Calibration and Adjustment of Bursting Strength Testers

Because the bursting strength tester is widely used by mills and laboratories for testing and control of board and components, it is highly desirable to have the testers give comparable readings with each other. Frequently this is not the case. Even in the same mill testers may not give the same bursting strength values on identical stock. No well defined methods have been given in the literature or even by the tester manufacturers to accomplish this. As a result of extensive work at The Institute of Paper Chemistry, it has been found possible to set up a calibration procedure which will enable testers to be adjusted to give more comparable bursting strength values for identical stock.

Calibration procedure has been broken down into two main divisions: The tester itself and the pressure indicating gages...

I. The Bursting Strength Tester

The pumping speed of the tester may be checked by attaching a 50 cc. burette in place of one of the gages by means of a rubber tube. (Figure 1) The burette 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, a good average may be obtained. Care should be taken that enough time is taken between trials to permit the glycerin to drain...
from the burette or abnormally high apparent pumping speeds will be given. The proposed pumping speed is given as 170 ± 15 cc. per minute; however, it is found to be as high as 194 cc per minute in some testers. It has been observed in speed of loading tests that approximately 35 cc/min. change in pumping speed at 180 cc/min. can give a 1% change in bursting strength values.

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 in the gage lines. As the pressure increases, the air is compressed permitting glycerin to flow. Because there is resistance to glycerin flow by friction in the gage lines and valves, glycerin may flow more readily into one gage than into another, thereby transmitting the pressure more readily to one gage. This will cause lower readings in the second gage. Experiments in which water has been substituted for glycerin have shown that water will give slightly different readings than glycerin. This may be explained by the difference in flow resistance between the two liquids when air is present. If air is removed, there can be a minimum of flow and therefore a minimum of resistance. Air is best removed by pumping clean, air free, glycerin through the hydraulic system. The glycerin may be freed of air by placing it in a sturdy vessel and evacuating it. Air bubbles will be seen to form. When the vapor pressure of glycerin has been reached, the glycerin will tend to foam up. At this point the glycerin can be considered air free and ready for use. The gages are removed from the tester and the tester is tipped forward, as shown in
Figure 2. While in this position, the gage valves are opened and the tester started. Running the tester in this position will push 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 Figure 3, 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 again the chamber is filled with glycerin while retracting the piston. If care has been taken, all air should now be out of the tester.

The type of diaphragm used in the tester may influence the readings obtained. It has been found desirable to select diaphragms which give a pressure of between 40 and 45 p.s.i. when extended 1.8 centimeters above the lower platen. When diaphragms are to be changed, make sure that the control lever has been thrown into reverse and has returned automatically to neutral. The clamp handwheel is turned down tight to enable easy removal of the diaphragm nut by means of a special spanner wrench. Before the diaphragm nut has been completely removed, whirl the clamp handwheel upward and remove the demountable tripod. The diaphragm nut and lower platen may then be easily removed. Before inserting a new diaphragm, fill the chamber...
with air free glycerin to the top of the saucer-like depression so that it is even with the clamping ridges. These ridges must be kept clean and dry to minimize capillary leakage past them. If glycerin spills, wash 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 Figure 4) the diaphragm into place starting from the rear of the surface and rolling it forward so that no air is trapped. The lever plate 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. If the demountable tripod is replaced and the handwheel screwed down tight, the tightening of the diaphragm nut may be facilitated. 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 no glycerin gun is available, it will be necessary to add glycerin through the filling reservoir which has been capped by a knurled nut (Figure 5) seated and lapped to prevent leakage. 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.

Diaphragm height may be checked by means of a U shaped gage constructed so that its inner height is 1.8 cm and of width enough to completely clear the diaphragm as it comes up. (Figure 6) Diaphragm height may be adjusted on the new Model A Mullen tester by means of an adjustable
collar at the left end of the clutch throw-out shaft. (Figure 5) Moving this collar to the left will increase the height while moving it to the right will decrease the height. It should be adjusted so that when the operating lever is thrown to the raise position the lever will be moved back to the neutral position when the diaphragm height is 1.8 cm. At this point, the diaphragm pressure should be between 40 and 45 p.s.i. If the pressure is below 40 p.s.i., the diaphragm should be changed. If above 45 p.s.i. on a new diaphragm, the pressure can sometimes be brought down within range by flexing the diaphragm with repeated burst cycles. However, the tester should not be used for bursting strength tests during this period. If it is not possible to bring the maximum pressure down to 45 p.s.i. another diaphragm should be tried. Thickness of the diaphragm rubber does not serve as a reliable means for the selection of proper pressure ranges. Care should be taken when adjusting the pumping stop screws that they are not set so that the piston nut will contact its screw stud (which keeps the piston from rotating). (Figure 5) If this occurs, damage to the tester may result.

The old type Model A mullen tester stroke may be adjusted by means of a screw at the extreme right end of the gear cabinet. (Figure 7) The three screws holding the guide plate in place should be removed; when the guide plate is removed, a screw with cross pin will be noted. This screw may be turned in or out to adjust the stroke. When trying after adjusting, make sure the guide plate is replaced so that the screw will not be turned.

Platen condition may be checked by placing a sheet of filter paper over the lower platen then placing a sheet of carbon paper face down on top of the paper. The upper platen is then held so 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. (Fig. 5)
If the platens are in good condition, a uniform print of the entire platen surface will be made. Frequently it will be found that the lower platen has been strained so that only the central portion will print. 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 Allen set screw in the center of the yoke assembly which contacts the cylinder and then rotating the cylinder in the proper direction and relocking the set screw. It may sometimes be necessary to loosen the cylinder nut also before the cylinder can be rotated.

Lateral alignment of the platens should be checked to make sure 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. If the two platen holes are not concentric, adjustment should be made by rotation or by the addition of shims between the cylinder and the yoke assembly.

Platen aperture size should be 1.245" ± .005" with the edges of the hole relieved of sharpness (.025" radius). If the hole edges are sharp enough to cause "cutting" of the specimens, the bursting strength values will be lowered appreciably.

Because clamping pressure may greatly influence bursting strength on combined board, it is highly desirable to have a means for determining this clamping pressure. Report 1 of Testing, Bursting Strength dated February 1, 1947, describes a simple and highly effective means for determination of clamping pressure together with a description of its calibration method. Clamping devices such as a torque wrench on the clamping screw appear to be unsuitable due to the uncertainty of the friction on the screw thread.
II. Pressure Indicating Gages

Two types of pressure indicating gages are commonly used on bursting strength testers. The Ashton maximum indicating gage (Figure 8) and the Clapp "lazy hand" indicating gage (Figure 9). In general, their calibration and use are similar.

All air in the gage bourdon tube must be removed and replaced by glycerin to minimize flow of liquid through the gage manifolding. This may most easily be accomplished by evacuating the gage, as shown in Figure 6. A vacuum pump is connected to a small vessel about 1/3 filled with glycerin. Two tubes are connected 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 while 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. 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 is completely out of the bourdon tube, a minimum of glycerin will be pushed out of it upon re-evacuating the system.

Several devices have been used to calibrate gages for the bursting strength tester. Of these devices, only the dead-weight tester appears to have the accuracy and range needed for gages used in testing fiberboard. Since there are a number of models available, only a general description of
the fundamental requirements will be given. The dead-weight 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. It shall be provided 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. Calibrated weights shall be provided which may be placed on the piston to transmit known pressures in pounds per square inch. A glycerin reservoir shall be provided such that additional glycerin may be introduced into the system when needed.

