THE FATIGUE BEHAVIOR OF WOOD AND PLYWOOD SUBJECTED TO REPEATED AND REVERSED BENDING STRESSES

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FOREST PRODUCTS LABORATORY
Madison 5, Wisconsin
In Cooperation with the University of Wisconsin

THE FATIGUE BEHAVIOR OF WOOD AND PLYWOOD SUBJECTED TO REPEATED AND REVERSED BENDING STRESSES[1]

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Summary

The information presented in this report is based on tests of approximately 1,100 specimens of several species of wood and several plywood constructions. Tests were made in which completely reversed stress cycles (the mean stress equal to zero) and repeated stress cycles in one direction (the mean stress equal to one-half the maximum stress) were applied. All tests were made in constant deflection, flat-plate-type fatigue machines, using cantilever-beam specimens acting as their own dynamometers.[3] The tests were conducted under controlled conditions of 75° F. and 65 percent relative humidity (approximately 12 percent moisture content in the wood) and the specimens were bivrated at a rate of 1,790 cycles per minute.

The tests to date (stress reversals or repetitions up to 50 million cycles) have not yet been carried on far enough to establish the highest unit stress that can be repeated indefinitely without failure (endurance limit). The stress-number of cycles graph (S-N) for wood does not exhibit a "knee" as do the graphs of ferrous metals.

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[1] Results here reported were obtained during 1943.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[3] In the operation of this machine the specimen is placed in position and is loaded to produce a stress equal to a predetermined percentage of the modulus of rupture as found from static-bending tests of specimens that are carefully matched to the specimen that is to be subjected to fatigue test. The machine is then adjusted to repeat or reverse the deflection caused by the load.

The endurance strength for 50 million cycles of reversed stress is approximately 27 percent of the static modulus of rupture for the species investigated (yellow birch, yellowpoplar, Sitka spruce, and Douglas-fir) whether in the form of solid wood or plywood.

The endurance strength of solid Sitka spruce and Douglas-fir at 50 million cycles of repeated stress (from 0 to a maximum stress in one direction only) is approximately 36 percent of the static modulus of rupture of the materials. The variability of wood specimens results in a scatter of test points to form a band on the S-N graph rather than a single curve.

Testing of additional species and at other moisture content values will give data that may necessitate a revision of these values. The specific values obtained are associated with the particular details of tests employed, particularly the microswitch clearance as a criterion for discontinuing the test even though complete failure of the specimen has not occurred.

Introduction

Fatigue is the deterioration of a material due to a continued repetition of stress. Repeated applications or reversals of stress will cause fatigue and ultimate fracture, and with the advent of high-speed machine and engines, the subject of fatigue became important in the use of metals. Since fatigue is the action which takes place in material only after a large number of applications of stress, it is necessarily a long-time research project. Many investigators have spent years upon this subject, for both ferrous and nonferrous materials and have published many articles upon the prevention of fatigue failures in metals and upon endurance limits of metals. These publications indicate that the effect of overstress, understress, stress combinations, corrosion, and other factors on the fatigue life of metals is being actively studied. Aircraft designers are particularly interested in fatigue since overdesign of rotating and vibrating parts and the excess weight involved can be avoided only if the fatigue properties as well as other properties of the materials are known.

Today, with the importance of wood and plywood structures in aircraft, the fatigue behavior of the material should be studied to enable the design of parts that will endure the vibrations encountered. Wood has good qualities when used correctly, particularly its ability to dampen vibrations.

Several investigators[4,5] have reported endurance limits for various species of wood ranging from 22 to 33 percent of the static-bending strength, but the conclusions were based on a limited series of tests from which the so-called endurance limits were estimated and were not based on complete curves of applied reversed stresses against the number of cycles to fracture (S-N curves). The endurance limit is defined as the stress to which a specimen can be subjected an infinite number of times without failure. The data here reported indicate that if an endurance limit for wood exists, it occurs above 50 million cycles.

The study of fatigue is necessarily a long-time investigation, because of the high number of cycles that must be applied to the specimens before failure occurs. For steels, a life of 10 million cycles affords reasonable assurance that the endurance limit has been reached, and except in extremely strong steels, a life even of 2 million cycles is fair assurance that the endurance limit lies at a stress not far below that which gave such a life. For wood and plywood, however, a life of 50 million cycles of stress has been found insufficient to give an accurate evaluation of the endurance limit.

The purpose of this report is to present the results from data obtained during the past year on the fatigue properties of wood and plywood, in connection with the current testing program concerning these materials.

Material Tested

The materials tested include solid Sitka spruce and Douglas-fir, and five-ply plywoods of yellow birch and yellowpoplar. All specimens were conditioned and tested at 75° F. and 65 percent relative humidity.

The Sitka spruce specimens were cut from two planks; 187 specimens in one and 406 specimens in the other. The Douglas-fir specimens were also cut from two planks; 143 from the first and 281 from the second. The five-ply yellow birch and yellowpoplar plywood was made (into panels nominally 24 inches square) using 1/16-inch-thick rotary-cut veneer and thermosetting phenol-formaldehyde Tego film glue. Two panels of yellow birch (102 specimens) and one of yellowpoplar (51 specimens) were tested. All specimens were rectangular in shape, 9 by 1-1/4 inches, with thicknesses of 3/8 inch for the solid wood and 5/16 inch for the plywood. All tests were made over a cantilever span length of 6 inches. (Determination of specimen shape is given later.)

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[4] Dietz, A.G.H., and Grinsfelder, H., Behavior of Plywood Under Repeated Stresses. Trans. A.S.M.E., April, 1943.

[5] Moore, H. F., and Kommers, J. B., Fatigue of Metals, with Chapters on the Fatigue of Wood and of Concrete. New York, 1927, pp. 244-250.

The specimens from any one plank or plywood panel were divided into two groups, one group of specimens for the determination of the static strength properties, and the other group for the fatigue tests. The average static strength of the control specimens from each plank or panel was used as the control strength for the test specimens subjected to fatigue from that plank or panel.

All wood specimens were of clear straight-grained material with the annual rings parallel to the width. The thickness of the glue line and the weight of the glue in the plywood specimens are assumed to be negligible throughout the calculations in this report. The average specific gravities of the materials tested, based on the volume at test and the weight when oven-dry, were 0.427 and 0.341 for the Sitka spruce planks, 0.505 and 0.514 for the Douglas-fir, 0.699 and 0.700 for the yellow birch plywood panels, and 0.493 for the yellowpoplar plywood panel.

Methods of Test and Equipment Used

Specimen Shape

It was evident that the shape of the specimens should be standardized in such a manner as to produce the desired stress at a known position in the specimen. The specimens that were tried in the first preliminary tests had shapes as shown in figures 1 and 2, which were patterned after shapes used for plastic material. The specimen shown in figure 1 was of uniform thickness and was designed to be of uniform strength between fillets. Different sizes of fillet were employed at the ends of the uniform-strength part of the specimen. It was found that these specimens, as well as the type shown in figure 2, failed by opening up a longitudinal crack, which started at the edge on either the top or bottom in the fillet near the gripped end. In the plywood specimens, the crack penetrated to the next ply, and in the solid wood specimens the crack progressed towards the center. This type of failure was evidently caused by the stress at the lateral edges of the specimen applied to fibers that were not continuous throughout the specimen and therefore not sufficiently supported. It was concluded that specimens of the shapes shown in figures 1 and 2 were not suitable.

Figure 3 shows another type of specimen that was tried. It was rectangular in shape and was of uniform thickness. The fibers at the lateral edges were parallel to the length, thus avoiding the objectionable features of specimens in figures 1 and 2. The beveled pieces shown in figure 3 were made of hardwood (maple) and at first were glued to the specimen;

the object being to prevent localized high stresses where the steel grips were applied to the specimen. Gluing of the beveled pieces to the specimen was not satisfactory as the glue joints failed during the test. It was more desirable to have the beveled pieces inserted at the grips without being glued, with the bevel away from the specimen. Figure 4 shows the specimen shape used for the tests with the grip pieces inserted before test.

