lever arm and the slight hollow at the end of the screw assembly through which the specimen is clamped (see Fig. 5). Caution: The bursting strength tester must be rigidly clamped to a secure mounting during the actual calibration operation to prevent the tester from tipping over.

The calibration data give the total force required to deflect the yoke the indicated amount. For actual use, this total force is more conveniently expressed in terms of the clamping pressure, which is simply the total force divided by the effective specimen clamping area.

PLATEN CONDITION

Platen condition may be checked by placing a sheet of smooth paper over the lower platen and then placing a sheet of soft pencil carbon paper face down on the top of the paper. The upper platen is then held so that no rotation takes place while the screw clamp is tightened. When the clamp is raised and the paper removed, a print of the platen contact will be found on the paper. Rotate the clamp and repeat the operation. If the platens are in good condition, a uniform print of the entire platen surface will be obtained (see Fig. 6A, Satisfactory). Frequently, it will be found that the lower platen has been strained so that only the central portion will print (see Fig. 6B, Unsatisfactory). If this occurs, it is advisable to replace the lower platen or reface or lap the surface until a uniform print is made. If the print is heavy on one side, the platens are not coming together parallel. This may be remedied by loosening the



B. Unsatisfactory

A. Satisfactory

Figure 6. Platen Contact Patterns [Ref. (33)]

Allen set screw in the center of the yoke assembly which contacts the cylinder, rotating the cylinder in the proper direction, and relocking the set screw. In some cases, it may be necessary to loosen the cylinder nut before the cylinder can be rotated.

It is important to note that many patterns will be of intermediate quality — neither as extreme as Fig. 6B, nor as uniform as Fig. 6A. Thus, platen patterns are, at best, a crude means for judging platen condition nor do they provide information regarding the relative smoothness of the platens. For these reasons considerable judgment is required and caution should be exercised in accepting a given pattern as being satisfactory.

If the platens become contaminated with wax or other substances that may change the coefficient of friction, they should be thoroughly cleaned with an appropriate solvent such as acetone, carbon tetrachloride, etc.

Lateral alignment of the platens should be checked to make sure that the hole in the upper platen is concentric with the hole in the lower platen. This may be done by clamping the upper platen against the lower platen and observing the concentricity. If the two platen holes are not concentric, adjustment should be made by the addition of shims between the cylinder and the yoke assembly.

DIAPHRAGM INSERTION

The characteristics of diaphragms used in the tester may influence the readings obtained. When disk-shaped diaphragms are to be changed, make sure that the control lever has been thrown into reverse and has returned automatically to neutral. Pressure is applied by means of the handwheel or hydraulic

system to enable easy removal of the diaphragm nut by means of a special spanner wrench. Before the diaphragm nut has been completely removed, remove the clamp pressure and take off the demountable tripod. The diaphragm nut and lower platen may then be removed easily. Before inserting a new diaphragm, fill the chamber with air-free glycerin to the top of the saucerlike depression so that it is even with the clamping ridges and the inner valley between ridges is filled. These ridges must be kept clean and dry to minimize capillary leakage past them. If glycerin spills, wash the ridges with alcohol and wipe dry. A new diaphragm is then carefully placed on the surface of the fluid with the flat side down and the reinforced side up. To minimize the trapping of air, it has been found best to "roll" (see Fig. 7) the diaphragm into place, starting from the rear of the surface and rolling it forward so that no air is trapped. The lower platen may then be laid on the diaphragm so that the small hole in the platen fits over the pin at the rear of the cup. The diaphragm nut may then be replaced and screwed down tight. The tightening of the diaphragm nut may be facilitated if the demountable tripod is replaced and a clamping pressure of 100 p.s.i. is applied. Glycerin is then added, preferably by means of a glycerin gun, until the diaphragm is flush with, but not above the surface of, the lower platen. If a glycerin gun is not available, it will be necessary to add glycerin through the filling reservoir which has been capped by a knurled nut. While removing this nut and before adding glycerin, press gently upon the diaphragm to keep the fluid level with the top. Gradually diminish the pressure to compensate for the fluid added, taking care that no air is trapped while filling. It is well to add slightly more glycerin than necessary and then bleed it out until the diaphragm is flush with the top surface of the lower platen.

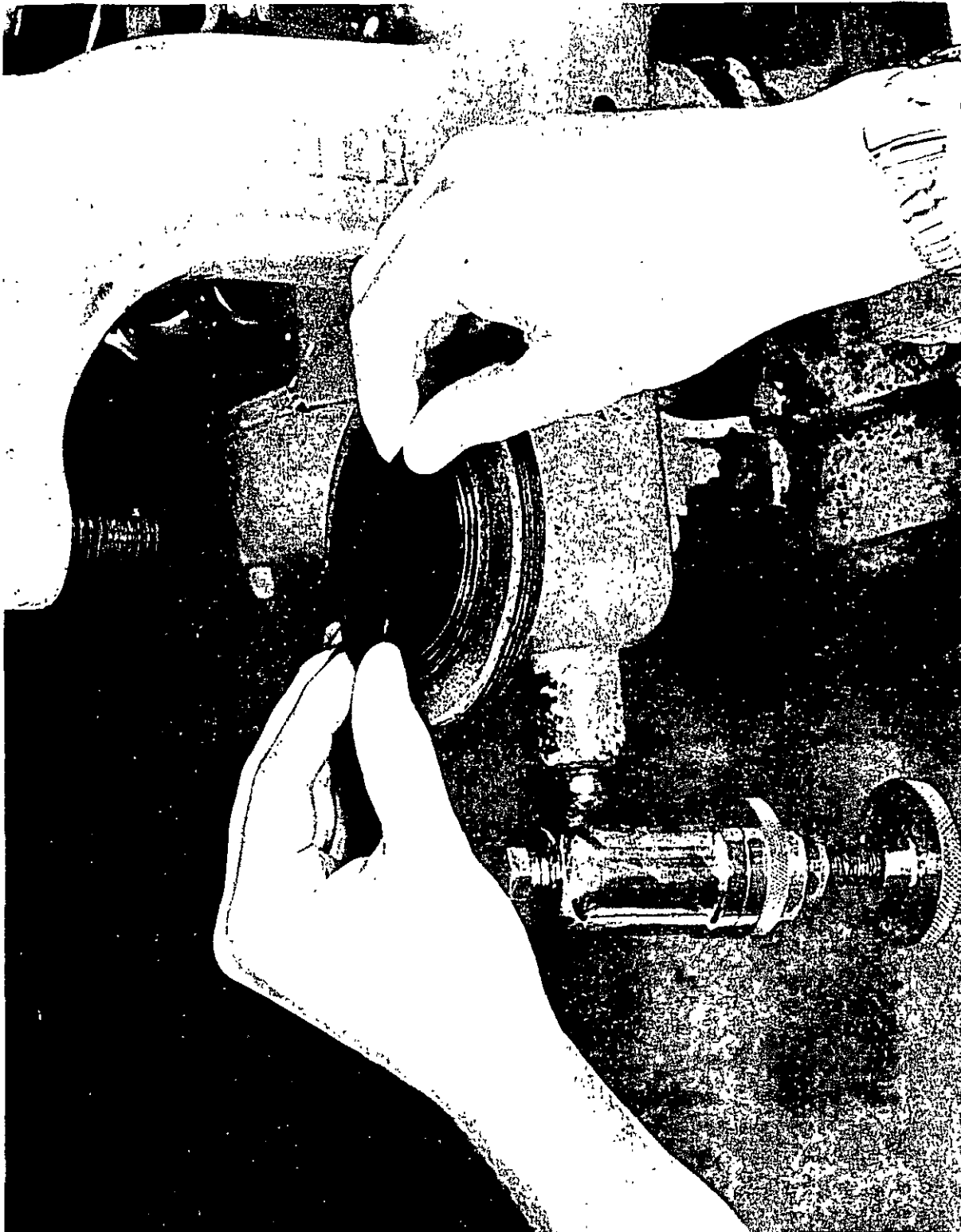


Figure 7. Method of Inserting Diaphragm

The diaphragm height may be checked by means of a U-shaped gage constructed so that its inner height is 9.53 mm. ($3/8$ in.), and of sufficient width to completely clear the diaphragm as it comes up (see Fig. 8).