Because the rate of pressure application in a bursting strength tester is approximately logarithmic in form, it is difficult to duplicate the rate of pressure increase with a dead-weight tester. Experience has shown that the loading rate at the moment of burst has the greatest influence on bursting strength values. It has, therefore, been found desirable to adjust the linear loading rate of the dead-weight tester to approximately the same speed as the maximum obtained on the bursting strength tester. This loading speed may be reproducibly controlled by introducing a needle valve between the glycerin system of the dead-weight tester and the gage to be calibrated. (Figures 10 and 11) This needle valve may be of 1/4 inch pipe size fitted with a short nipple to screw into the dead-weight tester and may be of brass, bronze or stainless steel. It may be adjusted so that when the gage needle is at zero and about 3/4 of full scale load is suddenly applied, the needle moves at the same speed as on the bursting strength tester prior to burst. If a stop watch is available, the valve may be adjusted until the needle moves through 3/4 of scale range in approximately one second.
The dead-weight tester should be completely free of air when it is used so that movement of the weights is minimized. This is readily accomplished by pumping air free glycerin through the tester taking special care that no air is trapped in the needle valve. The presence of air may be checked by closing the needle valve and applying a weight to the piston. If the piston moves, air is present and must be removed by pumping glycerin through the system while tipping the tester. When the gage to be calibrated is attached, the tester may be again checked by opening the needle valve and noting whether any movement occurs when sufficient weight is used to move the gage needle through full scale.

The pressure is now removed from the gage, the needle returned to zero, and the needle valve closed. Weight equivalent to full scale of the gage is now placed on the piston, the piston rotated to minimize friction, and the needle valve opened just enough to cause the gage needle to move slowly over the scale (10 p.s.i. per second or slower). If the needle moves smoothly, the gage is in condition to be calibrated. If the needle moves in jerks or shows tight or loose spots, the gage should not be calibrated until it has been cleaned or repaired. (See section on gage repair.)

Gage calibration points are selected as 20, 40, 60, 80, 100% of full scale readings. On 0-300 p.s.i. gages it is customary to calibrate at 50 p.s.i. intervals. The gage must be attached to the dead-weight tester so that it is in the same position as it is used on the bursting strength testers. Many gages do not have the moving parts of the gage properly counterbalanced so that calibration may not be the same as the gage occupies different positions.
When the needle valve has been adjusted to give the proper speed of loading the pressure is removed in the glycerin system and the gage needle returned to zero. If the dead-weight tester has a regular gage valve in the line this may be closed while the proper weights are placed on the piston (which should be about one inch off its seat). This gage valve should then be "snapped" open while the weights are spinning to allow the glycerin to flow through the needle valve and apply pressure in the gage. If the dead-weight tester has no gage valve, the piston should be held up by hand while adding weights and then releasing it while spinning the weights. The position of the gage needle may then be observed. Care should be taken that the tester is not jarred while the weights are being released or the needle may be moved higher on the scale than would ordinarily occur.

Deviation from actual pressure should then be plotted against true pressure on graph paper. This is important since it is only by plotting these points that the shape of the curve may be determined and the type of error observed. These points are plotted for the entire scale range.

Three basic types of gage error are recognized. Type A error: gage deviation forming a straight line parallel to the zero deviation axis. Type B error: gage deviations forming a straight line but at an angle with the zero deviation axis. Type C error: gage deviations forming a smooth curve—convex or concave (Figure 12). When gage calibration and adjustment are complete, deviations should be plotted in the same manner but with the addition of divergent straight lines starting at zero deviation and 0 p.s.i. and passing through points representing 1% of scale readings, e.g., at 300 p.s.i. the lines will pass through points of ±3 p.s.i. deviation. If the calibration curve falls inside these divergent straight lines, the gage may be considered
satisfactory for use on a bursting strength tester. For precise work it may be desirable to keep this correction curve posted in a prominent spot near the tester so that corrections may be made to observed gage readings.

Gage Repair

1. Correcting Type A gage error.

This type of error indicates that the gage needle is incorrectly placed on the hand shaft. Remove gage needle with a needle puller (DO NOT PRY OFF WITH A SCREW DRIVER OR PULL OFF WITH THE HANDS - THE SHAFT MAY BE BENT OR DAMAGED). Replace needle in correct position and fasten in place with a suitable punch. The needle may most easily be positioned by removing it, loading the gage to 50% of full scale and, without disturbing the gage, gently place the needle back on the hand shaft pressing it finger tight. Make several pressure determinations to prove its correctness and then stake in place. On the Clapp gage an eccentric screw is provided on the hand which may be rotated to shift the hand with relation to the hand shaft.

2. Correcting Type B gage error.

This type of error indicates that the adjustable arm on the gear sector is of incorrect length. It may be lengthened to correct for an ascending graphic line or shortened to correct for a descending line. The gage needle must be removed and then the gage dial to make this adjustment.

3. Correcting Type C gage error.

This type of error indicates that the link connecting the bourdon tube to the gear sector makes the wrong angle with the gear sector. On the Ashton type gage this link consists of an "L" shaped hook which may be lengthened or shortened by means of two clamping screws at the end of the
bourdon tube. On the Clapp gage three screws will be noted at the center of the gage case. When these are loosened, the entire central indicating mechanism may be rotated to change the angle between the link and the gear sector. In theory this link must be pulling along a tangent to the arc of the gear sector pin. In other words a line passing through the gear sector pivot and pin will be at right angles to a line passing through the gear sector pin and the point of attachment of the link on the bourdon tube.

In general, the link should be shortened to correct for a concave curve (in the Clapp gage rotate mechanism clockwise) or lengthened to correct for a convex curve. This is not an infallible rule, however.

4. Irregular gage errors.

These errors are usually caused by dirt or irregular friction of the moving part of the gage. This requires disassembly and cleaning of the gage.

5. Cleaning and overhaul of gages.

Gages should be overhauled only by skilled personnel who have the proper tools and equipment.

Gage mechanism should be disconnected from the bourdon tube and removed from the case of the gage. The hairspring on the handshaft of the Clapp gage should be carefully unpinned before removing the plates from the mechanism. The Ashton gage does not have a hairspring to unpin and the upper plate may be removed without harm. If the plates are discolored, they may be cleaned by dipping in petroleum ether until free of grease or oil and then washing in ammonium oleate solution, dipping the grease free plates in ammonium hydroxide or by polishing with rouge on a chamois skin and
rewashing. The pivot holes are then pegged out with pagwood (orange wood) by sharpening a stick the size of a match stick to a point, inserting it in the pivot hole, and twirling it. As often as it comes out dirty it is resharpened to a fresh surface and the process repeated until it comes out clean. The holes are then inspected for signs of wear. After the plates have been washed and dried, they should not be touched with the bare hands but handled by means of clean paper. The handshaft is scrubbed with a toothbrush using clean petroleum ether, dried and examined by means of a magnifying glass. The pinion teeth must be clean with no evidence of burs and the pivots must be round and of a high polish. If they are rough or dull they may be polished by placing them in a drill press or jewelers lathe and lapping the surface with a small flat surface of boxwood to which rouge with a very small amount of oil has been added. When they are mirror bright they may be washed and set aside for reassembly. They are checked at this time for bend and if bent, straightened. Care should be taken with the Ashton gage handshaft that the points of contact with the friction spring are also polished.

The gear sector should be washed and examined under a magnifying glass for burrs on the gear teeth. If present, these must be removed and the teeth polished by buffing with a very fine wire brush or a toothbrush with M302 emery flour. It is very important that these teeth be smooth and free of burrs. The brushing strokes should be parallel with the teeth and proceed from the teeth toward the pivots. The pivots may then be polished as described for the handshaft. The gear sector is then washed and carefully dried.

In the Clapp gage, the bourdon tube link is then washed and the
holes pegged out until clean. The two screws which act as pivots are then washed, dried, and tried in these holes. If they are loose examine the link holes for signs of wear and if worn replace with a new link. There should be no burrs on the pivot screws which may cause binding. If present they should be polished off.