Method of Testing

The rotating-beam type of fatigue machine does not lend itself to the testing of plywood, as the bending strengths of the material perpendicular to the plywood faces and edges vary considerably. Therefore the fatigue tests were all made on Frouse flat-plate machines, using a cantilever specimen (fig. 5). The flat-plate type of fatigue machine has not generally been used by other investigators for testing wood specimens, although it has been used to some extent for metals and plastics. In the flat-plate type of machine, the specimen operates as its own dynamometer for the stress intensity is a function of the deflection of the specimen. If neither plastic flow nor a modification in stiffness results from repetition of stress, the stress intensity will remain constant, since the machine operates at a fixed maximum deflection. For reversed stress the "throw" is to the same deflection on both sides of the neutral position of the specimen. However, when a stress cycle is applied to a specimen such that the mean stress of the cycle is not zero, plastic flow will take place and the maximum stress intensity will change with time. If completely reversed stress cycles are applied the mean stress is equal to zero and very little plastic flow is expected to take place especially since the specimen is subjected to reversals of stress at a high rate (1,790 cycles per minute).

The machine is operated by an electric motor that rotates an adjustable eccentric, which has a maximum deflection of 2 inches and a maximum load of 150 pounds. The motion of the eccentric is transferred to the end of the specimen by a connecting rod. To dampen the vibrations each machine is bolted to a wood baseboard which, in turn, is bolted to the top of a concrete slab 24 inches long, 16 inches wide and 4 inches thick. The baseboard forms a convenient place for the attachment of dials, switches, fuse boxes, and other necessary apparatus. The entire unit rests on five automobile-valve springs. Using this method of mounting, eight machines were placed on one frame (fig. 10) resulting in a compact unit with negligible vibration.

One of the necessary mechanisms for any fatigue-testing machine is the device used for stopping the machine when fracture of the specimen occurs.

Several types of shut-off switches have been used in testing plastics or metals. These switches are actuated by the free swing of the connecting rod when the specimen breaks completely into two parts. Such a system cannot be adapted to the testing of wood because complete breakage of the specimen does not occur. It was, therefore, necessary to devise a new type of shut-off that would stop the machine when the outside fibers of either the top or bottom face of the specimen first failed.

The method employed for this purpose depends for its operation upon the fact that as the outermost fibers of the specimen fail, the elastic curve of the specimen changes. Small microswitches placed to clear the center of the span of the specimen at its full deflection and adjusted to the correct clearance before starting the test will be actuated by the specimen itself when its elastic curve straightens (fig. 6).

Failure due to fatigue in wood, just as in other materials, is progressive and the specimen may be severely damaged long before complete breakage occurs. It was therefore necessary to run a series of exploratory tests varying the clearance or gap between the specimen and the actuating element of the microswitch to determine the effect of the amount of clearance on the fatigue life of the specimen, and also to determine the amount of residual strength remaining in the specimen after shut-off had occurred. The results of these tests are given in figures 7 and 8.

From these tests, which were all made a reversed stress value of 46 percent of the static modulus of rupture, it was decided to use a switch gap of 0.003 inch. Smaller gaps prove too sensitive to outside disturbances and greater gaps result in failures considerably further progressed than initial fracture. The residual static strength in the specimens after removal from the fatigue machine, using a switch gap of 0.003 inch, was approximately 85 percent of the control static strength of the material.

The type of failure that occurs from completely reversed stress tests is a fine hairline crack across the width of the specimen near the beveled wood strips at the grips. This crack is usually not visible unless the specimen is bent while viewing it.

During the test of a specimen the energy absorbed heats the specimen slightly at the maximum-stress cross section. This rise in temperature, while not as serious as in plastic specimens, may cause a slight reduction in the moisture content of the wood, resulting in a stronger specimen after a period of time than at the beginning of the test. This change of moisture content has not yet been accurately checked, as the section used for moisture determination was cut from the unbroken portion of the specimen and does not represent the moisture content at the cross section of failure. One specimen, however, was subjected to reversed stress (38 percent of the static modulus of rupture) for one hour and then cut transversely into 1/4-inch strips, from which moisture contents were determined. Figure 11 shows that the moisture content has been lowered about 1 percent near the maximum-stress cross section.

Testing Procedure

Static Cantilever Test

All static cantilever-bending tests were made in a hydraulic testing machine of 100-pound capacity. Figure 9 shows the apparatus used. The load was applied to the specimens by means of a loading rocker, rod, and notched plate to assure the application of vertical loads only. The span from the center of the applied load to the edges of the steel grips was 6 inches. In all static tests the moving head of the testing machine descended at a rate producing the standard rate of fiber strain of 0.0015 inch per inch per minute. The formula from which rates were determined is:

$$R = 0.001 \frac{l^2}{h}$$

where R = rate of descent of loading head in inches per minute, l = span length of the cantilever specimen in inches, and h = thickness of specimen in inches. For a 3/8-inch nominal-thickness specimen, the rate of descent was 0.096 inch per minute.

The static test apparatus was used for the control-strength determinations of unstressed specimens and for residual-strength determinations of specimens removed from the fatigue machine.

Fatigue Test

Krouse flat-plate fatigue machines were used to apply both reversed stresses and repeated stresses in one direction from the unstressed or neutral position. The testing procedure consisted of a series of machine adjustments to produce the kind of cycle and intensity of stress required. Figure 5 shows a test specimen in place in a Krouse machine as used throughout the tests.

The only difference between the adjustments made for a reversed-stress cycle and a repeated-stress cycle was that the neutral position of the eccentric in a reversed-stress cycle coincided with the unstressed position of the specimen, while in a repeated-stress cycle one maximum position of the eccentric setting coincided with the unstressed position of the specimen and the opposite maximum coincided with the position of maximum stress.

At the beginning of the testing program, machines were used that had geared revolution counters with a 1,000-to-1 ratio of stress cycles to recorded cycles. In the tests of highly stressed specimens that failed within approximately 10 minutes, this type of counter was not sufficiently accurate. To remedy this, a light was put in series with the microswitches and the interval the light was on was timed with a stop watch. Knowing the running speed of the machine, from check tests, the number of cycles to shut-off was computed. In this manner, coasting of the machine after shut-off of the switches and inability to obtain accurate short-time readings from the counter were eliminated. During the long-time tests (approximately 30 minutes and longer), the switches were placed in series with the motor to cause direct shut-off, for the coasting of the motor after shut-off was then a negligible part of the total number of stress cycles and the counter was sufficiently accurate. Figure 12 shows a sketch of the electrical circuits employed for the short- and long-time tests.

Explanation of Charts

Figure 13 is the S-N graph of all test data from completely reversed stress cycle tests, including the different species and plywood construction, drawn upon semilogarithmic paper. The reversed stress intensity values are given in percentages of the control static modulus of rupture. This method of plotting seems to be more satisfactory than that using the actual stress values, which would necessitate the plotting of different species and plywood constructions on different graph sheets. It is also advantageous to use the percentage of the control static strength as an ordinate rather than an actual stress value, because specimens of the same species from different trees will vary considerably in strength.

The stress intensities applied to the specimens range from 80 percent to 26 percent of the static modulus of rupture of the material tested. Natural variation in the strength of wood specimens results in a band of test results rather than a single curve. The material tested includes solid Sitka spruce, solid Douglas-fir, and five-ply plywoods of yellow birch and yellowpoplar.

Figure 14 is the S-N graph of all test data from repeated-stress-cycle tests, for solid Sitka spruce and Douglas-fir. The test work using the repeated-cycle in incomplete, but the test data so far compiled is being included to show the trend of the results. Tests of only two species have been made, and the results show a considerable scatter of test points. Further testing may produce more consistent results.

Figures 15 through 18 show the same results separately for each species and plywood construction. Figure 18 includes final or residual-strength information on the solid Douglas-fir specimens after they have been subjected to repeated or reversed stress. This residual strength is determined by a static cantilever test at the standard rate of loading after the specimen has been tested in the fatigue machine. The residual-strength information is useful in showing the reduction in strength, or the degree of failure, due to the repetitively applied stress. One of the disadvantages of using a plate-type of fatigue machine is the fact that under constant strain cycles the specimens will not fracture but the outside fibers of the specimen at the maximum-stress cross section will fail and a hairline crack will appear. This crack will progress toward the center of the specimen, but only with a large increase in cycles. Complete failure of the specimen, either in plywood or solid wood, is not probable except at high stress intensities.

The basis for the 100-percent control strength as shown on figures 13 through 18 is the average static strength of all cantilever control specimens cut from each plant or plywood panel. For example, 100 specimens from a plywood panel may be divided into two groups of 50. The average strength of the first group, when tested statically to failure without previous stressing, is taken as the control strength to which the repeated or reversed stress applied to a fatigue specimen is compared.