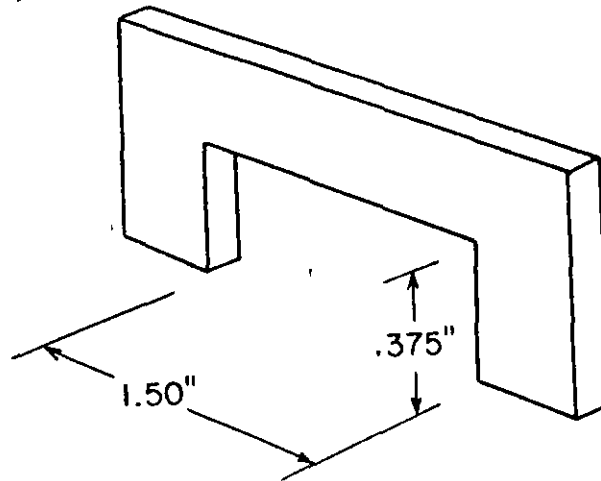


Figure 8. Diaphragm Height Gage (After Ref. (33))

Adjust the diaphragm so that its top surface is level with the top surface of the lower platen. Then operate the tester until the surface of the diaphragm just contacts the lower surface of the height gage. At this point the diaphragm pressure should be between 23 and 30 p.s.i.g.

An alternative method which may reduce operator error is to mount a microswitch in a jig which is placed over the diaphragm. When the diaphragm is distended to $3/8$ inch, it operates the microswitch which actuates a solenoid halting the piston.

If the pressure is below 23 p.s.i.g., the diaphragm should be discarded. If it is above 30 p.s.i.g. for a new diaphragm, the pressure required to extend the diaphragm $3/8$ inch can sometimes be brought within the desired range by

flexing the diaphragm with repeated extension cycles. However, the tester should not be used for bursting strength tests during this period. Alternatively, application of a small amount of dry lubricant to the top surface of the diaphragm may reduce the pressure to within the specified tolerance. If it is not possible to bring the maximum pressure down to 30 p.s.i., another diaphragm should be tried. The thickness of the diaphragm rubber does not serve as a reliable means for the selection of proper diaphragms.

PUMPING SPEED

The pumping speed of the tester may be checked by attaching a 50-cc. buret in place of one of the gages by means of a rubber tube (see Fig. 9). The buret should be held in the vertical position and a small amount of glycerin should be introduced to bring the glycerin level to one of the lower divisions. Using a stopwatch, start the tester and obtain the time for a given number of divisions. If this is repeated a number of times, an average can be obtained. Care should be taken that enough time is allowed between trials to permit the glycerin to drain from the buret, otherwise abnormally high apparent pumping speeds will be obtained. It has been observed in speed of loading tests that, with an operating pumping speed of 180 cc./min. as a reference point, a change of approximately 35 cc./min. may result in a 1% change in bursting strength.

AIR

The complete absence of air in the tester is very important, since glycerin flow through the gage lines must be kept at a minimum. Frequently, it has been observed that, when two carefully calibrated gages are connected to the tester so that pressure is applied simultaneously, there may be a difference in the individual readings. This difference may be caused by the presence of air

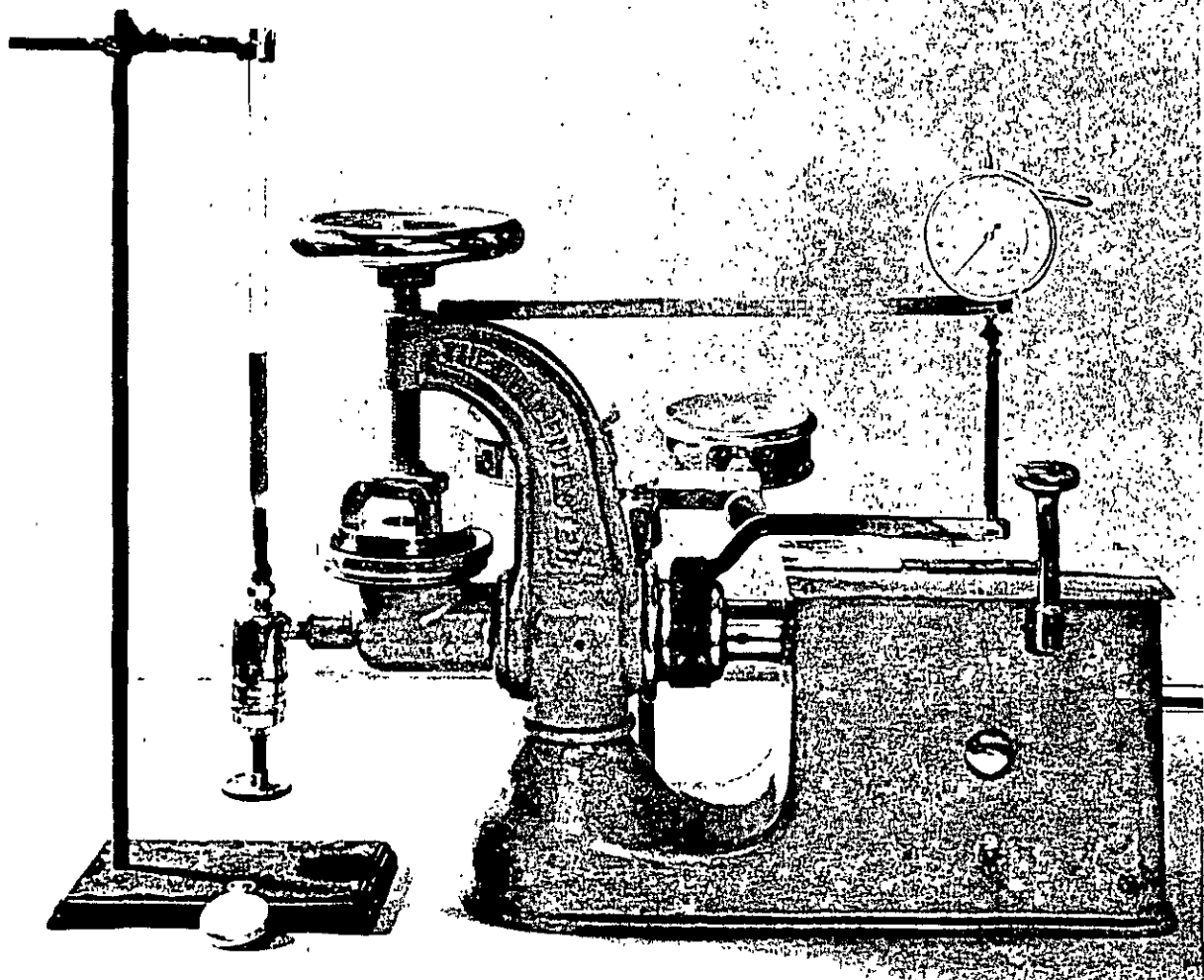


Figure 9. Method of Testing Pumping Speed [Ref. (33)]

in the gage lines. As the pressure increases, the air is compressed, permitting glycerin to flow. Because there is glycerin flow with attendant frictional resistance to pressure transfer, the glycerin may flow more readily into one gage than into another, thereby transmitting the pressure to one gage rather than to the other. This will cause lower readings in the second gage.