On the Ashton gage the "L" shaped lever should be examined to make sure the hook which contacts the pin in the gear sector is smooth, straight and free of dents or burs. If not, this must also be polished as must the pin which contacts it. The friction spring which contacts the handshaft should be polished at the points where it contacts the handshaft.

Check the bourdon tube for signs of leakage. If the inside of the gage case appears to have drops of liquid in it, leaks in the bourdon tube should be inspected. If these leaks occur at the soldered joints, they may be resoldered. If the leaks are in the tube itself, the tube must be replaced.

The mechanism may now be assembled but without attaching the springs. A light pressure is placed against the handshaft and then the gear sector is rotated by means of the pegwood or a clean pencil to test for even friction and uniform meshing of the gears. Frequently it will be found that the plate pivot holes have been worn so that even, smooth meshing of the gears does not take place. If this is the case, the holes must be bushed or the plates replaced. When the friction is satisfactorily low, the springs may be attached and a clean needle dipped into sperm oil and touched to the pivots. Do not use too much oil. Too little is far better than too much. Do not oil the gear teeth. Replace mechanism in gage case after
having cleaned the inside of the case and recalibrate the gage. The friction spring on the Ashton gage should be adjusted until a torque on the handshaft of 4 gram centimeters will just barely turn it when the gage case is tapped. This friction should be uniform throughout the range of needle movement. On the Clapp gage the lazy hand friction should be adjusted to this torque after polishing the contacting surfaces of the friction members of the lazy hand.

If a gage is not placed into service immediately after calibration it should be capped so that air cannot enter the bourdon tube.
Top View of Old Model Mullen Tester Gear Box

Stroke Adjusting Screw

Figure 7
FACTORS AFFECTING BURSTING STRENGTH TESTS

1. The Effect of Diaphragm Pressure:

The bursting strength of paper or paper board is the pressure differential across a sheet at the moment of failure (bursting), when the pressure is transmitted through a circular orifice on one side of the sheet, causing the test specimen to extend freely into the circular hole of an annular clamp employed to hold the sheet against the orifice. Two instruments are currently employed in testing the bursting strength of fiberboard -- the Jumbo Mullen tester and the Cady tester. In both these instruments, the pressure is transmitted from a hydraulic system through a rubber diaphragm to the test specimen. The observed gage reading measures the pressure within the hydraulic system. The actual bursting strength of the test specimen is the gage reading minus the pressure exerted by the extended rubber diaphragm. In view of the fact that the diaphragm pressure is dependent upon the amount of stretch before rupture of each specimen, as well as the thickness, age, and composition of the diaphragm itself, the diaphragm pressure frequently varies from one specimen to another. Therefore, no correction factor is possible and the observed gage reading is generally reported directly as the bursting strength reading. The term "points", instead of "pounds per square inch", is preferred for the reading because of this diaphragm effect.

A pressure recording gage assembly was built to enable a study of pressure phenomena to be made. A new Clapp gage was dismantled, a hole cut in the side of the gage housing, and a small, light weight mirror attached to the
Bourdon tube. A light source and a rotating camera were placed about one foot from the gage mirror so that an image from the light source would be reflected by the mirror and fall on a slit in the rotating camera. Figure 1 illustrates the operation of the instrument schematically. The fluid pressure to be measured is connected to the Bourdon tube. A change in the fluid pressure will cause the Bourdon tube to change conformation. This in turn changes the position of the mirror. Light from the source at the top right is focused by a lens on the mirror. A second lens is so arranged as to focus the reflected beam on the cylinder of the slit camera. Change in pressure moves the mirror, causing the light beam on the slit camera to move correspondingly but greatly magnified. The camera is equipped with a shutter to close the camera slot when exposure is not desired.

The drum within the slit camera is rotated by an electric motor from below at a speed of approximately one revolution in six seconds. To insure accurate time indications, a means was provided to give a time scale to the pressure record. A light source on the left was arranged behind a slotted shield and the shield mounted on a slender steel support so that the shield could be set in motion and continue to oscillate for some time. The shield was adjusted to oscillate 2.5 times a second permitting the light source, slot in the shield and camera slot to be in line five times a second. This gave a vertical exposure five times a second resulting in vertical timing lines on the pressure record.

To provide a calibration on each record made, a strip of clear acetate was placed over the camera slot with horizontal lines in drawing ink at the determined elevation (as obtained by the dead weight tester) for each ten pounds. The 100 pound marks were heavier to make identification easier.
These inked lines on the acetate cause a break in the reflected light beam and thus a break or blank space in the pressure record line as the beam crossed each ten pound calibration. This calibration would stay with the record regardless of the shrinkage of the paper. The natural frequency of vibration of the Bourdon tube was found to be 173 vibrations per second indicating sufficiently rapid response for bursting strength tests. This recording camera was connected to a Mullen tester so that pictorial records could be made of bursting pressure against time.

Since the pressure of the diaphragm has a much greater effect (on a percentage basis) for specimens of low bursting strength, diaphragm comparisons were made only with low bursting strength specimens. Curves were obtained for diaphragm pressure only, using a standard diaphragm and a special diaphragm made from rubber dental dam. Maximum pressure for the standard diaphragm (full extension of 1.8 cm.) was found to be 40 p.s.i. (This pressure will vary with different diaphragms and different extension points.) The maximum pressure observed for the rubber dental dam was 5 p.s.i. at 1.8 cm. extension. If a specimen is inserted and burst, it is possible to determine the time for burst by means of the recording gage. This time may be compared with similar time for the diaphragm alone and the diaphragm pressure for this point determined. As an alternate method, a double exposure could be made—first of the burst of the specimen, and then, starting at the same initial point, obtain a record of diaphragm only. If this test is repeated using dental dam on similar specimens, it is possible to observe the change due to resistance of the diaphragms.
Sample: 

<table>
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<th>Sample</th>
<th>0.0025&quot;</th>
<th>20-lb.</th>
<th>24-lb.</th>
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<td>11.0</td>
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<td>rag sheet</td>
<td>65.3</td>
<td>30.7</td>
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Average Mullen with standard diaphragm | 82.7 | 41.7 | 51.0
Average diaphragm pressure at burst point | 17.4 | 11.0 | 11.0
Difference | 65.3 | 30.7 | 40.0

Average Mullen with dental dam diaphragm | 66.3 | 32.5 | 45.5
Average diaphragm pressure at burst point | 1.0  | 1.0  | 1.0
Difference | 65.3 | 31.5 | 44.5

Diaphragm pressure pictures were also obtained for diaphragms which gave about 25 points for 1.8 cm extension. The effective pressure at the bursting point of combined board was compared with the average pressure for the 40 point diaphragm. The differences were found to be:

40 point diaphragm at 2.8 seconds = 26.3 p.s.i.
25 point diaphragm at 2.8 seconds = 18.5 p.s.i.

It can be seen from this that the type of diaphragm used has a definite effect on pressures indicated by bursting strength tester gages.

II. The Effect of Loading Rate on Bursting Strength Values:

It has long been known that bursting strength values may be "shaded" high or low in hand operated bursting strength testers by increasing or decreasing the speed of rotation of the handwheel. The speed of rotation of the handwheel as specified by TAPPI T403 is 120 revolutions per minute and should pump glycerin at the rate of 75 cc. per minute at this speed. The motor driven bursting strength tester was introduced to minimize the effect of pumping speed. Since some hand operated bursting strength testers are still in use, experiments were conducted to determine the magnitude of differences in bursting strength due to speed of loading changes.

The drive motor was removed from a Model A Mullen tester and remounted to the rear of the tester in such a fashion that a belt drive could be used.
Rotation speed of the Mullen tester shaft was checked by means of a General Radio Strobotac to insure constant values. Aluminum foil was burst at speeds of 81, 875, 1130, 1788 (standard speed), 2710 and 3420 R.P.M.; corresponding to pumping speeds of 8.3, 90, 116, 184, 278 and 352 cubic centimeters per minute. Higher speeds were not used because of the strain on the gear box and the tendency to overheat.