Discussion of Results

The flat-plate type of fatigue machine, while better suited to the testing of plywood and nonisotropic materials than the rotating-beam type of machine, introduces variables because it holds the maximum deflection constant rather than the maximum stress. Initial failures in a constant maximum-stress type of machine are followed almost immediately by complete fracture of the specimen. The initial failure sets up stress concentrations in the specimen and, because the load is constant, the farther the failure progresses the higher the intensity of stress becomes.

The opposite reaction occurs, however, in a constant-deflection type of fatigue machine for the initial failure causes a reduction in the stiffness of the specimen. Since the deflection is constant, this loss of stiffness reduces the stress in the specimen and retards rather than increases the rate of failure after the initial failure has occurred. It is for this reason that the significance of failure produced by flat-plate fatigue machines has been given careful consideration. The use of the microswitch mechanism to shut off the fatigue machine records the initial failure of the specimen, found to be comparable to the failure which would be recorded by a constant-load type of machine. Tests made at Wright Field[6] on solid maple and yellow birch specimens using the rotating-beam-type (constant stress) fatigue machines, show very close agreement with the data when the S-N curves are superimposed upon the data in figure 13. It is believed that the resulting endurance-strength values from rotating-beam-machine tests at 50 million cycles (approximately 28 and 26 percent, respectively of the static modulus of rupture of solid birch and maple) justify the use of microswitches with 0.003-inch clearance as a suitable mechanism for establishing initial failure of a specimen in the flat-plate-machine test. The failure produced at shut-off in a reversed-stress test is a fine hairline crack across the width of the specimen. This small crack does not reduce the static strength of the specimen appreciably, but it is a failure of the outside fibers and as such is considered fatigue failure.

The results of the completely reversed stress-cycle tests seem to be consistent up to approximately 50 million stress cycles. The results of tests plotted on figure 13 produce a band on the chart, and no attempt has been made to draw a smooth curve through the points. The endurance strength of 27 percent of the static modulus of rupture at 50 million cycles is not the endurance limit of the material, since the slope of the S-N curve is still negative. The endurance limit, as defined, is the highest unit stress whose repeated application can be indefinitely endured without failure; while endurance strength is a value used for materials for which the true endurance limit has not been reached and is the unit repeated stress at which failure will not occur before a definite number of stress cycles has been endured. Below stresses of approximately 27 percent, the life of wood and plywood under completely reversed stress cycles is sufficiently long to have negligible effect in most structures. With the information presented, it is a very simple procedure in design to safeguard against failure due to fatigue provided the intensities of the repeated or reversed stresses are known. Local stress intensification due to abrupt changes in cross section of members, lightening holes, surface imperfections, and other factors, however, must be considered, as the actual stress rather than the nominal stress should be the basis for design.

In the use of plywood as an aircraft structural material it has not been known how well the veneer-bonding agents used will withstand vibration and

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[6] "Fatigue Characteristics of Natural and Resin-Impregnated, Compressed, Laminated Woods" by F. B. Fuller and T. T. Oberg, Journal of the Aeronautical Sciences, March 1943.

repeated stress. The tests so far completed were made to determine the fatigue properties of the wood rather than the glue in the plywood. With the size of specimen used, the maximum glue-line shear stress in a three equal-ply plywood is approximately 150 pounds per square inch when the ultimate fiber stress in bending is reached. This value of shear stress is less than one-half of the ultimate shear strength required by Army-Navy Specification AN-NN-P-511b for plywood. Since the shear stress is relatively low compared to the fiber stress in bending, it has been found that plywood specimens tested as cantilever beams subjected to repeated or reversed bending stress, with the plane or the veneers perpendicular to the load and the grain of the outside plies parallel to the span, will fail in the wood before separation of the veneers occurs. These tests were made on plywood specimens bonded with Tego film glue. It is assumed that any good glue joint conforming to Army-Navy specifications will produce like results. The difference in the endurance strength at 50 million cycles exhibited between the repeated-stress tests and the reversed-stress tests is due largely to the plastic properties of wood. It has been shown[7,8] that the stiffness of the specimens decreases with the number of cycles and with time. In the completely reversed stress cycle the mean stress is zero; while plastic flow may take place during each cycle, the time interval is so small that permanent set of the specimen due to the plasticity probably does not take place. In the repeated-stress tests, the mean stress of the cycle is not zero, plastic flow probably takes place, and permanent set progressively reduces the maximum stress in the specimen.

The repeated-stress test results as shown in figure 14 exhibit greater scatter than those from the reversed-stress tests in figure 13. It is believed that this variance is inherent in the test rather than due to nonuniformity of the material. The repeated stresses produce crushing and buckling of the fibers on the compression side of the specimen, but the tension side is relatively unaffected and the curvature of the specimen does not change sufficiently to cause immediate shut-off of the machine. When reversed stresses are applied, however, the fibers are crushed on both sides of the specimen. When the fibers are stressed in tension on the following cycle, breakage occurs causing shut-off. Shut-off of the repeated-stress tests is dependent upon the degree or amount of crushing that has taken place rather than breakage or failure of fibers in the specimen.

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[7] Effect of Ten Repetitions of Stress on the Bending and Compressive Strengths of Sitka Spruce and Douglas-fir. Forest Products Laboratory Report No. 1320.

[8] Effect of 5,000 Cycles of Repeated Bending Stresses on 5-ply Sitka Spruce Plywood. Forest Products Laboratory Report No. 1305.

Figure 18, in addition to showing the fatigue data, shows the residual strength in the specimens after failure and removal from the fatigue machine. Failures that occur in specimens subjected to reversed-bending stress of less than 40 percent of the ultimate static strength do not seem to weaken the static strength materially even though more than 100,000 cycles of stress have been applied. This may be explained by the fact that when failure of the outside fibers of the specimen occurs, and the shut-off mechanism is actuated, the relatively few additional cycles applied by coasting of the motor do not cause much progression of the failure. The presence of the fine hairline crack does not materially affect the residual-static-strength test, since the crack has not penetrated into the specimen much more than a few percent of the total thickness. In the very highly stressed specimens, however, after shut-off of the machine has occurred, the cycles applied during the coasting of the motor may exceed the number of cycles that caused initial failure and may cause the failure to progress sufficiently to weaken the specimen considerably.

The clearance or setting of the microswitch was kept constant at 0.003 inch in all tests to reduce one of the variables in the testing procedure. This setting will cause shut-off of the machine at the same degree of failure in the specimen, but it does not necessarily produce the same residual strength in the specimen when statically tested as a cantilever beam.

Conclusions

The endurance strength of solid Sitka spruce and Douglas-fir and five-ply plywoods of yellow birch and yellowpoplar at 50 million cycles of reversed stress is approximately 27 percent of the static modulus of rupture of the unstressed material. The endurance strength of solid Sitka spruce and Douglas-fir appears to be approximately 36 percent of the static modulus of rupture at 50 million cycles when subjected to repeated-stress cycles from zero to a maximum in one direction only. The two endurance strengths were based on the data from figures 13 and 14, wherein specimens shown as stressed below 27 and 36 percent of the static modulus of rupture resisted 100 million cycles without failure. All tests were conducted under controlled conditions of 65 percent relative humidity (approximately 12 percent moisture content in the wood) and 75° F. in flat-plate-type fatigue machines operated at 1,790 cycles per minute. The cantilever specimen acts as its own dynamometer.

These conclusions must be associated with the testing procedure, particularly with regard to the use of microswitch clearance as a criterion for discontinuing the test even though complete failure has not occurred.

Results here reported are for only a few species of wood and for one plywood construction. They do not necessarily apply to all wood species and plywood constructions. It does appear, however, that there is some correlation between the percent of the static modulus of rupture applied and the endurance strength for the various kinds of specimens tested.

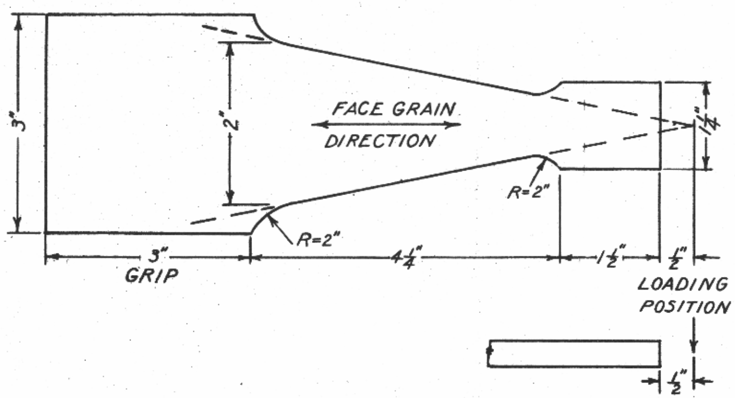

Figure 1.--Constant-stress type of specimen (between fillets) investigated for reversed and repeated stress cantilever bending tests.