Air is best removed by pumping clean, air-free glycerin through the hydraulic system. Glycerin may be freed of air by placing it in a sturdy vessel and evacuating the system. A high vacuum level (low absolute pressure) appears desirable (42). Air bubbles will be seen to form. When the vapor pressure of glycerin has been reached, the glycerin will tend to foam. At this point, the glycerin can be considered free of air and ready for use. The gages are removed from the tester and the tester is tipped forward, as shown in Fig. 10. While in this position, the gage valves are opened and the piston engaged with the motor running. Running the tester in this position will push the glycerin and any air present in the manifold line out of the tester. As soon as the glycerin stops flowing, the gage valves are shut off tightly and the tester tipped back to its normal position. If there are no gage valves, carefully fit a pipe plug, taking care that no air is trapped. The diaphragm is then removed and glycerin added through the opening while retracting the piston, taking care that no air is introduced. The diaphragm is then temporarily replaced and the tester tipped on end, as shown in Fig. 11, so that the piston is in the vertical position. The plug at the topmost part of the glycerin chamber is then removed and the piston again run forward to expel glycerin and any air which may have been trapped in the piston and cylinder assembly. The plug is then replaced, the tester set down, the diaphragm removed, and the chamber is again filled with glycerin while retracting the piston. If care has been taken, all air should now be out of

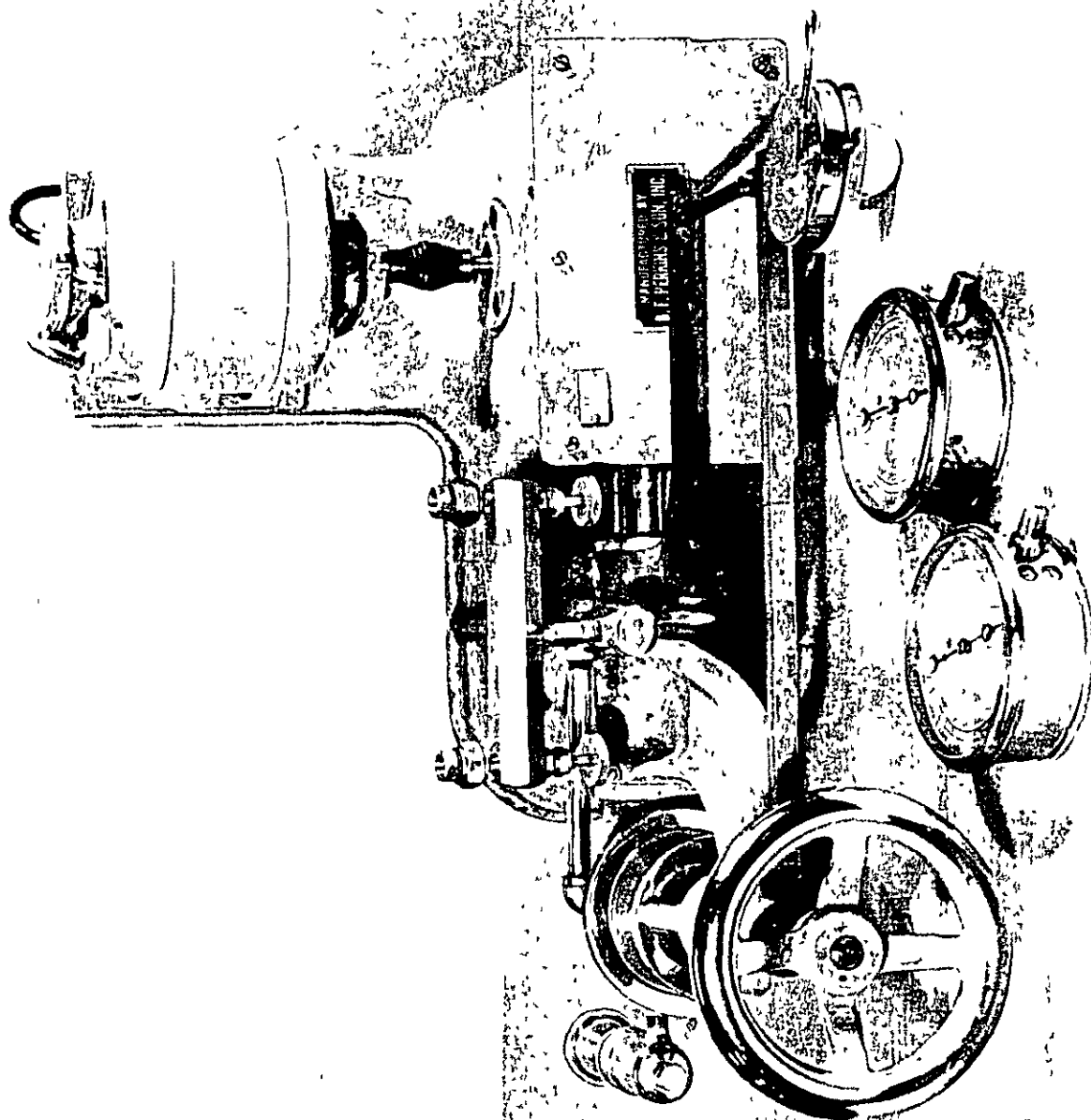


Figure 10. Tester Tipped Forward to Remove Air

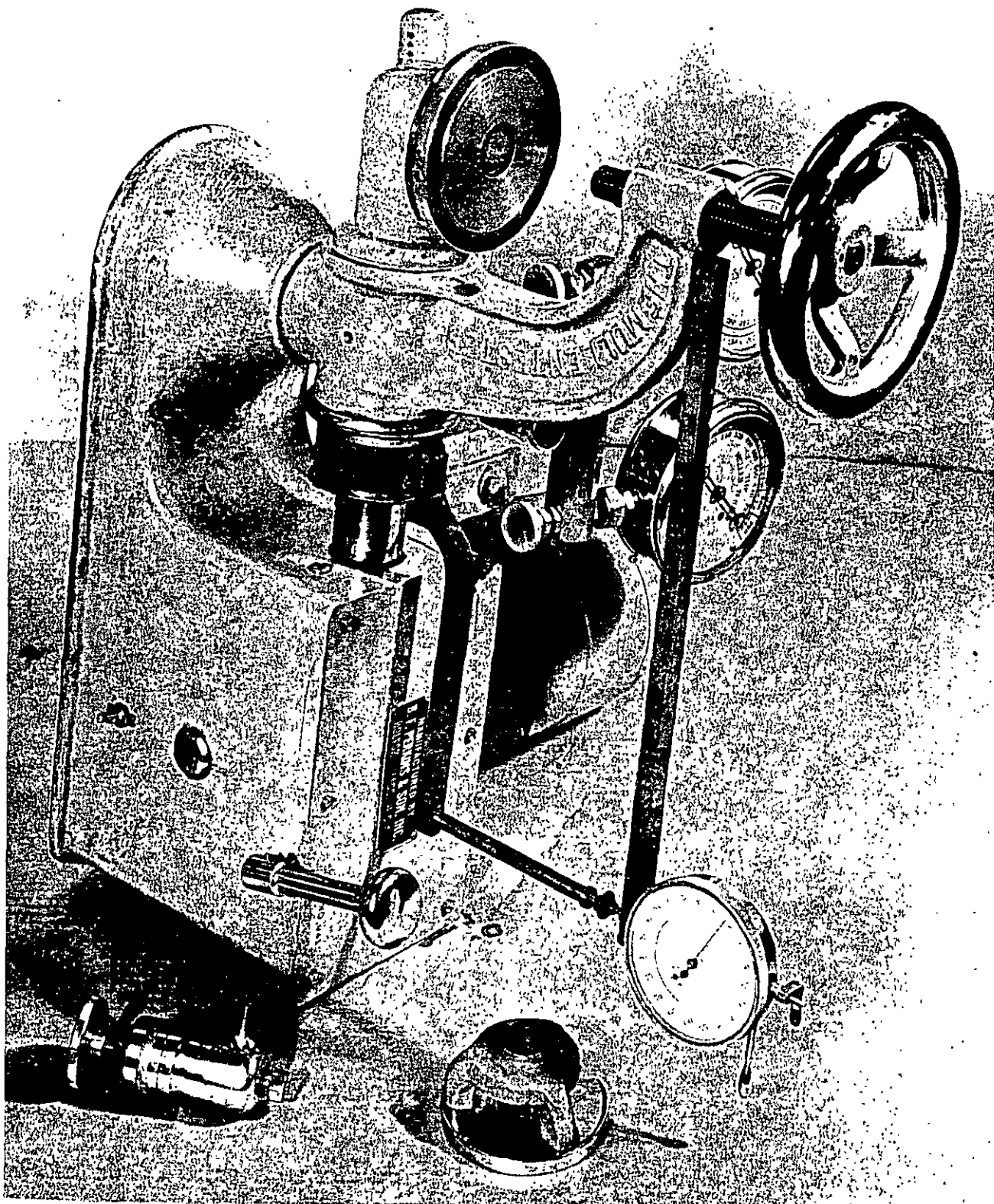


Figure 11. Tester Tipped on End to Remove Air

the tester. [Note: Before tipping hydraulic clamp testers on end or side, the vent in the hydraulic oil reservoir should be plugged.]