<table>
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<th>Foils</th>
<th>91 R.P.M.</th>
<th>875 R.P.M.</th>
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<th>1788 R.P.M.</th>
<th>2710 R.P.M.</th>
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<td>165.4</td>
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<td>172.5*</td>
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*estimated Double thickness of 0.0045" Foil

Jute stock was also burst at speeds of 745, 1248, 1788, 2770, and 3560 R.P.M. corresponding to pumping speeds of 76.5, 129, 184, 285, 367 cc/min.

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<th>2770</th>
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<td>126550</td>
<td>124.5</td>
<td>128.4</td>
<td>131.9</td>
<td>134.1</td>
<td>134.2</td>
</tr>
</tbody>
</table>

Twenty specimens of each sample of foil and fifty specimens of each sample of jute were used with a clamping pressure of 60 p.s.i. Figure 2 and 3.

This test was repeated on a Model C Mullen tester using 0.0025" foil. Clamping pressure used was equal to a total load of 800 pounds. Twenty specimens were used for each test.

1. Standard pumping speed with motor drive shaft running at 1788 R.P.M.

which completed test in 3.4 seconds, gave average Mullen value of 69.3 points.
2. Pumping speed reduced by operating motor drive shaft at 155 R.P.M. which completed test in 36 seconds and gave an average Mullen value of 66.4.

III. The Effect of Air in the Hydraulic System of Bursting Strength Testers.

TAPPI Standards T403 m44 Note 1 states: "Since the testing rate of both types of instruments may be changed by air trapped in them, care should be exercised to exclude air when diaphragm or gages are changed."

If it were possible to completely remove air from all portions of the hydraulic system (including the gage Bourdon tube) and a steel plate were placed over the rubber diaphragm to prevent its movement, pressure would rise from zero to maximum in a very small fraction of a second when the tester is started. By calculation, the presence of only 1.4 cc. of air would cause the pressure to rise from 0 to 100 p.s.i. in approximately one second, while 10 cc. of air would increase the time for this 100 p.s.i. pressure rise to approximately seven seconds. (Calculated from the equation:

\[
\frac{V_0 (P_1 - P_0)}{SP_1} = T
\]

Where \( V_0 \) = initial volume of air in cc.'s.
\( P_0 \) = initial pressure (atmospheric is approximately 15 p.s.i.)
\( P_1 \) = final pressure (gage reading plus atmospheric pressure.)
\( S \) = pumping speed in cc. per second = 1.25
\( T \) = time in seconds.

(Using TAPPI pumping speed of 75 cc/min)

From these calculations it would appear very important to remove all air from the hydraulic system or to work with some known air volume. A number of opinions have been expressed in the literature as to the effect of air on bursting strength values. Some operators have introduced air and determined the increase in time for a burst. From this increase in time they have stated that bursting strength values would be
lowered. Other operators have made careful observations of actual bursting strength with and without air present and were unable to come to any conclusion as to the effect of air. The recording gage attached to a bursting strength tester makes an ideal instrument for the determination of the effect of air on bursting strength values.

Specimens of combined board were tested using the recording camera on a Mullen tester in which extreme care had been used to remove all air from the hydraulic system. It was found possible to burst the board in 2.2 seconds. "2 cc. of air" were then introduced by removing 2 cc. of glycerin, allowing this space to be replaced by air and then re-introducing the glycerin at another point. The diaphragm height was again adjusted to just touch a straight edge placed across the lower platen. The time for burst of the same sample was increased to 2.7 seconds. "4 cc. of air" increased the time to 3.1 seconds. This appears to indicate an equivalent pumping speed of 142.5 cc/min. for the 2 cc. of air test and 130.6 cc/min for the 4 cc. of air.

However, the bursting strength did not decrease in value as would be indicated by the loading speed tests. The test was repeated using 60 specimens per group. Group one was tested with no air in the Mullen tester and simultaneous pictorial record obtained every seven specimens. Group two was tested with the addition of as much air as would still permit bursts. Again simultaneous pictorial records were obtained every seven specimens. The length of time for this burst was obtained and the drive motor speed changed to give the same time for burst with no air in the Mullen tester. Group three was tested at this slow pumping speed.
Average bursting pressure with no air and standard speed = 183.5
Average bursting pressure with no air and slow speed = 180.5
Average bursting pressure with air and standard speed = 200.6

Average time for burst at standard speed (no air) = 2.5 sec.
Average time for burst at slow speed (no air) = 5.8 sec.
Average time for burst at standard speed (air) = 5.1 sec.

The slope of the pressure/time curves were plotted on semi-log paper to compare the types of slope. Since the point of greatest interest is the speed just prior to burst, all plots were made starting at 180 p.s.i. as 4 seconds and plotting back to 10 p.s.i. The average curves are shown in figure 4. It will be noted that the slope of the three lines representing average values are different. Variation in loading speed should then cause the curve with air to give bursting values between the other two. However, the value appeared to be higher than either one. Careful examination of the points for each curve indicate a similarity between the two "no air" curves. Both curves start at a steeper slope than the average line and then flatted out to a lesser slope. With the curve for air, the curve will be seen to be just the reverse where it starts out at lesser slope and becomes greater near its peak. This indicates that the rate of loading at the bursting point is practically unchanged with air in the system from that at the same pumping speed but no air present.

A test was also made on a Model C Mullen tester using 0.0025" foil. Twenty specimens were burst at standard pumping speed with no air present. Average Mullen value 69.3 points. Test required 2.4 seconds.

Speed reduced to 155 R.P.M. with no air -- test completed in 36 seconds and gave an average Mullen value of 66.4 points.

A large quantity of air was introduced which necessitated pumping glycerin into the system to raise the initial pressure to 10 p.s.i. before a burst cycle could be made. Time of burst from 10 p.s.i. to the bursting point
averaged 12 seconds and gave an average burst of 69.0 points.

Again the difference due to air was not as great as would be the case if speed of loading were uniformly changed.

Experiments were tried with no air in the system and varying the height of the diaphragm from its standard position. Lowering the diaphragm had the effect of increasing the time required for a complete burst cycle, however the slope of the curve for pressure rise was unchanged. If the time is taken between 20 p.s.i. and the final burst, it will be found to be similar for low and high diaphragms. Therefore, with no air, it is to be expected that height of diaphragm has negligible effect on Mullen point values. It should be kept in mind however, that the diaphragm should not be much above the surface of the platen or initial distortion of the specimen will result. This may give incorrect readings. If the level is much below the platen, care should be taken that enough glycerin is pumped into the diaphragm to reliably burst all specimens.

IV. Gage Inertia:

It has been suspected that a bursting strength tester gage needle may tend to throw beyond the actual value when testing combined board or solid fiber with a burst of over 200 p.s.i. because of the rapid movement of the needle over this portion of the gage. Data obtained in the speed of loading study indicate that any inertia effect must be due to the gage itself rather than the bursting strength tester.

A study was made with the use of the pressure recording gage on a dead weight tester of the maximum rate of loading that could be obtained before gage inertia would cause incorrect values to be indicated. Two types of
maximum indicating gages were used in the study, an Ashton gage which uses a single pointer and which indicates only maximum pressure and a Clapp gage which uses a second "lazy hand" to indicate maximum pressures.

The recording gage and a 0 to 300 p.s.i. Ashton gage were connected to the deadweight tester with a needle valve in the hydraulic line between the gages and the deadweight tester gage valve. In this way, it was possible to reproducibly control the pressure loading speed of the gages. The needle valve was adjusted until rapid opening of the gage valve would cause needle throw of the Ashton gage with a 250 p.s.i. load in the deadweight tester. The recording gage gave a picture of rapid pressure rise from zero to 250 p.s.i. with no indication that the pressure rose above the 250 pound mark. The Ashton gage needle was moved off scale (over 300 p.s.i.). The needle valve was then closed by successive small steps until the Ashton gage gave correct values. The test was repeated using a Clapp "lazy hand" type of gage. Critical response time was taken as the fastest loading speed at which the gage needle would still indicate correct pressure readings. It is expressed as the number of seconds per 100 p.s.i. of load.