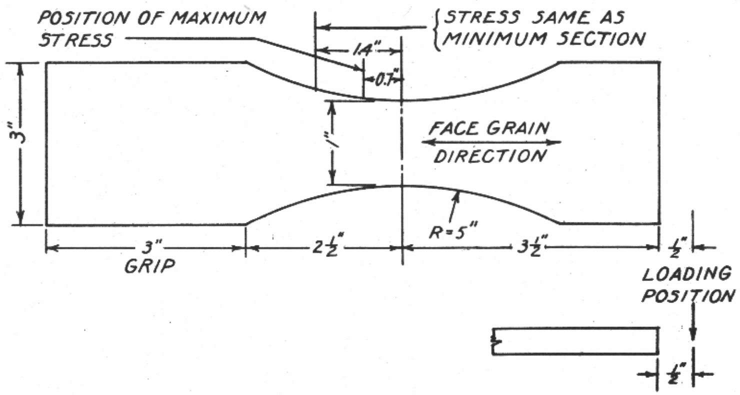

Figure 2.--Reduced-section type of specimen investigated for reversed and repeated stress cantilever bending tests.

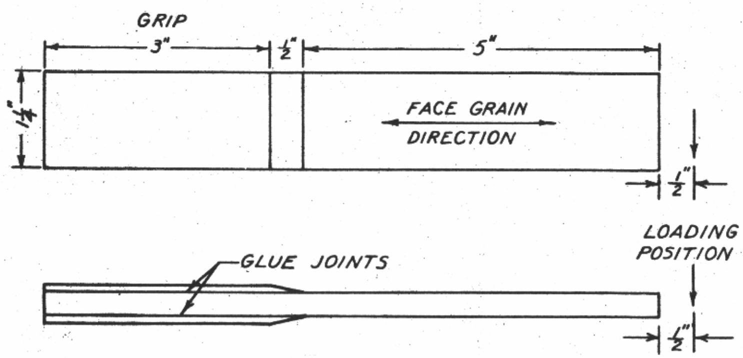

Figure 3.--Constant-width type of specimen investigated for reversed and repeated stress cantilever bending tests. Beveled wood strips glued to specimen over gripped portion.

Z M 49046 F

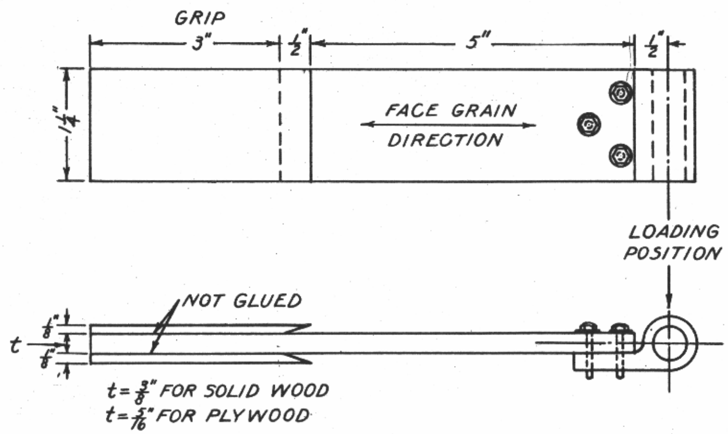

Figure 4.--Constant-width type of specimen as used in all tests reported. Beveled wood strips not glued to specimen.

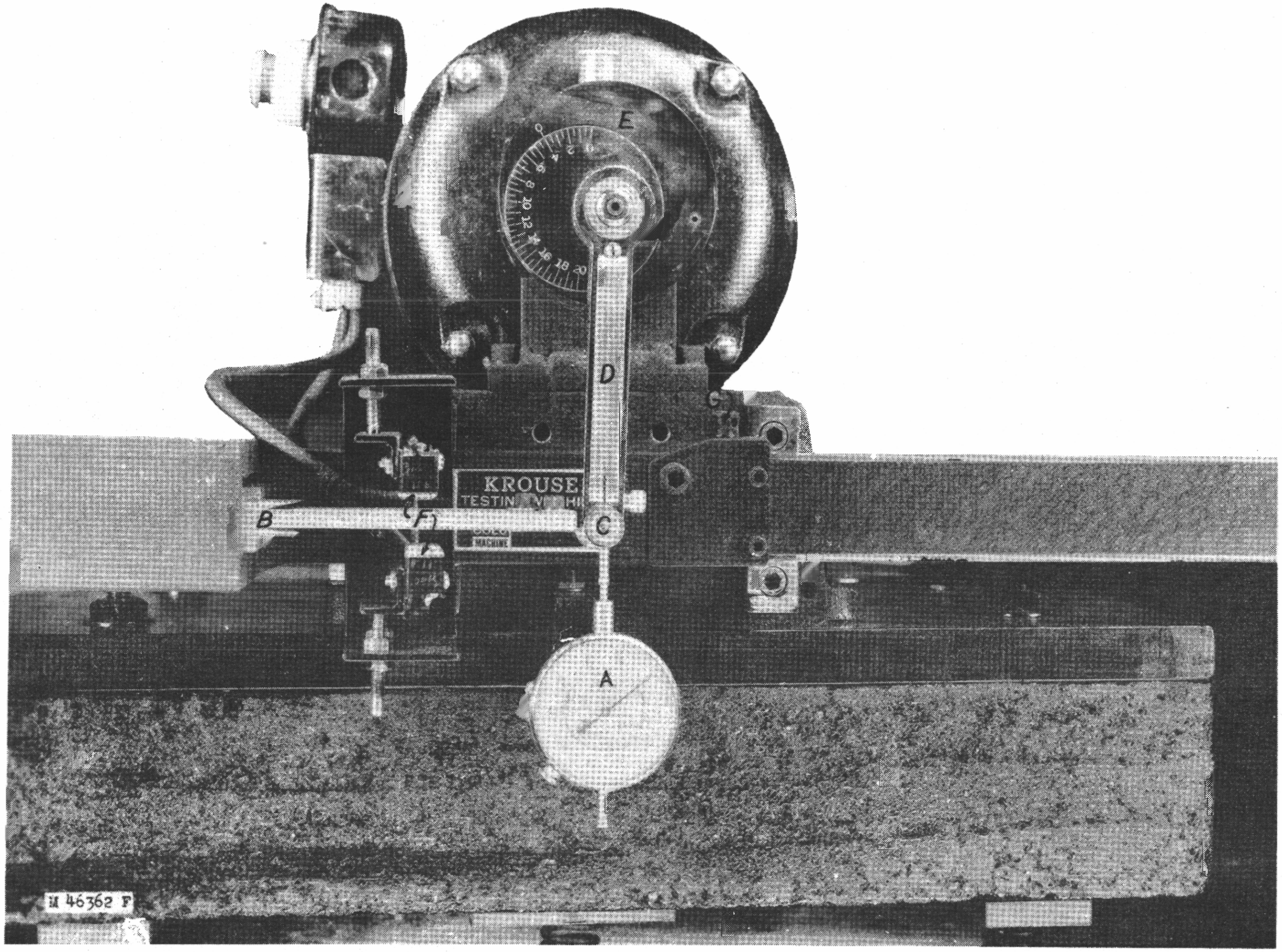

Figure 5.--Flat-plate fatigue machine used to apply the repeated and reversed stresses. A, Dial to establish deflection to be reached in each cycle, dial to be removed before stress cycles begin; B, grips; C, connecting-rod pin; D, connecting rod; E, eccentric head to provide adjustable throw; F, micro-switches; G, nut to adjust neutral or zero-stress position of specimen.