GAGE CALIBRATION

Two types of pressure indicating gages are commonly used on bursting strength testers: The "release-button" or lever maximum indicating gages and "lazy-hand" indicating gages. Gages of each type are illustrated in Fig. 12-14; gages of either type made by other manufacturers may differ in detail from those illustrated. In the Ashton release-button gage (Fig. 12), the Bourdon tube (A) has an "L"-shaped lever (B) attached to it which engages pin (D) on the gear sector (G) so that the sector may be pulled in only one direction. When the pressure is released, the lever (B) no longer contacts the pin (D) and the gear sector (G) remains in the maximum position until returned to zero by means of the push button (C) on the side of the gage housing. The adjustment (F) regulates the limit to which the push button (C) may be moved in so that the needle is returned to zero and not beyond. The gear sector (G), in turn, engages a central pinion (H) to which the gage needle (not shown) is attached. A tension spring (I) presses against the pinion shaft (H) to introduce sufficient friction to prevent the needle from "overrunning" when it is released by the lever (B). E and J are calibration adjustments for the gear sector and lever, respectively.

Another style of maximum reading gage in current use is the Star-Martin lever-return type shown in Fig. 13. This gage incorporates some of the main features of both the release-button and lazy-hand type gages. The Bourdon tube (A) is directly linked by arm (B) to the sector (C). This sector has a stiff wire arm (D) attached which is bent downward to engage gear sector (E) so that the gear sector may be pulled in only one direction. When the pressure is

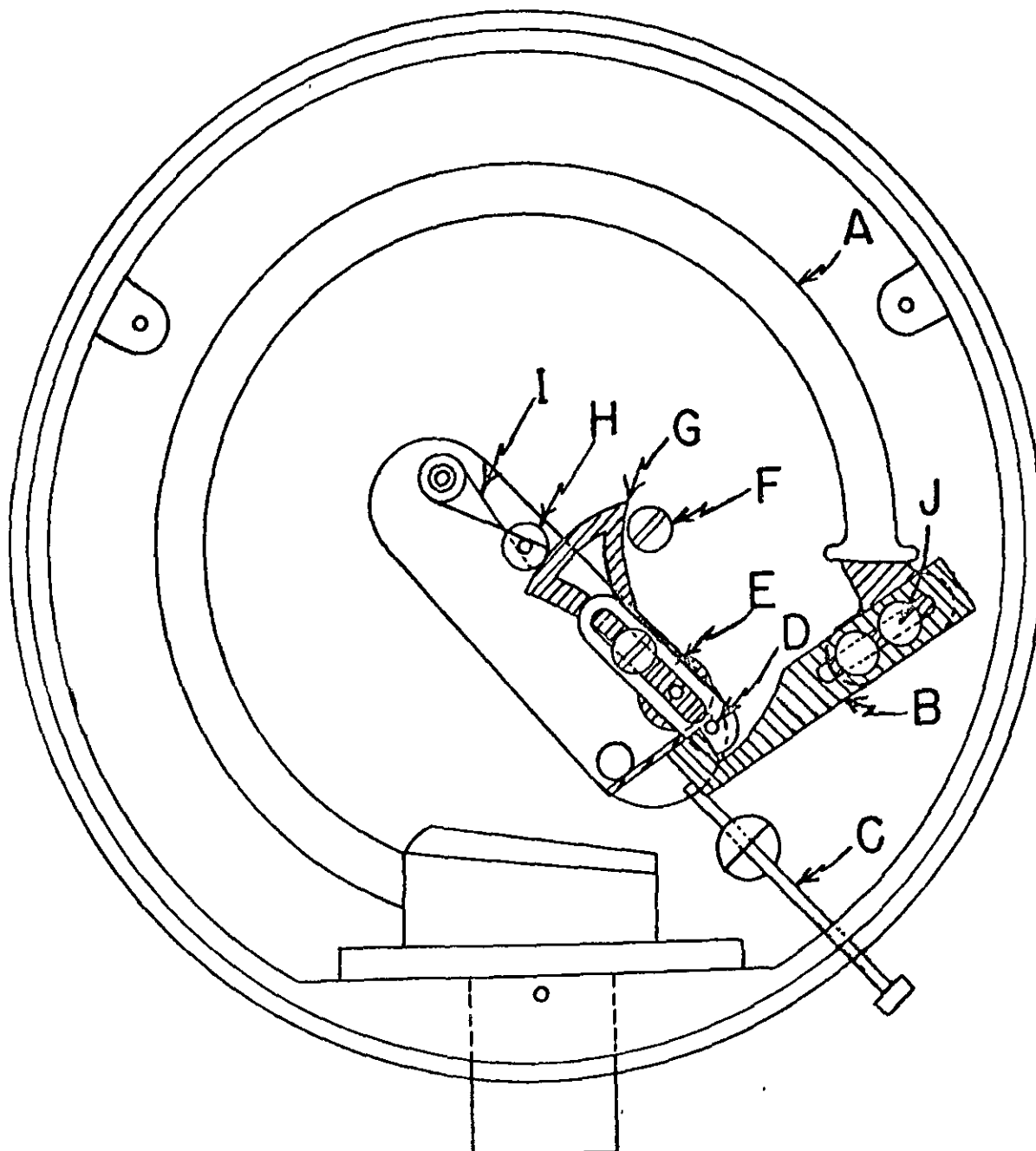


Figure 12. Ashton Maximum Indicating Gage [Ref. (33)]