Ashton gage = 0.127 sec/100 p.s.i.
Clapp gage = 0.507 sec/100 p.s.i.
Recording gage = 0.080 sec/100 p.s.i.

(Note: The recording gage could have followed a faster loading rate than this if a special quick opening valve had been used.)

Since normal loading in a bursting strength tester represents a rapidly changing curve of pressure against time (essentially logarithmic), the slope of the curve of loading as recorded by the camera gage was measured at its steepest position and used for comparative purposes.
Recording gage = 89.0°
Ashton gage = 86.5°
Clapp gage = 79.0°

Model A Mullen tester = 73.5°
Cady Bursting strength tester = 74.0°

(Note: While the Cady tester shows a slightly steeper slope at maximum pressure rise, the entire bursting cycle requires about 7.5 seconds as compared to the Mullen tester which will complete its burst in about 2.5 seconds).

It may be seen from the above data that Ashton type gages appear to be capable of following more rapid pressure rises than Clapp "lazy hand" type gages. "Needle throw" resulting from inertia of the moving parts of a gage (such as gear sector) may be controlled to some extent by adjustment of the friction spring on the maximum indicating needle. This friction adjustment has been found to be quite critical. As the tension is increased, slow rates of loading will cause the needle to lag below true readings (the Bourdon tube cannot exert enough force to overcome this friction) while rapid loading rates may cause needle throw due to inertia of the moving parts when lower spring tension is used.

It is obvious that under these conditions, the scale range of the gage becomes an important factor in indicating correct bursting strength pressures. For example, if bursting a specimen of 100 points, a gage with full scale of 120 p.s.i. will necessitate very rapid needle movement over the latter part of the bursting pressure which will probably cause the gage to indicate high values due to inertia. If a gage with a scale range up to 300 p.s.i. were used for indicating this burst, the gage needle would be moving more slowly and would be less effected by inertia. If a still larger scale range were used, the needle would be moved slowly enough that needle friction might become a factor and cause
the gage to read low. It has been recognized that these conditions exist and recommendations have appeared which state that a gage shall be selected such that bursts will be indicated in the range of 10% to 75% of full scale values.
Schematic Diagram
Pressure Recorder

Figure 1
CALIBRATION OF BURSTING STRENGTH PRESSURE GAUGES

The accuracy of pressure gages on bursting strength testers may influence bursting strength results more than any other factor. Recognition of this has resulted in emphasis on frequent calibration of gages so that at no time should a tester be used with a faulty gage. It has often been noticed that two testers may not agree with each other even when every effort is made to keep all factors equal. Many times the gage itself is responsible for these variations. It has been found that many operators have their own method for calibrating the maximum pressure indicating gages with the result that gages calibrated by one person may not agree with gages calibrated by others. With this in mind, a study was made in an effort to set up a better defined procedure so that closer agreement between gages may be obtained.

Up to the present time there appears to be no detailed method in the literature for calibration of maximum pressure indicating gages as used on bursting strength testers. TAPPI Standards 403 specify: "The gage shall be calibrated, while inclined at the same angle at which it is used during tests, by means of a deadweight gage tester of the piston type, or by means of a column of mercury. During calibration, the pressure shall be applied so that the travel of the needle of the gage simulates its action during the actual testing. (Note 2 -- The rate of applying the pressure in calibration can be regulated by means of the valve on the deadweight tester. The regulation is facilitated by providing the valve with a lever and stop.) Gages in frequent use should be calibrated at not less than monthly intervals. If a gage is accidently used "over capacity", it should be recalibrated before it is used again."
Loading speed on the bursting strength tester as specified by TAPPI Standards is as follows: "...This pressure shall be generated by a motor-driven piston forcing a liquid (usually glycerine) into the pressure chamber of the apparatus at the rate of 75 ml. (about 6 cubic inches) per minute. (Note 1 -- The specified rate of pressure application is attained in hand-driven instruments by turning the hand wheel 120 r.p.m.) Since the testing rate of both types of instruments may be changed by air trapped in them, care should be exercised to exclude air when diaphragms or gages are changed."

Several factors influence the bursting time in a tester. TAPPI Standards recognize the fact that presence of air will change loading speed but make no proposal for standardizing pressure rise. It if were possible to completely remove air from all portions of the hydraulic system (including the gage Bourdon tube) and a steel plate were placed over the rubber diaphragm in the tester to prevent its movement, pressure would rise from zero to maximum in a very small fraction of a second when the tester is started. The presence of only 1.4 cc. of air in the system would, by calculation, cause the pressure to rise from zero to one hundred p.s.i. in approximately one second, while 10 cc. of air would increase the time for this same pressure rise to approximately seven seconds. (Calculated from the equation:

\[
\frac{V_O (P_f - P_o)}{S P_f} = T
\]

Where
- \(V_O\) = initial volume of air in cc.'s.
- \(P_o\) = initial pressure (atmospheric pressure is approximately 15 p.s.i.)
- \(P_f\) = final pressure (gage reading plus atmospheric pressure.)
- \(S\) = pumping speed in cc. per second = 1.25
- \(T\) = time in seconds

Similarly, the stretch of the specimen burst may influence the speed of pressure
application. For example, bursting a specimen with 2% stretch may give approximately twice the speed of loading that is obtained with a specimen of 4% stretch when both rupture at the same pressure.

Two types of gage were used in this investigation. The first type was an Ashton gage which uses a single pointer and which indicates only maximum pressure. (Figure 1) In this gage the Bourdon tube (A) has an “L” shaped lever (B) attached to it which engages a pin (D) on a gear sector (G) to pull it in one direction only. When the pressure is released, the lever (B) no longer contacts the pin (D), and the gear sector (G) remains in position until returned to zero by means of a push button (C) on the side of the gage housing. The gear sector (G) in turn engages a central pinion (H) to which the gage needle is attached. A spring (I) presses against the pinion shaft (H) to introduce enough friction so that the needle will stop when the pressure is released in the Bourdon tube.

A Clapp gage (Figure 2) was the second type of gage used. This gage has a linkage arm (B) connecting the Bourdon tube (A) to the gear sector (C). In this type of gage, the central pinion may rotate in either direction as pressures in the Bourdon tube vary. 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 in 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. This type of gage may be convenient for observation of multiple pop phenomena in combined board since the gage needle pushes the lazy hand around until one layer has burst, at which time the gage
needle may fall back slightly and then, as pressure rises again, moves forward until it contacts the lazy hand again, pushing it to its highest position. In some cases the first position may be its highest position.

In the case of multiple pops of combined board or, at any time when there is rapid pressure increase, there is frequently a question as to whether the gage needle is accurately indicating the peak pressure or whether the needle is thrown beyond the true reading by inertia. Similarly, it is sometimes noted, particularly at low loading rates, that a gage needle will move irregularly giving rise to the question of whether the gage is accurately following pressure rise. Obviously, it is desirable to adjust a gage so that these inaccuracies will be minimized.

There are three generally accepted devices for calibrating fluid pressure gages, each presenting unique advantages and disadvantages.

1. Mercury Column

This device relies on pressure exerted by a vertical column of mercury and is the most accurate means for obtaining specific pressures. The main difficulties encountered with this apparatus are those of the apparatus being nonportable, very fragile, and impractical for higher pressures.