Z M 49047 F

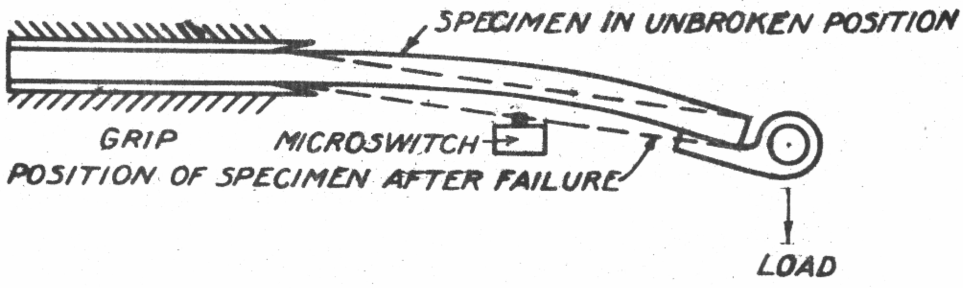

Figure 6.--Diagrammatic sketch showing how a failed specimen operates the microswitch.

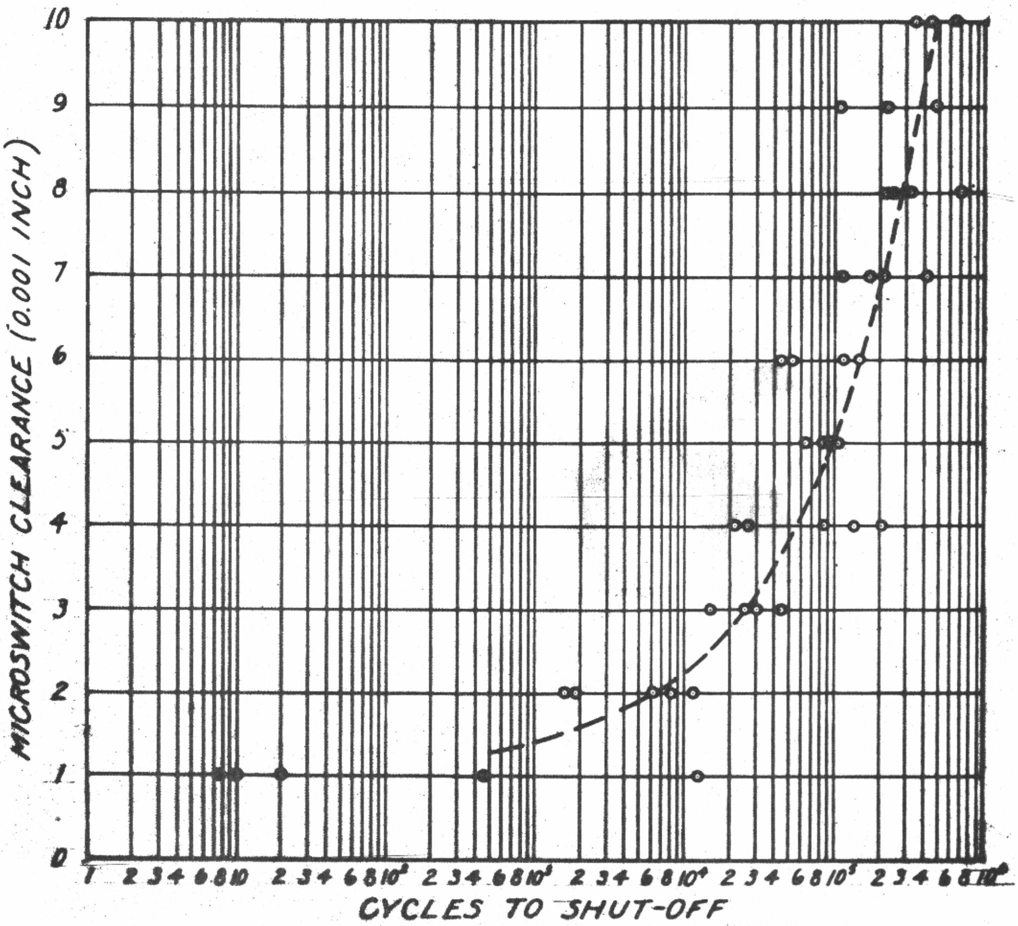

Figure 7.--Effect of microswitch clearance on the fatigue life of Sitka spruce cantilever specimens. Reversed-stress value was 46 percent of the static modulus of rupture.

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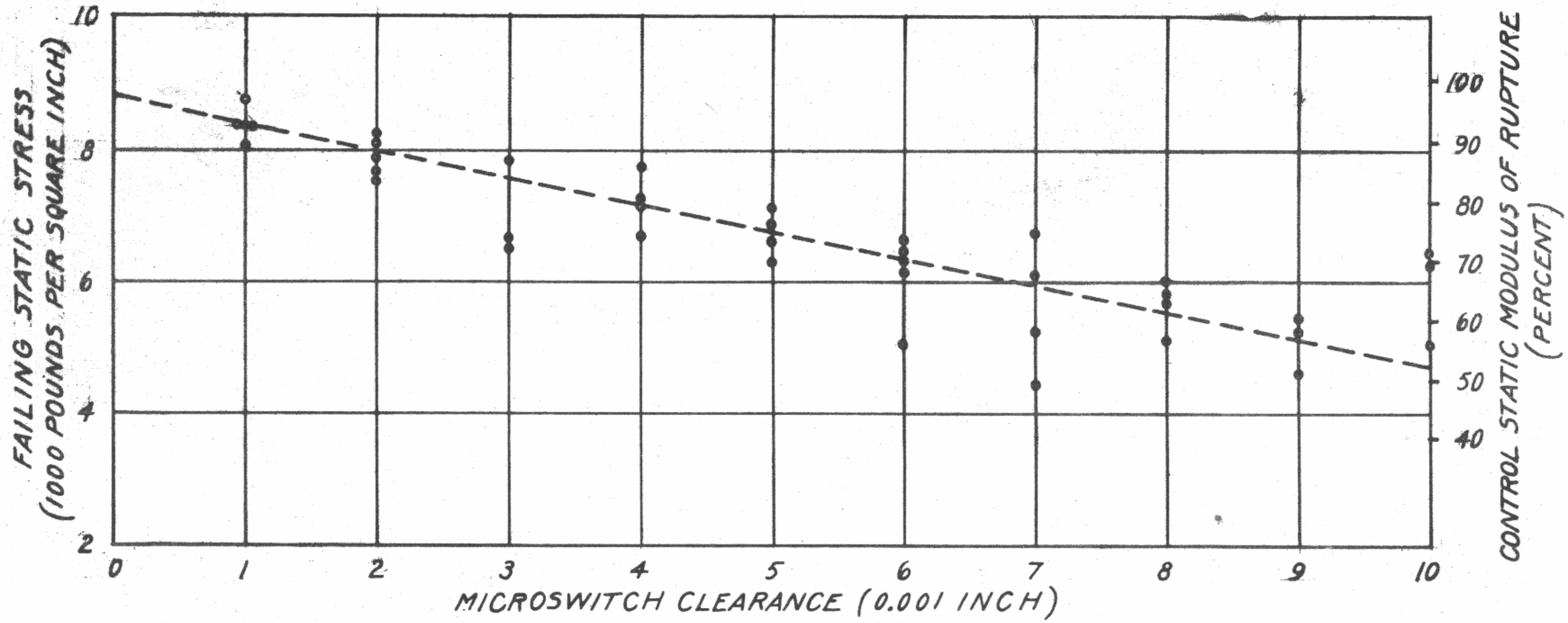

Figure 8.--Results of static cantilever tests on solid Sitka spruce to determine the residual strength in the specimens after being subjected to reversed-stress fatigue using various microswitch clearances to detect failure. All tests were made at a reversed stress of 46 percent of the average static modulus of rupture of the control specimens.