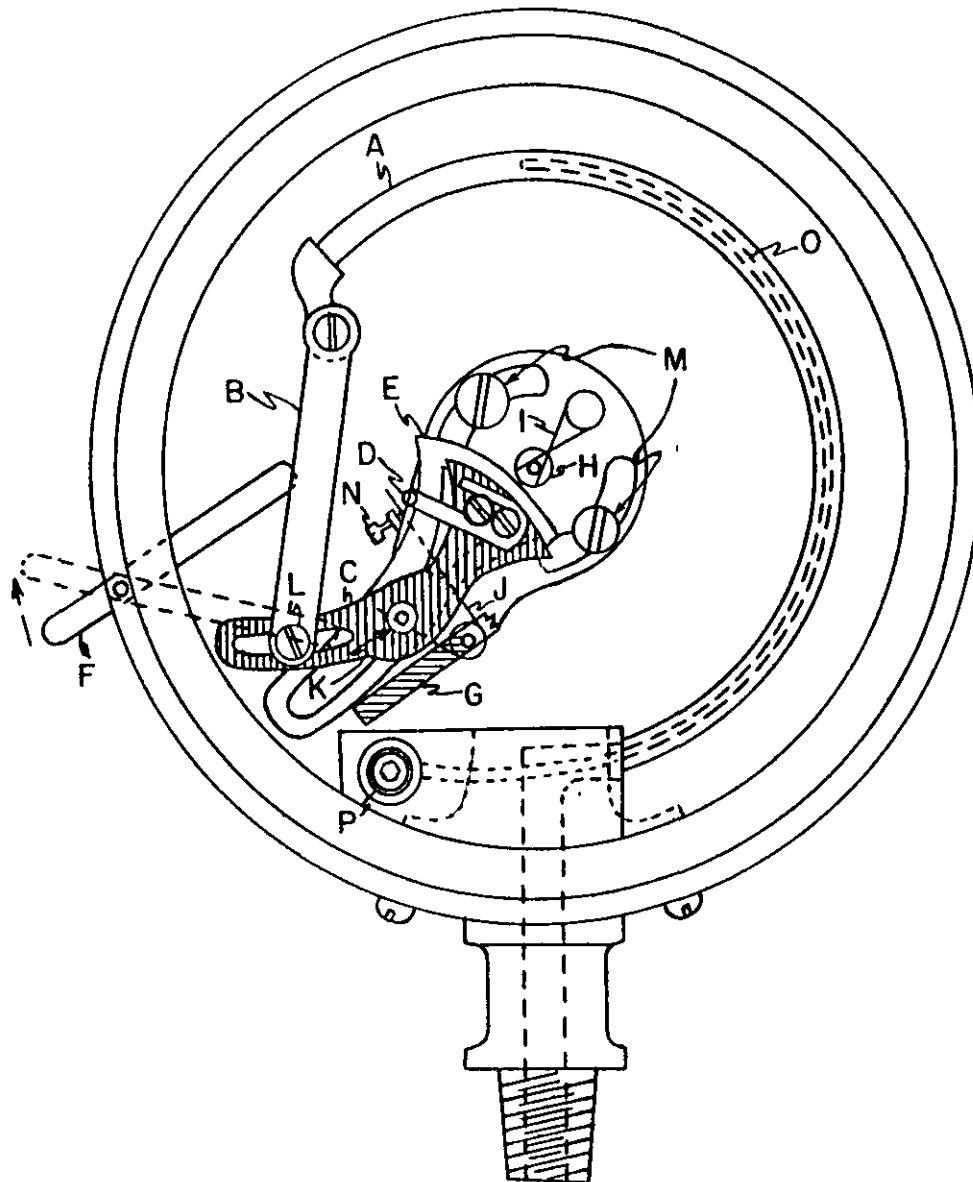


Figure 13. Star-Martin Lever-Return Maximum Indicating Gage

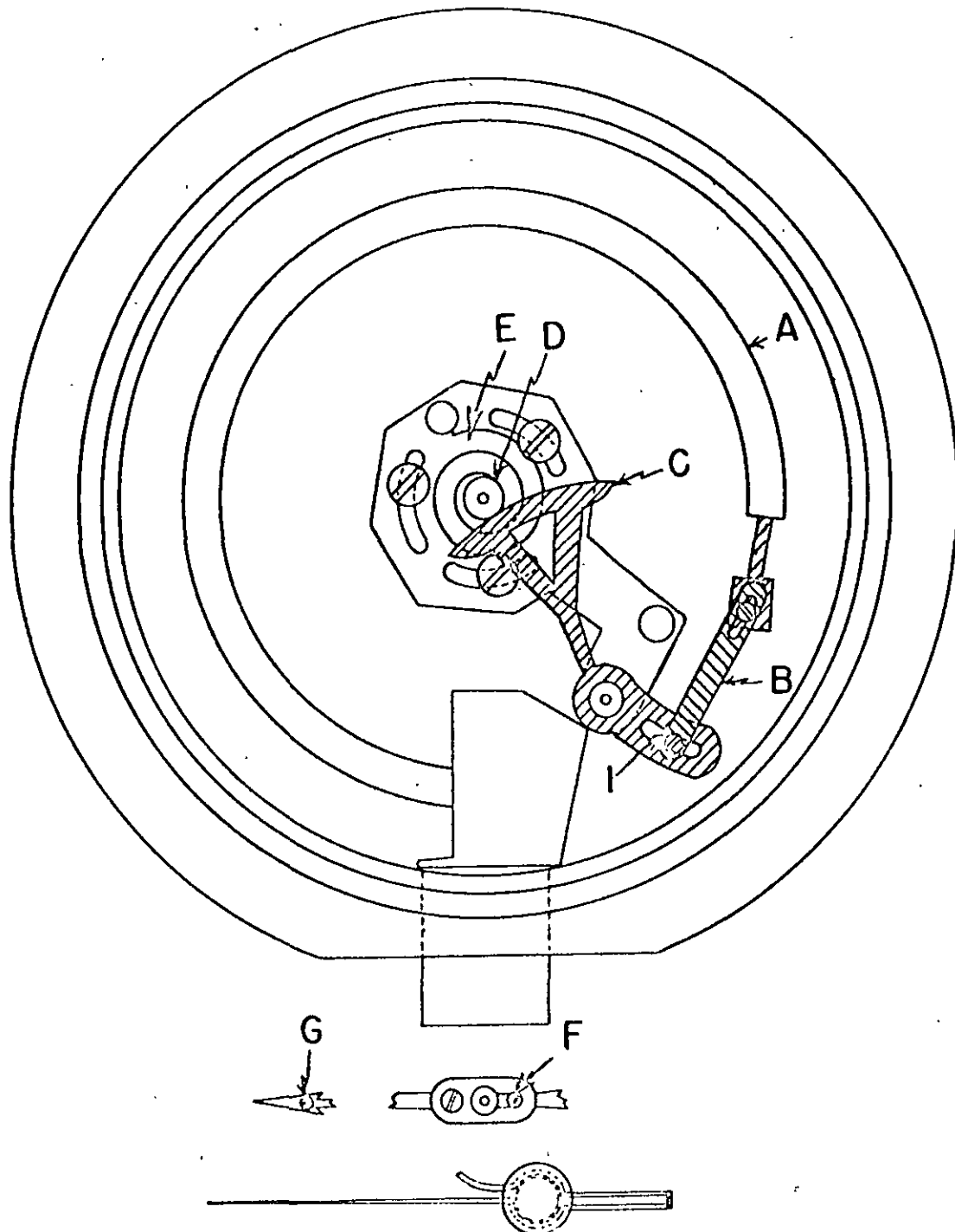


Figure 14. "Lazy-hand" Indicating Gage [Ref. (33)]

released the wire arm (D) no longer contacts gear sector (E) and the latter remains in the maximum position until returned to zero by means of the lever (F) on the side of the gage housing. The adjustment (G) regulates the limit to which the lever (F) may move the gear sector (E) so that the gage needle is returned to zero and not beyond. The gear sector (E), in turn, engages a control pinion (H) to which the gage needle, not shown, is attached. A tension spring (I) presses against the pinion shaft (H) to introduce sufficient friction to prevent the needle from overrunning when the pressure to the gage is abruptly released. Another tension spring (J) presses against the gear sector pinion shaft (K) to introduce sufficient friction to prevent the gear sector (E) from overrunning when it is released by the wire arm (D). (L) and (M) are the two calibration adjustments for the gage, (L) for the lever arm adjustment, and (M) for the angle of pull on the gear sector. Set screw (N) is the adjustment for the gear sector (E) friction, whereas the adjustment to the tension spring (I) is made by bending sufficiently to obtain the correct pressure.

This type of gage is generally equipped with a means of bleeding air out of the Bourdon tube. A capillary tube (O) is inside Bourdon tube (A) and exits at set screw (P) near the gage base. The capillary tube (O), being open at its end inside the Bourdon tube (A), allows air and glycerin to be removed from the gage by loosening set screw (P) and forcing fresh glycerin through the gage nipple (Q) into the Bourdon tube. When all air has been removed, tightening of set screw (P) again seals the system.

In the Clapp lazy-hand gage, as shown in Fig. 14, the Bourdon tube (A) is directly linked by the arm (B) to the gear sector (C). In this type of gage, the central pinion may rotate in either direction as the pressure in the Bourdon tube varies. The maximum gage reading is indicated by means of an auxiliary

lazy-hand which is pushed to its maximum position by a pin (G) on the gage needle. A knob extending through the center of the gage glass is turned to return the lazy-hand to its starting position. The lazy-hand is attached to this knob by means of a wire clip which may be bent to increase or decrease the friction which holds the hand at its maximum position. There is danger with this type of arrangement that the lazy-hand, because of its inertia, may coast beyond the maximum position. On the other hand, if the friction holding the lazy-hand is too great, the energy required to move the indicating assembly may become excessive. The Clapp gage has a needle adjustment (F), as indicated in the figure, which may be used for adjusting the needle to zero. D is the pinion which carries the needle. E and I are the two calibration adjustments for the gage.

All air in the gage Bourdon tube must be removed and replaced by glycerin to minimize flow of liquid through the gage manifold. This may be accomplished most easily by evacuating the gage, as shown in Fig. 15. A vacuum pump is connected to a small vessel about 1/3 filled with glycerin. Two tubes are inserted into the vessel, one extending almost to the bottom and the other extending just inside the stopper. The latter is connected to the vacuum pump, whereas the tube extending to the bottom is connected to the gage Bourdon tube. The vacuum pump is turned on and the vessel tipped just enough to uncover the tube connected to the gage. This will insure a minimum of back pressure while drawing the air from the gage. A high vacuum level (low absolute pressure) is desirable (42). Evacuation is continued for several minutes after the glycerin in the vessel appears to "boil." The vessel is then tipped until the tube leading to the gage is well immersed in the glycerin and air then is slowly admitted into the vessel. This will force glycerin into the gage Bourdon tube. If the air has been completely removed from the Bourdon tube, a minimum of glycerin will be pushed out of it upon reevacuating the system.