2. Dead Weight Tester (Figure 3.)

In this apparatus a known weight is applied to a piston of known area transmitting pressure through a liquid medium to the gage. The piston area must be accurately known and the piston must fit the cylinder with a minimum of friction and leakage. The values of the weights used must be accurately known. This apparatus is
relatively easy to use because it is portable. However, skill and care are required on the part of the operator.

3. **Standard Gage**

   This method employs a secondary standard (another fluid pressure gage) which itself must be calibrated by either of the first two methods before it can be used. This is by far the easiest method for use in calibrating gages; its main disadvantage lies in its use as a secondary standard.

   The dead weight tester was selected for use in this study because it is the most generally accepted apparatus for calibrating fluid pressure gages.

   Many operator techniques have been observed in the use of a dead weight tester. Among them some of the following are typical:

   1. Gage attached to the dead weight tester in horizontal position.
      
      weights placed on piston with gage valve open and screw plunger moved in until weights and piston is lifted from its seat. Piston is rotating while plunger is screwed in at a speed such that the gage needle movement approximates movement on bursting strength tester during actual testing.

   2. Gage attached to the dead weight tester in horizontal position.
      
      Gage valve closed while weights are placed on piston and piston lifted from its seat by means of the screw plunger. Weights are given a spin to insure minimum friction and valve opened slowly to allow pressure to be indicated on gage.

   3. The same as procedure 2, except that the gage valve is opened rapidly.

   4. Gage attached as before. Gage valve open and screw plunger moved in to raise piston from its seat. Piston is then held up by hand while
weights are added at which time piston is released by hand to simulate correct needle movement.

5. The same procedure as No. 4, except that piston is not held up by hand. Weights are gently laid on piston to simulate loading speed.

6. Gage placed in position as before. Gage valve open, piston about half way up on its stroke. Weights placed on piston and spun. While weights are spinning, gage needle return plunger is gently depressed several times to bring needle to correct position.

These techniques were investigated to determine the magnitude of variation to be expected when gages are calibrated by these methods. The oil in the dead weight tester was replaced by glycerine to insure a homogenous liquid between the tester and the gages.

Procedure 1.

Weights placed on piston and load applied to gage by means of the screw plunger with valve open.

(a) Gage: 120-lb. Ashton. Dead weight load = 100 p.s.i. Glycerine used in both gage and dead weight tester. Gage readings: 103, 114, 107, 120, 116, 104, 109, 119, 111, 120.

(b) It was found that the glycerine film between the piston cup and the piston of the dead weight tester caused adhesion so that the gage needle tended to move well beyond its correct position. The glycerine was removed from the tester and transformer oil substituted to minimize the adhesion. The piston cup and piston platform were kept dry to aid in reducing adhesion.
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<table>
<thead>
<tr>
<th>Weight, p.s.i.</th>
<th>Gage Reading, p.s.i.</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>50 50.5 51.0 51</td>
</tr>
<tr>
<td>90</td>
<td>92 91.5 90.5 91</td>
</tr>
</tbody>
</table>

(c) Air was introduced in the dead weight tester to minimize shock of initial lifting of weight.

<table>
<thead>
<tr>
<th>Weight, p.s.i.</th>
<th>Gage Reading, p.s.i.</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>51.0 50.5 50.5 51</td>
</tr>
<tr>
<td>90</td>
<td>91.5 90.0 90.0 91</td>
</tr>
</tbody>
</table>

Procedure 2.

Valve on gage line opened slowly after each weight was placed on piston.

300 p.s.i. Ashton Gage

<table>
<thead>
<tr>
<th>Weight, p.s.i.</th>
<th>Gage Reading, p.s.i.</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>3 2 3 2 3 3 3.5 3</td>
</tr>
<tr>
<td>25</td>
<td>22.5 22 22 22 22.5 23</td>
</tr>
<tr>
<td>50</td>
<td>48.5 48 48 48.5 48.5</td>
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<td>100</td>
<td>99 99.5 99.5 98.5 100</td>
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<td>149 149.5 149.5 147.5 150</td>
</tr>
<tr>
<td>200</td>
<td>200 200.5 200.5 197.5 201</td>
</tr>
<tr>
<td>250</td>
<td>249 249 249 246.5 249.5</td>
</tr>
<tr>
<td>300</td>
<td>298.5 298 298 296 297.5</td>
</tr>
</tbody>
</table>

Procedure 3.

Valve on gage line opened rapidly after each weight was placed on piston.

<table>
<thead>
<tr>
<th>Weight, lbs.</th>
<th>Gage Readings, p.s.i.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>3 3 3 3 3.5 3 3.5 2</td>
</tr>
<tr>
<td>25</td>
<td>22.5 22 23 23 22.5 23</td>
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<tr>
<td>50</td>
<td>48 48.5 48.5 49 48.5 50.5</td>
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<td>200.5 200.5 201 205.5 203</td>
</tr>
<tr>
<td>250</td>
<td>271 250 249.5 258.5 250</td>
</tr>
<tr>
<td>300</td>
<td>330 320 300 305 301</td>
</tr>
</tbody>
</table>

Procedure 4.

Valve on gage line left open and piston held up by hand while each weight was added; after each weight was added, the piston was released.
Weight, lbs. | Gage Readings, D. & L. |
---|---|
5 | 3.5 3.5 3.5 3.5 3.5 3.5 3.5 3 |
25 | 22.5 22.5 23 23 22.5 23 22.5 22 |
50 | 49 49 49 49 49.5 49.5 48.5 48 |
100 | 101 101.5 103 100 101 101 100 102 |
150 | 153.5 153.5 153 149.5 149.5 150.5 149.5 149.5 |
200 | 204.5 202.5 201.5 201.5 201 201 200 200 |
250 | 255.5 250.5 248 250.5 248.5 250 249 253 |
300 | 305 303 299.5 306 305 299 298.5 291 |

Procedure 5:
Value on gage line left open while weights were laid on piston.

Weight, lbs. | Gage Readings, D. & L. |
---|---|
5 | 3 3.5 3.5 3.5 3.5 4 3.5 2 |
25 | 22.5 22.5 23 23 23 23 22.5 22.5 |
50 | 48.5 48.5 49 49 49 49 48.5 48.5 |
100 | 101.5 100.5 101 100 100 101 100 99 |
150 | 150.5 150.5 152 150 150.5 150.5 150.5 149 |
200 | 201.5 201.5 202 201.5 201.5 201 201 201 |
250 | 250 250 250.5 253.5 250 249 251.5 249 |
300 | 298.5 298.5 299.5 300 299 300 298 300 |

Procedure 6:
Value on gage line left open and needle return button pressed gently several times after each weight was added.

Weight, lbs. | Gage Readings, D. & L. |
---|---|
5 | 4.5 4.5 4.5 4.5 4 4.5 4.5 3 |
25 | 23.5 24 24.5 24.5 24 23.5 23 23.5 |
50 | 49.5 50 48 50 49.5 50 49.5 49.5 |
100 | 101 101.5 101 101 101 101 100.5 100 |
150 | 151.5 151.5 150.5 150.5 150.5 151 151.5 149.5 |
200 | 203 203 201 201.5 202.5 203 202 198.5 |
250 | 251.5 251.5 251.5 251.5 252 251.5 251.5 248.5 |
300 | 300.5 300.5 300 301 300.5 300 298.5 299 |

It is evident that procedure 6 gave the most consistent gage readings; however, the loading of the gage did not correspond to the loading rate obtained during actual use. Procedure 3 was capable of giving loading rates approaching that in actual use, but data shows this method to give the most inconsistent readings.
It has been thought that hydraulic pressure surges might occur in the line when the gage valve is opened rapidly, with the gage needle indicating this surge and showing higher values than the weights would indicate. Accordingly, it became desirable to explore the type and speed of pressure rise when the gage valve was opened.