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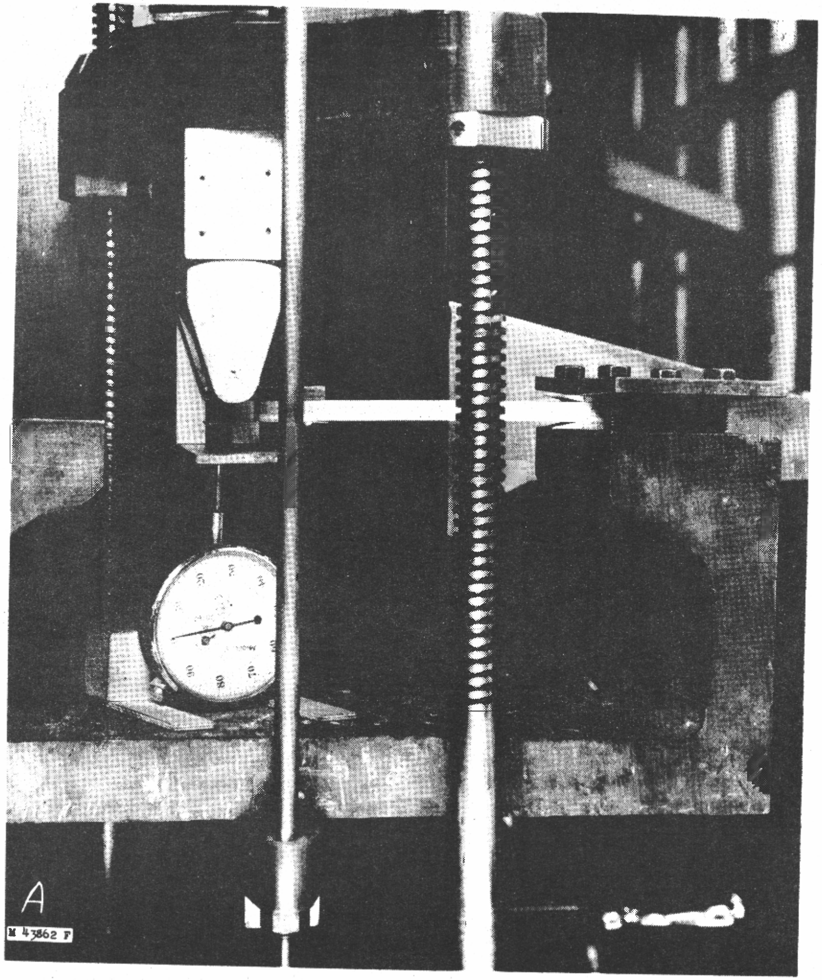

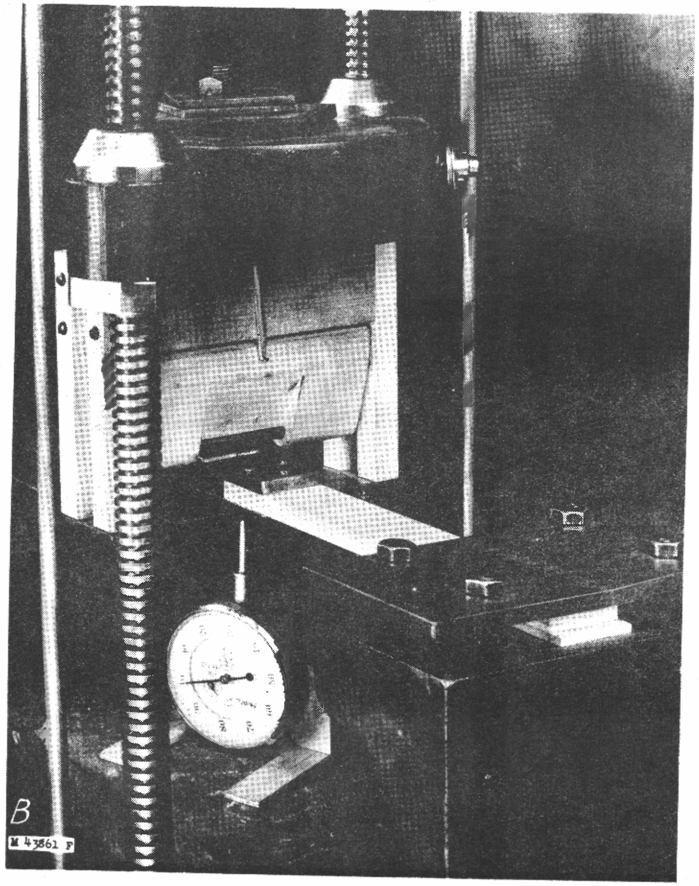

Figure 9.--Static cantilever apparatus used for testing controls and for determining final strength of fatigue specimens. A, Side view of loading rocker, with 0.001-inch dial deflectometer in position directly beneath; B, end view, showing loading rocker, rod, and notched plate used to avoid application of any but vertical loads.

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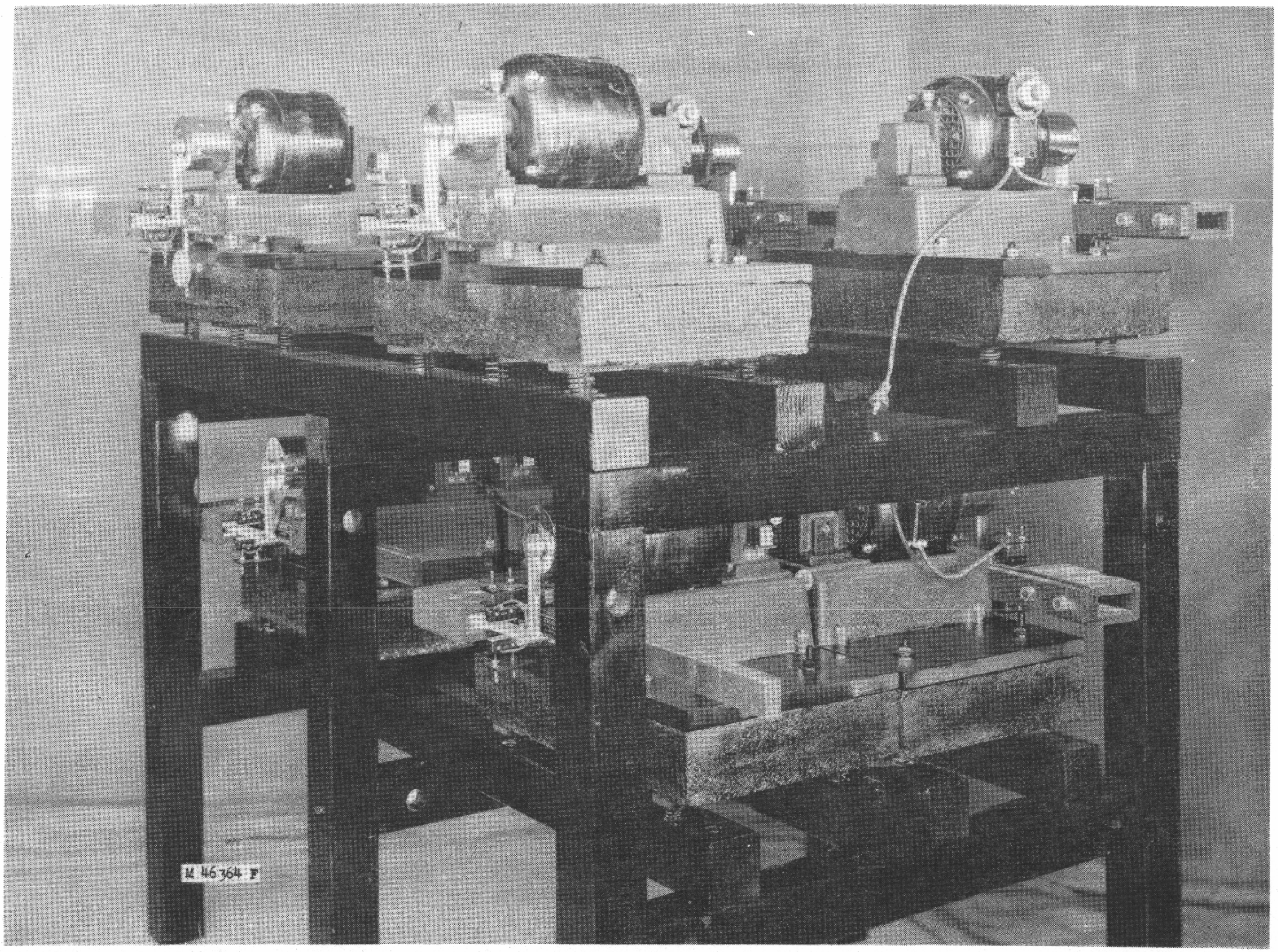

Figure 10.--Assembly of eight fatigue machines used for the series of tests reported.