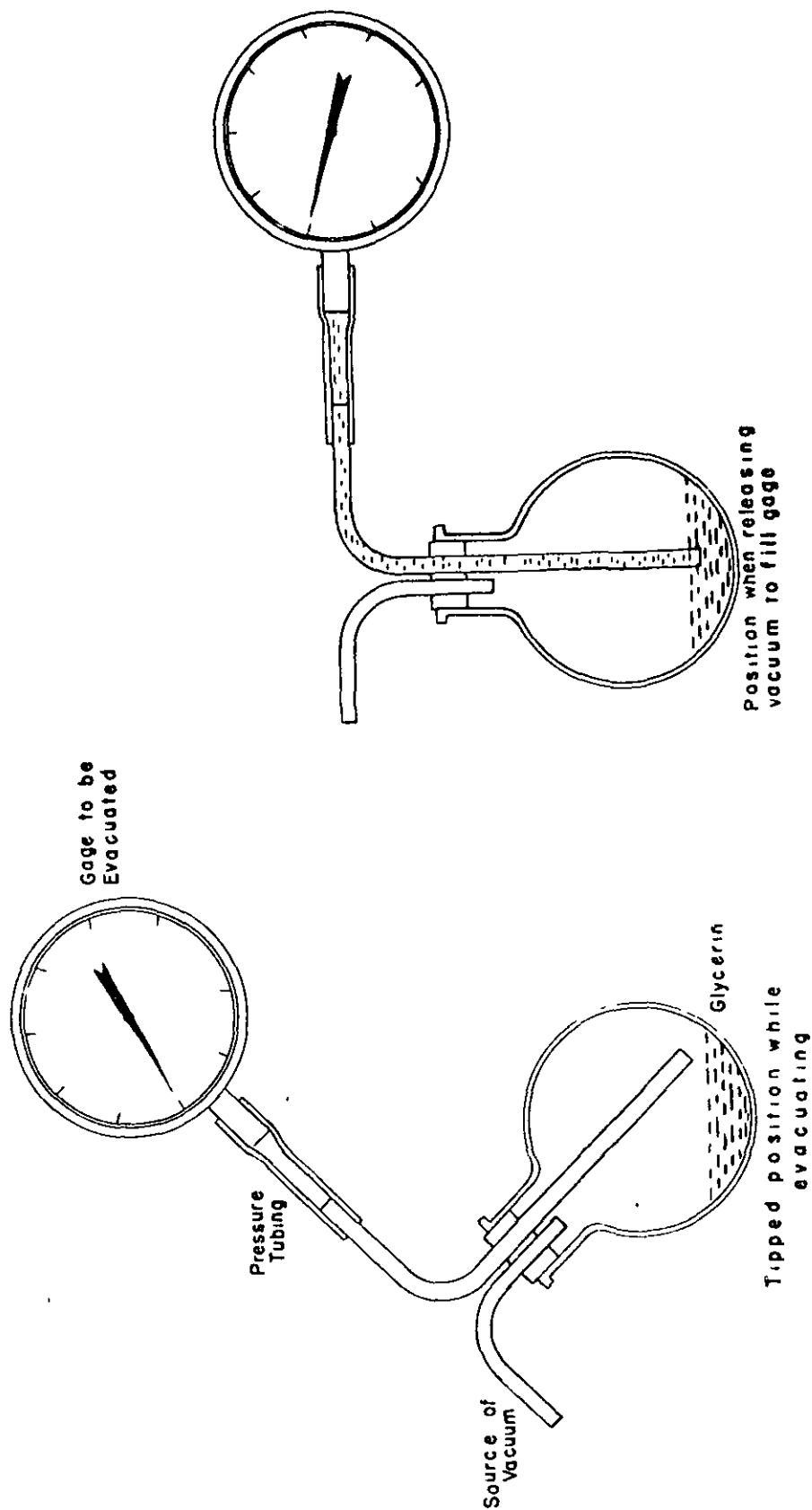


Figure 15. Gage Evacuation [Ref. (33)]

As mentioned previously, some gages are available with a bleeder mounted inside the Bourdon tube which may be used to bleed off the air instead of removing it by the vacuum procedure described.

Several devices have been used to calibrate gages for the bursting strength tester. Of these devices, only the deadweight tester appears to have the accuracy and range needed for calibrating gages used in testing paperboard and box materials. Because there are a number of models available, only a general description of the fundamental requirements will be given. The deadweight tester shall consist of a glycerin system (so that no oil can possibly be transferred to the bursting strength tester through the gage) so arranged that the gage to be calibrated may be attached without leakage, with a piston or plunger of known area fitted to a carefully lapped cylinder in such a manner that friction is at a minimum and leakage of glycerin past the piston is at a minimum, and a glycerin reservoir such that additional glycerin may be introduced into the system when needed. Calibrated weights shall be provided which may be placed on the piston to transmit known pressures in pounds per square inch.

Because the rate of pressure application in a bursting strength tester is approximately logarithmic in form, it is difficult to duplicate this rate of pressure increase with a deadweight tester. Investigations have shown that the loading rate at the moment of burst has the greatest influence on bursting strength values. Therefore, it has been found advisable to adjust the rate of loading during calibration of the gage in such a manner that the gage needle will travel at approximately the same rate during calibration as it does during the later stage of a bursting strength determination (before rupture occurs). This loading speed may be reproducibly controlled by introducing a needle valve between the glycerin system of the deadweight tester and the gage to be calibrated

(Fig. 16 and 17). This needle valve may be of 1/4-inch pipe size fitted with a short nipple to screw into the deadweight tester and may be of brass, bronze, or stainless steel. It may be adjusted so that, when the gage needle is at zero and the full scale load is suddenly applied, the needle moves at the same speed as on the bursting strength tester prior to rupture. If a stopwatch is available, the valve may be adjusted until the needle moves through the scale range in approximately 0.75 sec.

The following calibration procedure is recommended for all gages used with bursting strength testers:

1. Check the deadweight tester to make sure that its fluid system is free of air. This can be done conveniently by raising the piston off its seat by means of the crank while the gage valve is closed. Press down firmly on the piston. The piston should feel solid — that is, there should be only negligible movement. If the piston feels "spongy" — that is, there is appreciable movement — the tester probably contains air. Air may be removed by pumping air-free glycerin through the tester.

2. Connect the gage to the deadweight tester (a gage should always be connected in such a manner that it is calibrated in the same position as it is to be used) and, after opening the gage valve, repeat the preceding step. If air is now detected, it may be in the gage. As mentioned previously, the air may be removed from the Bourdon tube by attaching the gage to a source of vacuum through a trap filled with glycerin or whatever fluid is used in the gage, or by using the bleeder tube in gages so equipped.