A pressure recording gage assembly was built to enable a study of pressure phenomena to be made. A new Clapp gage was dismantled, a hole cut in the side of the gage housing, and a small, light weight mirror attached to the Bourdon tube. A light source and a rotating camera were placed about one-foot from the gage mirror so that an image from the light source would be reflected by the mirror and fall on a slit in the rotating camera. Figure 4 illustrates the operation of the instrument schematically. The fluid pressure to be measured is connected to the Bourdon tube. A change in the fluid pressure will cause the Bourdon tube to change conformation. This in turn changes the position of the mirror. Light from the source at the top right is focused by a lens on the mirror. A second lens is so arranged as to focus the reflected beam on the cylinder of the slit camera. Change in pressure moves the mirror, causing the light beam on the slit camera to move correspondingly but greatly magnified. The camera is equipped with a shutter to close the camera slot when exposure is not desired.

The drum within the slit camera is rotated by an electric motor from below at a speed of approximately one revolution in six seconds. To insure accurate time indications, a means was provided to give a time scale to the pressure record. A light source on the left was arranged behind a slotted shield and the shield mounted on a slender steel support so that the shield could be set in motion and continue to oscillate for some time. The shield was
adjusted to oscillate 2.5 times a second, permitting the light source, slot in the shield and camera slot to be in line five times a second. This gave a vertical exposure five times a second resulting in vertical timing lines on the pressure record.

To provide a calibration on each record made, a strip of clear acetate was placed over the camera slot with horizontal lines in drawing ink at the determined elevation (as obtained by the dead weight tester) for each ten pounds. The 100-pound marks were heavier to make identification easier. These inked lines on the acetate cause a break in the reflected light beam and thus, a break or blank space in the pressure record line as the beam crossed each ten-pound calibration. This calibration would stay with the record regardless of the shrinkage of the paper. The natural frequency of vibration of the Bourdon tube was found to be 173 vibrations per second, indicating sufficiently rapid response for gage calibration tests.

The recording gage and an Ashton gage were connected to the dead weight tester in such fashion that the gage valve would apply the load to both gages. A weight equivalent to 250 p.s.i. was placed on the dead weight piston and the gage valve snapped open as rapidly as possible. The needle of the Ashton gage was moved off scale (over 300 p.s.i.) while the recording gage gave a picture of rapid pressure rise from zero to 250 p.s.i. with no indication that the pressure rose above the 250-pound mark.

To insure best response and minimum movement of the dead weight tester piston, the dead weight tester was flushed out with air-free glycerin. It was found that when all the air had been removed from the dead weight tester,
the gage valve closed, and the piston raised from its seat about an inch by pumping glycerin into the system by means of the screw plunger. No movement of the piston could be detected when pressure was placed on it. The recording gage and the gage to be tested were freed of air by attaching them to a vacuum pump and evacuating them to a pressure of one millimeter of mercury. Glycerin was then allowed to flow into the Bourdon tubes under atmospheric pressure to completely fill the tubes. This was repeated to ensure the removal of all air. The gages were then attached to the dead weight tester and tested for freedom of air in the hydraulic system. The piston was again raised about an inch by pumping glycerin into the system and the gage valve opened. Pressure on the piston gave less than one millimeter movement for full scale (300 p.s.i.) movement of the Ashton gage needle. The rapid loading test was then repeated to determine if the presence of air could influence gage response by its cushioning action. Again the Ashton gage needle was pushed off scale while the recording gage picture showed a rapid rise from zero to 250 p.s.i., leveling off at the 250 p.s.i. mark with no indication of vibration or pressure changes. The pressure rise from 0 to 250 p.s.i. was obtained in 0.2 seconds.

A needle valve was placed in the line between the gage valve and the gages. This valve was capable of fine adjustment so that the rate of loading when the gage valve was snapped open could be reliably reproduced. Photographic recordings were obtained at various rates of loading to determine the response characteristics of Ashton and Clapp gages. Critical response time was taken as the fastest loading speed at which the gage needle would still indicate correct pressure readings. It is expressed as the number of seconds per 100 p.s.i. of load.
Ashton gage = 0.127 sec./100 p.s.i.
Clapp gage = 0.507 sec./100 p.s.i.
Recording gage = 0.080 sec./100 p.s.i.

(Note: The recording gage could have followed a faster loading rate than this if a special quick opening valve had been used.)

Average loading speed in Model A Mullen Tester when all air is removed from hydraulic system = 0.819 sec./100 p.s.i.

Since normal loading in a bursting strength tester represents a rapidly changing curve of pressure against time (essentially logarithmic), the slope of the curve of loading as recorded by the camera gage was measured at its steepest portion and used for comparative purposes.

Recording gage = 89°
Ashton gage = 86.5°
Clapp gage = 79°
Model A Mullen Tester = 73.5°
Cady Bursting Strength Tester = 74°

(Note: While the Cady tester shows a steeper slope at maximum pressure rise, the entire bursting cycle requires about 7.5 seconds as compared to the Mullen tester which will complete its burst in 2.5 seconds.)

Representative recordings of pressure rise as obtained by the use of the recording camera are given in Figures 5, 6, and 7.

Figure 5 shows four pictures of pressure rise using a 160 p.s.i. Clapp gage on a dead weight tester. A dead weight load of 150 pounds was used. Vertical lines represent 0.2 second intervals (in some cases double lines occur because of overlapping exposure). The curve of pressure rise is interrupted at 10 p.s.i. intervals to enable pressures to be indicated. The first and second curves from the left gave gage throw of the gage needle while the last two resulted in gage needle throw.
Figure 6 shows pressure rise on a Mullen tester of jute liner stock on the left and combined board on the right. The double burst on the right is typical of combined board bursts.

Figure 7 illustrates the type of pressure rise obtained with a Cady bursting strength tester. It will be noted that the camera revolved twice before the pressure indication was completed.

It may be seen from the above data that Ashton type gages appear to be capable of following more rapid pressure rises than Clapp "lazy hand" type gages. "Needle throw" resulting from inertia of the moving parts of a gage (such as the gear sector) may be controlled to some extent by adjustment of spring tension of the friction spring on the maximum indicating needle. This friction adjustment has been found to be quite critical. As the tension is increased, slow rates of loading will cause the needle to lag below true readings (the Bourdon tube cannot exert enough force to overcome this friction) while rapid loading rates may cause needle throw due to inertia of the moving parts when lower spring tension is used.

It is obvious that under these conditions, the scale range of the gage becomes an important factor in indicating correct bursting strength pressures. For example, if bursting a specimen of 100 points, a gage with full scale of 120 p.s.i. will necessitate very rapid needle movement over the latter part of the bursting pressure which will probably cause the gage to indicate high values due to inertia. If a gage with a scale range up to 300 p.s.i. was used for indicating this burst, the gage needle would be moving more slowly and would be less effected by inertia. If a still larger scale range were used, the needle would be moved slowly enough that needle friction might become a factor and cause the gage to read low.
recognized that these conditions exist and recommendations have appeared which state that a gage shall be selected such that bursts will be indicated in the range of 10% to 75% of full scale values.

Numerous experiments on 300 p.s.i. gages indicate that the most desirable spring tension will just permit 4 gram-centimeters torque on the needle to move it. This may be measured with a weighted hook which weighs 2 grams by hanging it on the gage needle at a distance of 2 centimeters from the handshaft. The gage needle should be in the horizontal position and the gage housing gently tapped. Frequently it will be found that there are tight and loose spots where the gage needle will either stop or move rapidly. It is then necessary to disassemble the gage, carefully clean the parts, and polish all bearing surfaces—including the spring that bears against the handshaft. If this is carefully done, it will be found possible to obtain uniform friction throughout the entire movement of the needle.