7 M 49050 F

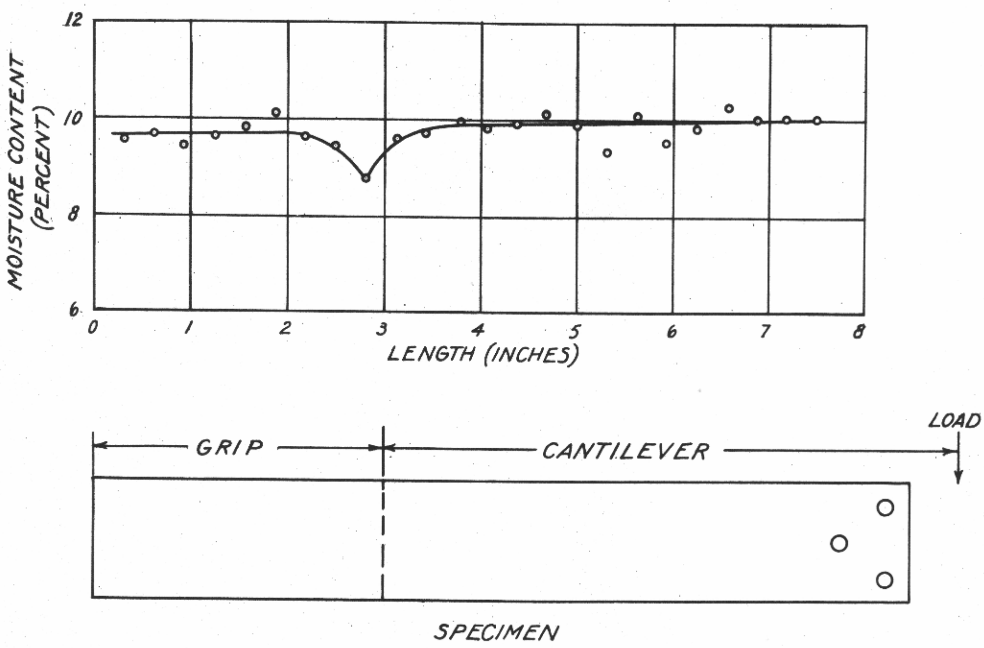

Figure 11.--Distribution of moisture in fatigue specimen (Douglas-fir) after being subjected to reversed stress for one hour at 1,790 r.p.m.

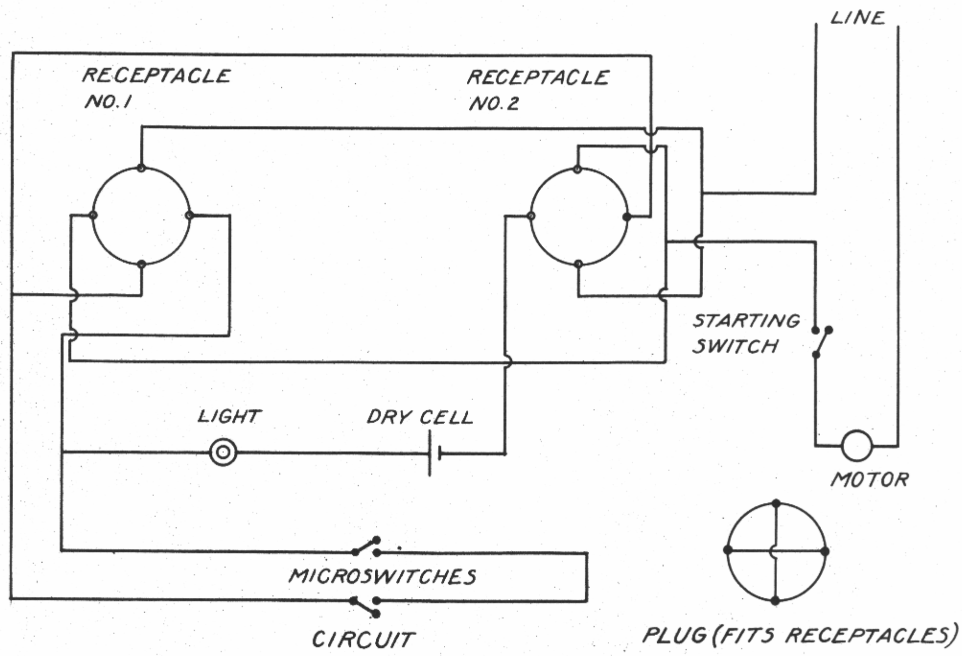

Figure 12.--Alternate microswitch connections as used on flat-plate fatigue machines. Plug in receptacle No. 1 puts microswitches in series with motor (long time tests); plug in receptacle No. 2 puts microswitches in series with light and dry cell (short time tests).

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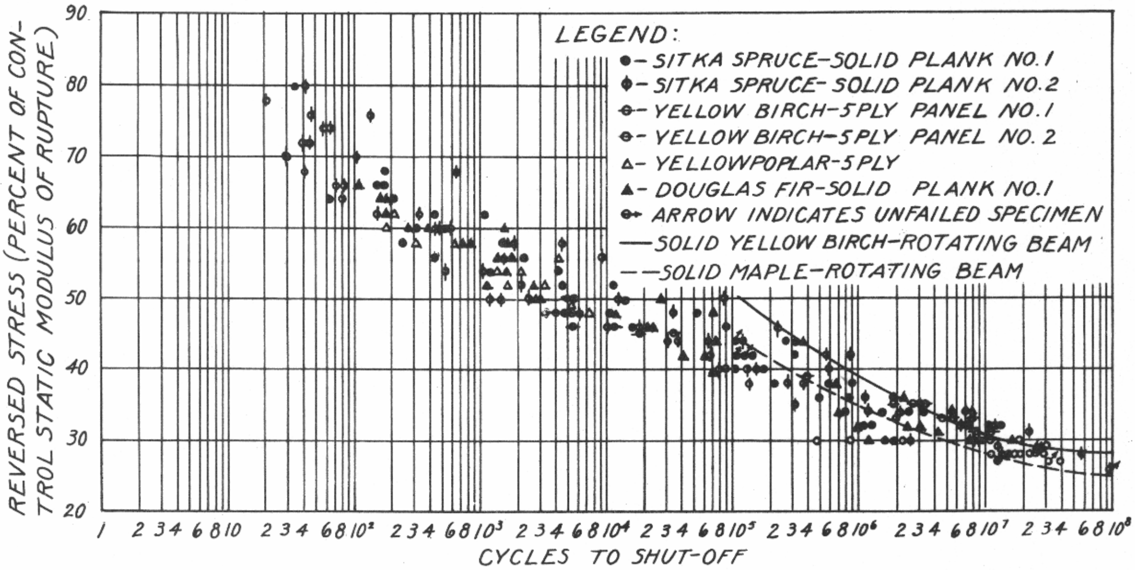

Figure 13.--Results of tests to determine endurance of wood and plywood when subjected to reversed bending stress. Rotating-beam fatigue data was obtained from results of tests by F. B. Fuller and T. T. Oberg at Wright Field.

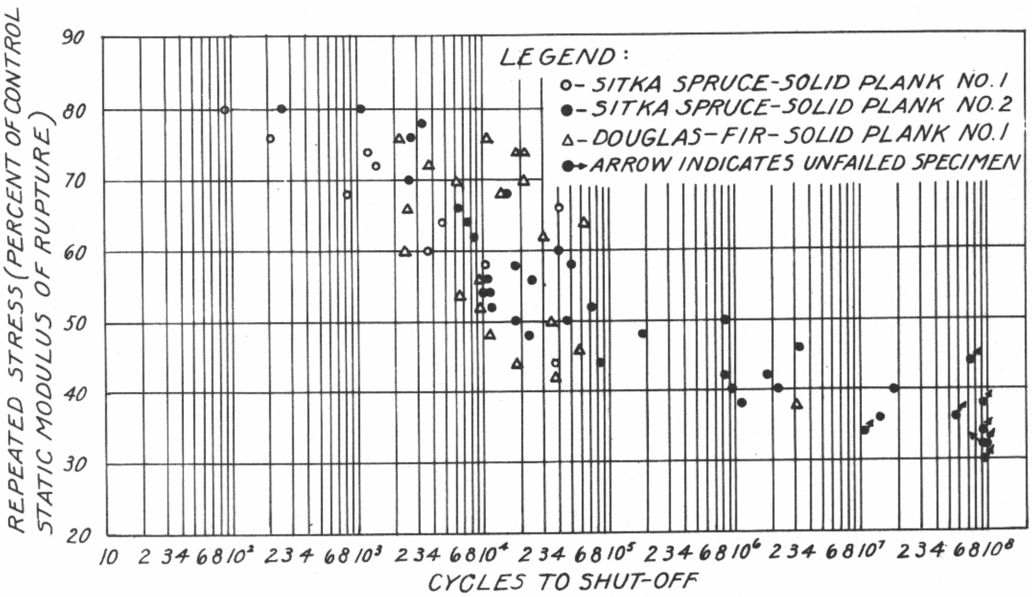

Figure 14.--Results of tests to determine endurance strength of Sitka spruce and Douglas-fir when subjected to repeated bending stress.