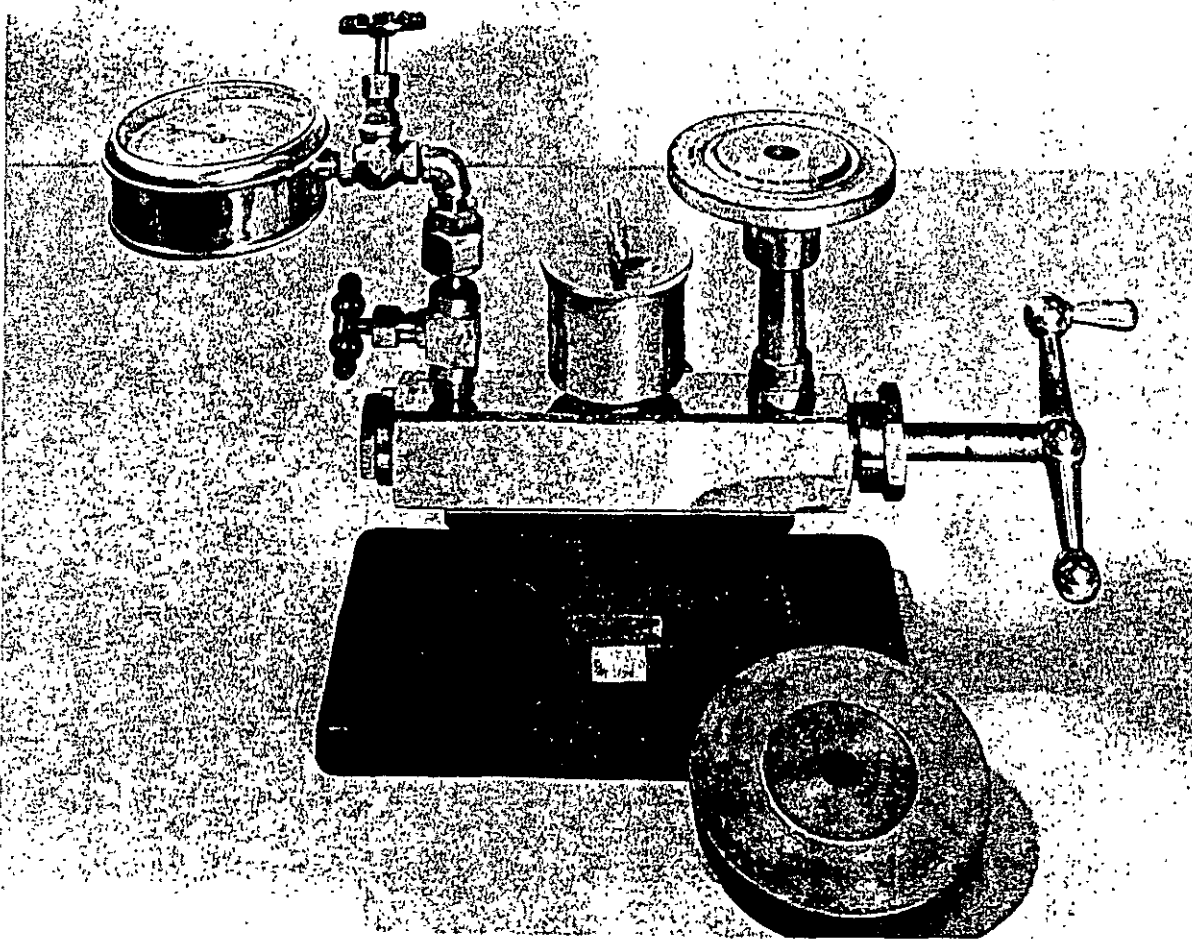


Figure 16. Deadweight Tester with Auxiliary Needle Valve Installed [Ref. (33)]

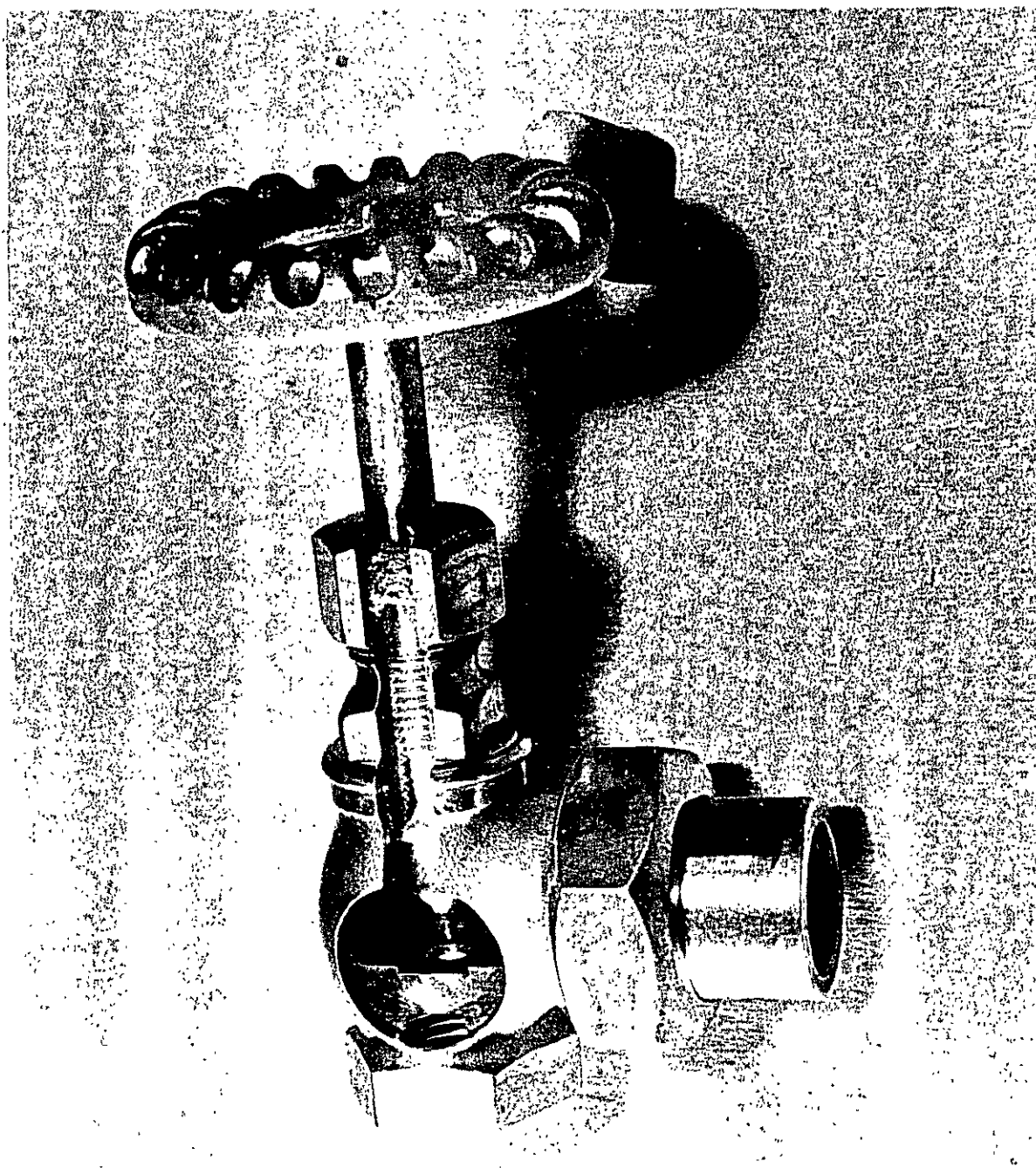


Figure 17. Demonstration Needle Valve Showing Construction Details [Ref. (33)]

3. The torque friction of the gage needle should be checked for uniformity. As the result of considerable study of this point, The Institute of Paper Chemistry has adopted the following method (see Fig. 18) for the checking of release-type gages:

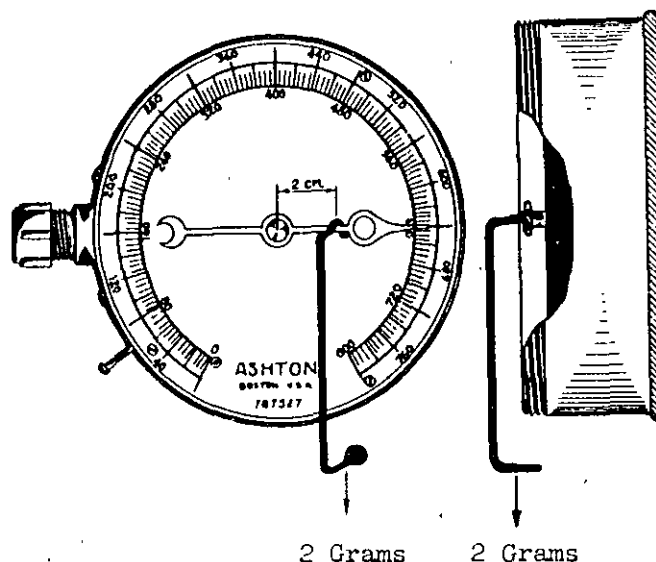


Figure 18. Method of Checking Torque Friction [Ref. (33)]

The desired spring tension is one which requires a 4 gram-centimeter torque on the needle to move it. This may be measured by means of a hook weighing 2 grams which is hung on the gage needle at a distance of 2 centimeters from the handshaft. The friction torque is checked with the gage in a vertical position and the needle in a horizontal position. The hook is attached at the specified location and the case of the gage is gently tapped. If the needle just moves in a smooth manner, the needle friction torque is considered satisfactory. Sometimes it may be found that there are tight and loose spots where the gage needle will either stop or move rapidly. To eliminate this erratic movement, it is necessary to dismantle the gage, carefully clean the parts, and polish all bearing surfaces, including the spring that bears against the handshaft. When this is done, it should be possible to obtain uniform friction throughout the entire movement of the needle.