Since it is impractical to duplicate the logarithmic rate of loading that occurs on the bursting strength tester by the use of the dead weight tester, it is desirable to adjust the linear loading of the dead weight tester to the speed at most rapid pressure rise on a bursting strength tester. This appears to be best accomplished by introducing an adjustable needle valve between the dead weight tester gage valve and the gage to be calibrated. The needle valve should be opened slightly so that when the gage valve is rapidly opened, the gage needle will move at the same approximate speed as obtained on a bursting strength tester. The amount of this opening should be noted and marked so that future calibrations may be made at the same speed. It has been proposed that a fixed orifice be used to obtain this speed of loading, however, several tests have indicated that the hole necessary would be too small
to be practical. This is especially true when no air is present in the hydraulic line as under these conditions there is a minimum flow of pressure transmitting fluid. The presence of air in the hydraulic system is particularly detrimental when pressures needed are high enough to necessitate the use of the small size piston (above 300 p.s.i.). When the small, high pressure piston is used, great care must be used to remove air so that the movement of the piston from zero to full pressure will be within the limit of travel set by the piston stops.

When a number of gages of one type and range are to be calibrated, a fixed orifice may be used. To overcome the disadvantages of small hole size mentioned in the previous paragraph, an expansion chamber should be used between the orifice and the gage to be calibrated. This expansion chamber may consist of a sylphon bellows and spring arranged as shown in Figure 8. In use, the chamber is filled with glycerin and attached to the dead weight tester gage valve. The gage to be tested is attached at the other end. Spring tension is adjusted to allow the dead weight piston to move about one centimeter under load when the gage valve is opened. The fixed orifice should be of such size that gage needle will move at the approximate speed obtained in a bursting strength tester. This method has been found to be very useful for gages below 300 p.s.i. pressure range.

**GAGE CALIBRATION AND ADJUSTMENT PROCEDURE**

1. Fill the Bourdon tube with glycerin as described in text.
2. Check the torque friction of gage needle for uniformity, as described in the text.
(Note: The above two steps need be done only semi-annually unless gage has been misused.)

3. Attach gage in horizontal position to air free deadweight tester containing glycerin. Needle valve is placed between gage valve and gage.

4. Place 80% full scale load on tester and open valve to allow gage needle to move slowly while the weights are spinning. If needle movement is erratic, gage mechanism must be cleaned, polished, and adjusted as in step 2.

5. Adjust needle valve to give correct gage needle speed with 80% of full scale load. Return gage needle to zero.

6. Check gage at 0, 20, 40, 60, 80, and 100% of full scale values. Weights must be spinning to minimize friction. Plot deviation from correct values on graph paper so that type of error may be determined. Return gage needle to zero for each load test.

7. Check calibration graph against the standard curves of Figure 9 to determine type of errors:

Corrections

Type 1. Gage needle is pulled from handshaft by the use of a hand puller. Replace needle to give correct reading. Make sure needle is replaced tightly.

Type 2. This type of curve indicates the linkage on the gear sector (see Figure 1-G and 2-C) is too short. If curve is opposite, linkage is too long. Loosen clamping screws and adjust, then reclamp. When the correct length adjustment is found, graph will probably show Type 1 error. Adjust as in Type 1.
Type 3. This type error is caused by the movement of lever B not being at a tangent to a circle scribed by pin D (Figure 1). Correction may be made by shifting lever B in or out on Bourdon tube A. Stop pin F must be readjusted to stop sector when pin D just touches lever B. When the Clapp type gage is used, link B must be shortened or lengthened.

Type 4. This is a composite error which may be shifted to Type 3 by changing linkage as in Type 2 error. Correction should then be made for Type 3 error.

When a gage is correctly calibrated, graphic errors should be within an error curve plotted as ± 0.25 at 10 p.s.i., ± 0.5 at 46 p.s.i., ± 1.0 at 100 p.s.i., and ± 2.0 at 200 p.s.i. For precise work, it is desirable to place the calibration curve in a prominent spot near the gage so that corrections may be readily obtained.
HIGH SPEED PRESSURE RECORDING APPARATUS

A proposal was made to purchase an instrument or if necessary to develop an instrument capable of recording hydraulic pressures. This instrument was to be used to study the pressure developed in the hydraulic system of the Mullen Tester. This application required an instrument that would be rapid in response to change in pressure. Preliminary appraisal of the problem indicated two means of approaching the problem.

The first means was to gage the pressure with an element that is sensitive electrically to pressure change. Study of this problem indicated the following would be required: 1. A pressure sensitive element, 2. An oscillograph to indicate the pressures, (Ordinary electrical meter would not respond rapidly enough.) 3. A photographic attachment to record the result produced on the oscillograph. This equipment could be purchased. However, the cost was extremely high and it would require an experienced electrical technician to operate the instrument.

The second means of recording pressures was with a mechanical pressure recorder such as is used on steam and Diesel engines to indicate pressures in the cylinders. This means was investigated and found to
be less expensive. However, its disadvantages were: 1. Limited speed of response, 2. Accuracy in doubt.

These inquiries turned up a suggested third method of solving the problem. That was to mount a small mirror on the end of the tube of a Bourdon pressure gage, removing the linkage to the indicating hand. Pressures would be indicated by a reflected light beam. The tube being free of the linkage would have a much faster response than the usual Bourdon pressure gage. This method appeared to offer the best solution at the least expense.

Figure 1 illustrates the operation of the instrument schematically. The pressure fluid to be measured is connected to the Bourdon tube. A change in the fluid pressure will cause the Bourdon tube to change conformation. This in turn changes the position of the mirror. Light from the source at the right is focused by a lens on the mirror. A second lens is so arranged as to focus the reflected beam on the cylinder of a slit camera. Change in pressure moves the mirror, causing the light cast upon the slit camera to move correspondingly. The camera is equipped with a shutter to close the camera slot when exposure is not desired.

The drum within the slit camera is rotated by an electric motor from below at a speed of one revolution in six seconds. Since it was not positive that the speed of rotation was uniform and constant, a means was provided to give a time scale to the pressure record. The light source on the left is arranged behind a slotted shield and the shield mounted on a slender steel support so that the shield can be set
in motion and it will continue to oscillate for a considerable time. The shield is adjusted to oscillate 2.5 times a second. This permits the light source, slot in the shield and camera slot to be in line 5 times a second. Thus a vertical exposure was made 5 times a second resulting in vertical lines on the pressure record.

To calibrate the pressure recorder, a static pressure gage tester was connected in the fluid line. The light beam was adjusted to be at the lower end of the camera slot at zero pressure and near the top end of the slot at the maximum pressure. An exposure was made recording pressures at ten pound intervals. It was intended that this sheet be used as a calibration rule to read the experimental records. It was found that the paper changed dimension too much to rely on this as a calibration.

To provide a calibration on each record made, a strip of clear acetate was placed over the camera slot with horizontal lines in drawing ink at the determined elevation for each ten pounds. The 100 pound marks were heavier to make identification easier. These inked lines on the acetate cause a break in the reflected light beam and thus a break or blank space in the pressure record line as the beam crosses each ten pound calibration. This calibration would stay with the record during shrinkage of the paper.

Some difficulty was encountered in eliminating air from the fluid system. The best method used was to evacuate the system with a vacuum pump and then allow the system to fill from a fluid reservoir.
Experiments were performed to determine the natural frequency of the Bourdon tube. This was determined to be 173 vibrations a second. Had the natural frequency proved to be much lower, within the range of speed we were attempting to record, the record would be unreliable. However, this is not the case. Details of this experiment are in notebook 115.

Figure 2 is a photograph of the pressure recording instrument connected to a Mullen Tester. A light shield covers the slit on the camera to permit operation in a well lighted room without fogging the sensitized paper. It was necessary to use photostat reproduction paper to have sufficient sensitivity to record properly.

Figure 3 is a sample of a record produced by this instrument.

The instrument thus developed was provided for investigation of the Mullen Tester.
Schematic Diagram
Pressure Recorder

Figure 1