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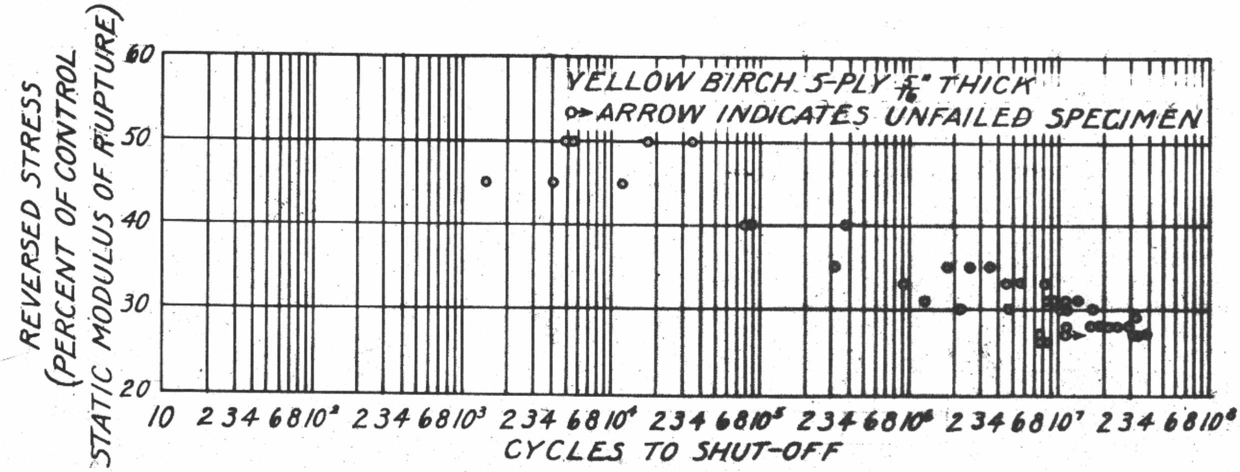

Figure 15.--Results of tests on 5-ply, 5/16-inch yellow birch plywood to determine endurance strength when specimens were subjected to reversed bending stress.

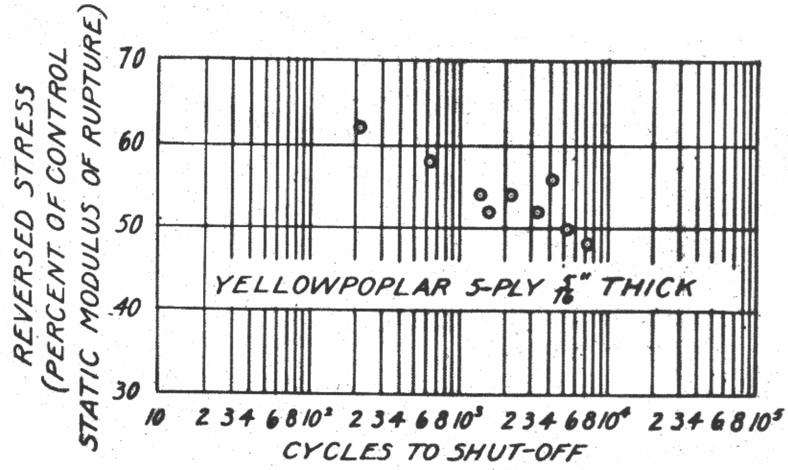

Figure 16.--Results of tests on 5-ply, 5/16-inch yellowpoplar plywood to determine endurance strength when specimens were subjected to reversed bending stress.

Z M 49053 F

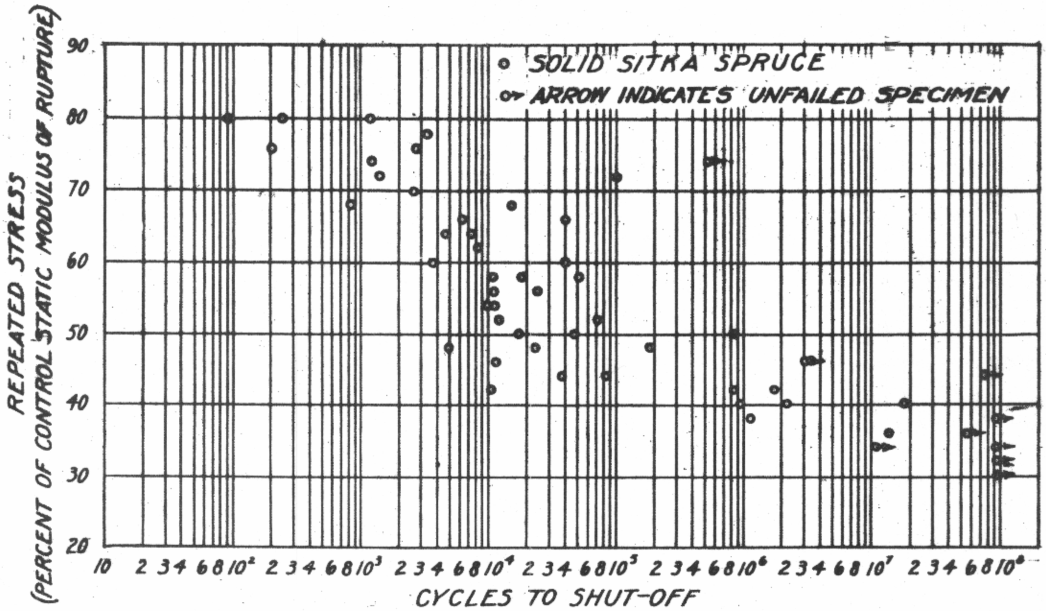

Figure 17.--Results of tests on solid Sitka spruce to determine endurance strength when specimens were subjected to repeated bending stress.

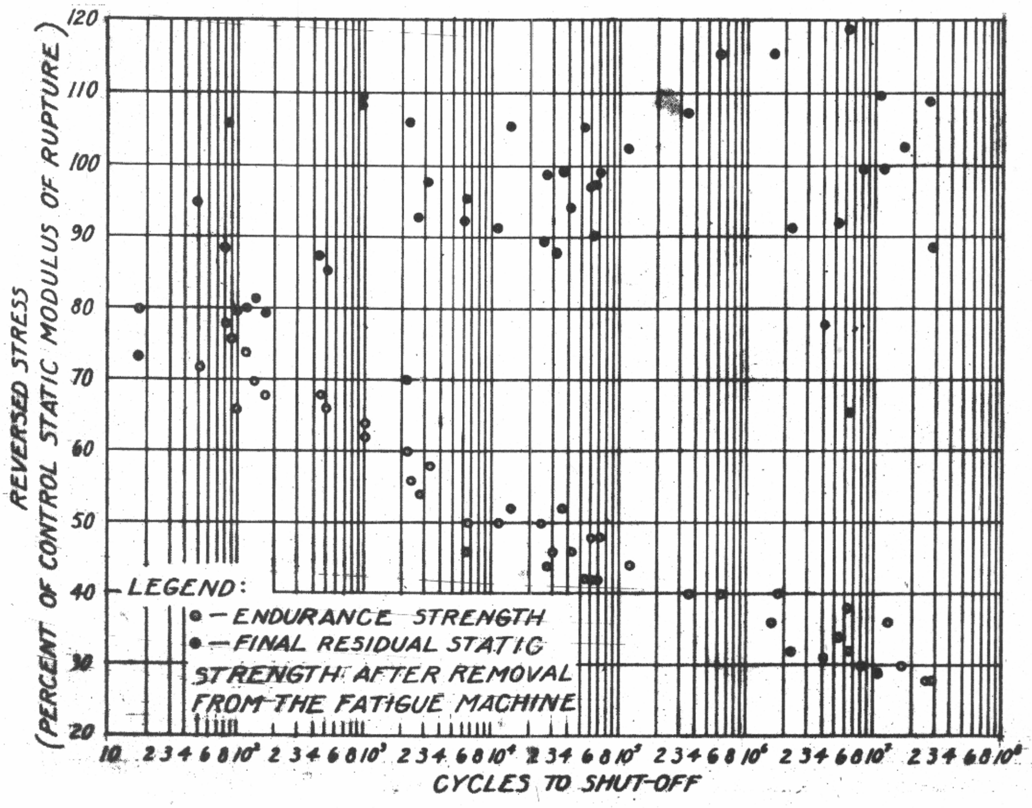

Figure 18.--Results of tests on solid Douglas-fir to determine endurance strength when specimens were subjected to reversed bending stress.

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