4. Connect the gage to the deadweight tester through a needle valve.

Both the deadweight tester and the gage should be free of air as determined by Points 1 and 2 above. Adjust the needle valve so that the gage hand moves slowly across the gage when calibrating weights corresponding to the full capacity of the gage are on the piston. The movement of the gage hand is observed. The gage hand should move smoothly; otherwise, the gage should be disassembled, cleaned and adjusted.

5. Adjust the needle valve until the gage hand moves to full-scale reading in about three-fourths of a second. Then proceed to calibrate the gage, selecting weights to cover the complete scale of the gage. The weights are added to the piston and given a spin so that friction is minimized. The piston should be about an inch above its lowest position. The gage hand should be returned to zero after each determination. With the weights spinning, the gage valve is opened and the gage reading recorded. It is recommended that a graph of the deviations of the observed gage readings from the applied pressure be plotted against the applied pressure. The graphic presentation facilitates the detection of calibration errors and the identification of the cause of such errors.

6. The deviation of the observed readings from the applied pressure should not exceed 0.5% of the full-scale pressure as prescribed in TAPPI Methods T 807 and T 810. If the deviations exceed these limitations, the gage must be adjusted. For research work, a tolerance of 0.5% of the applied pressure, or 1/2-scale division, whichever is greater, is recommended. The tolerance lines may be plotted on the same graph paper as the gage calibration to determine when the gage needs adjustment.

7. Detection and correction of different types of gage errors (see Fig. 19):

A. If the gage consistently reads an equal number of pounds high or low (Fig. 19, Type A), remove the needle by means of a needle puller and replace it in its correct position. This is done most easily by placing weights equal to about one-half scale readings on the dead-weight piston, opening the valve, and then placing the needle to give this value on the gage. When the needle is in its correct position, set it firmly by means of the punch in the deadweight kit.

B. If the gage shows increasing or decreasing errors (Fig. 19, Type B), it indicates that the leverage through the gear sector is incorrect and must be changed. Remove the gage needle and the dial. The adjustable arm on the gear sector which rotates the handshaft can be moved in or out by loosening the clamping screws. Shortening the arm will increase the scale spread, whereas lengthening the arm will decrease the spread.

C. For the Ashton-type gage, the calibration line may generally be straightened by changing the length of the connection between the Bourdon tube and the gear sector. If the curve exhibits a maximum value (Fig. 19, Type C), the connection should be lengthened; if the curve exhibits a minimum value (Fig. 19, Type C'), the connection should be shortened. If this type of gage error cannot be eliminated by changing the length of the connection, the bearing surface of the link is probably worn so that it is no longer a straight edge, and the part should be resurfaced or replaced. In the Clapp or

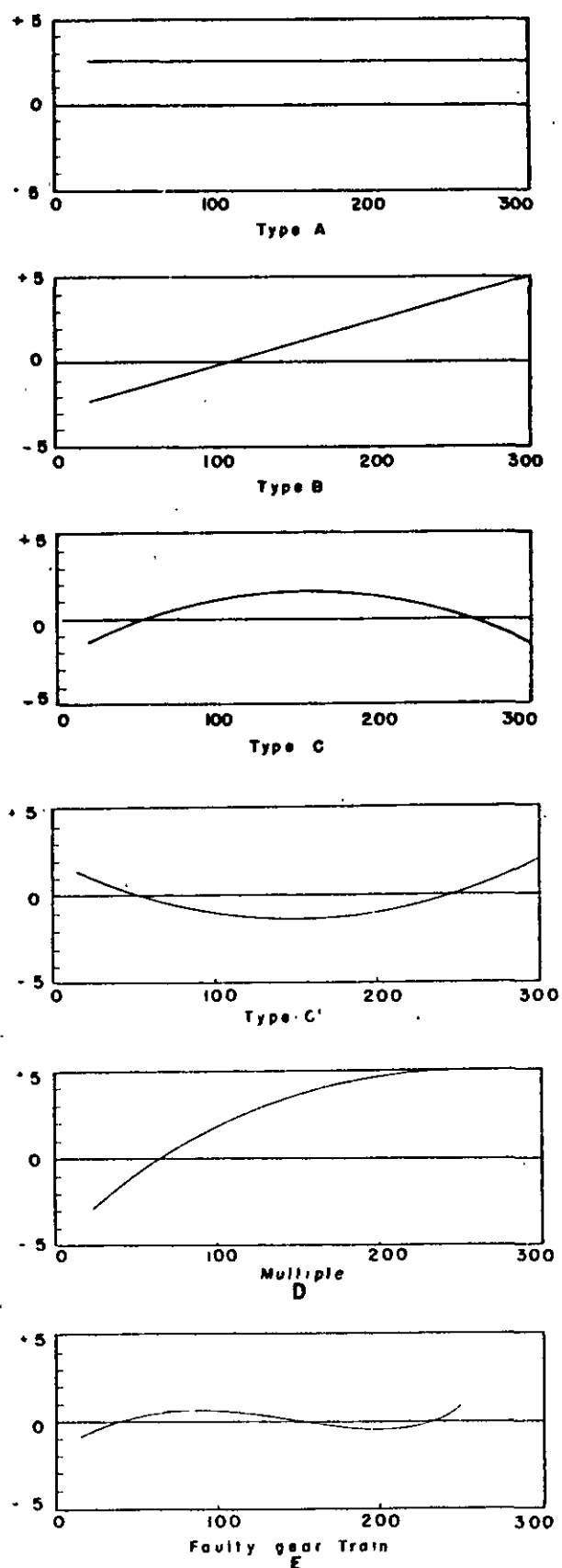


Figure 19. Various Types of Cage Errors [Ref. (33)]

Star-Martin gages, the gear sector assembly may be rotated to obtain the correct line of pull.

D. Erratic variations along the scale (Fig. 19, Type E) may be the result of a faulty gear train.

a. Check the needle shaft to see if it is bent. Careless removal of the gage needle may bend this shaft and cause errors.

b. The sector shaft in rare cases may be bent.

c. Dirt or burs in the gear sector or needle pinion are a common cause for the errors of inconsistent magnitude illustrated in Fig. 19, Type E. The dirt or burs may be removed by brushing with a toothbrush dipped in a solvent such as kerosene or carbon tetrachloride.

d. The linkage screws may be loose. If so, they should be tightened.

e. The Bourdon tube may be strained beyond its permissible pressure range. It is better to obtain a replacement Bourdon tube, inasmuch as it is seldom possible to correct a Bourdon tube strained beyond its elastic limit.

f. The spring tension on the pointer shaft may be uneven. The parts should be polished and adjusted to give the proper torque (4-gram centimeters).

g. The bearing face of the L-shaped lever may be uneven. This should be straight and smooth.

If the gage is out of calibration and requires adjustment, it is possible for any number of the above types of errors to be present.

For example, in the multiple-type error illustrated in Fig. 19,
Type D, corrections of Type A, B, and C will be required.

As alternatives to the above procedure for gage calibration, the methods
suggested in References (39,40) may be used.

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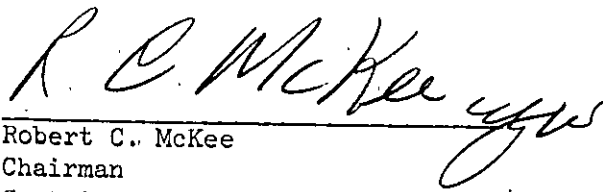
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