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DEVELOPMENT OF A TEXTILE CORD LOAD TRANSDUCER

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I. INTRODUCTION

The rational design of pneumatic tires could be substantially advanced if tire cord loads could be measured directly. Such measurements are absolutely necessary for a quantitative evaluation of tire strength as well as for assessing the validity of methods of calculating such strength. A number of attempts have been made to make such measurements,[1,2,3] and at least four of these are of some historical importance.

Early in the tire industry, efforts were made to measure cord strains by inserting needles into the tire carcass in such a way that the needles passed through the tire cords. The tire was then inflated or loaded and the relative motion between the needles measured and used as an indicator of strain. While this method was simple, it had the disadvantage that both membrane and bending strains were represented in the result so that it was extremely difficult to separate out the actual cord load as a function of needle displacement.

A number of efforts have been made to utilize X-ray techniques in various forms for the determination of tire-cord strain. Two techniques have been rather successful in this regard. One involves manufacturing a special tire with small steel balls imbedded in the rubber adjacent to the tire cords, along with steel needles of known length. X-ray photographs are taken of the tire in the inflated and loaded state, and compared with similar photographs taken in the uninflated and unloaded state. The relative displacements between the balls may be measured on an absolute scale by reference to the lengths of the imbedded steel needles as seen on the X-ray film. By such methods the strains immediately adjacent to the cords can be determined in the inflated condition, and sometimes in the loaded condition, although this is considerably more difficult to accomplish. A similar but somewhat more sophisticated technique involves treatment of one strand of a twisted tire cord with lead acetate prior to manufacture of the tire. X-ray photographs taken of the tire cord show an essentially sinusoidal trace as the lead acetate treated strand weaves its way through the twisted cord. If two photographs are taken, one before loading and inflation and the other after, the difference in wavelength of the sinusoidal trace on the film can be taken as indivative of cord strain directly, so that this technique has the advantage of direct use of the cord itself. Unfortunately, however, both of these methods require that special tires be built, and such methods are difficult to apply in the contact patch of a loaded tire, which is the region of greatest interest.

About 15 years ago several efforts were made to develop a strain gauge suitable for use on rubber by utilizing a small rubber capillary tube filled with mercury and acting as a variable resistance element when elongated. This is a direct counterpart to the normal resistance strain gauge and was intended to function as such. This gauge was generally made to be imbedded in a tire after manufacture, and required hollowing out the rubber immediately adjacent to the tire cord and inserting the gauge. Some difficulties have been experienced with such gauges, and they tend to be somewhat bulky and disruptive to the tires' original geometry. Their use was discontinued until quite recently when further efforts have been made to perfect this gauge using low melting point liquid metals other than mercury.

Perhaps the most extensive effort at development of a strain gauge suitable for pneumatic tire purposes originated in Holland and was developed under the name of the Peekel gauge. This gauge consists of a fine rubber thread or filament which is circular in cross section, and is extended in a holder while strain gauge resistance wire is wound helically around it for a length of perhaps 1/2 in. Upon release of the tension in the rubber thread, the thread expands and causes the helically wound wire to go into a state of tension. This state of tension is altered as the rubber thread is extended or compressed from its normal condition, and may be measured quantitatively by inserting the wire in a normal Wheatstone bridge circuit. Such a gauge is relatively small in diameter and length, so that it can be rather easily imbedded in a region immediately adjacent to a tire cord in a tire. This has been its normal manner of usage. At the present time the Peekel gauge seems to suffer from at least two difficulties. The first is the fact that it does not measure cord strain directly, but rather the strain in the rubber adjacent to a cord. The second is that it is apparently quite sensitive to stresses at right angles to its measuring direction, so that there is some question concerning its accuracy and the proper means for calibrating it. These gauges are difficult to make and at the present time have not found wide acceptance in tire measuring work. Nevertheless, they have been used as the basis of what appears to be the most complete tire cord load study yet accomplished, namely that of Biderman.[1] Additional work using more conventional strain gauge methods has also been recorded in the literature by Kern.[2]

All of these efforts have contributed to knowledge of cord loads. However a great deal is still unknown and the research being reported was undertaken in an attempt to develop a simpler and more reliable method for making such measurements.

The technique described here is based on existing strain gauge technology, adapted directly to the problem of tire cord-load measurement. It consists of building a small force-transducer into a tire cord in such a way that the cord load can be measured directly. The force transducer utilizes thin-walled metal tubing, commercially available epoxy cements and foil resistance strain gauges, and ordinary production tire cord. All necessary materials are cheap and readily available, but certain skills needed to successfully construct and install these transducers can only be learned by practice.

II. SUMMARY

A technique has been developed whereby a small force transducer can be built directly into a tire cord. The technique has so far been applied to one size of cord only, but can be used for any size.

Calibration of these transducers gives a linear and reproducible output signal for cord loads ranging from zero to six pounds, a range that includes most loads experienced by a cord in ordinary automotive tire operating service. This linearity exists whether or not the transducer is imbedded in a rubber matrix. The influence of normal pressure has negligible effect on the calibration or other operational characteristics of the transducer.

Insertion of this transducer into the inner ply of an existing tire has been successfully demonstrated. It is accomplished by removing a single cord from the inner ply and replacing it with a transducer-instrumented cord of the same size. Such tires have been run in slow-rolling, flat plank tests, giving direct cord load measurements. Data has been collected from a two ply tire. A tire has also been manufactured with the transducers inserted during the building process. In this tire the transducers were placed in all plies at several different locations. It has also been run in slow-rolling, flat plank tests.

The results of these tests have provided an enlightening set of data, and have indicated that many possible parametric studies can be made using these direct load measuring transducers. So far, data has been gathered on measurement of cord loads in the crown region, shoulder region and sidewall region for various tire loading conditions as listed below:

(a) Cord loads due to inflation only under various internal pressures.

(b) Cord loads due to varying vertical load with constant internal pressure.

(c) Cord loads due to varying internal pressure for constant vertical deflection.

III. TRANSDUCER CONSTRUCTION

The basis of this transducer is the insertion of a metallic load cell "in series" in a tire cord, by means of cutting the cord and bonding each cut end to a small metallic (or other linearly elastic) tube which can be suitably instrumented with strain gauges. In this fashion, calibration of the transducer before use will provide a relationship between cord load and electrical signal output which will be linear for a well designed transducer. This linear relationship can then be used to interpret electrical signal output in terms of cord load after the transducer has been inserted into a tire, either before or after the tire is built.

The primary considerations in design of the transducer are the ease of making the bond to the tire cord, and the bond strength, along with obtaining sufficient area upon which to mount gauges. At the same time, the transducer must be kept small enough so that it does not result in a severe geometric interruption or distortion of cord load relationships in the transducer area.

A sketch of the preferred configuration of the transducer developed for tire cord measurements is given in Fig. 1.

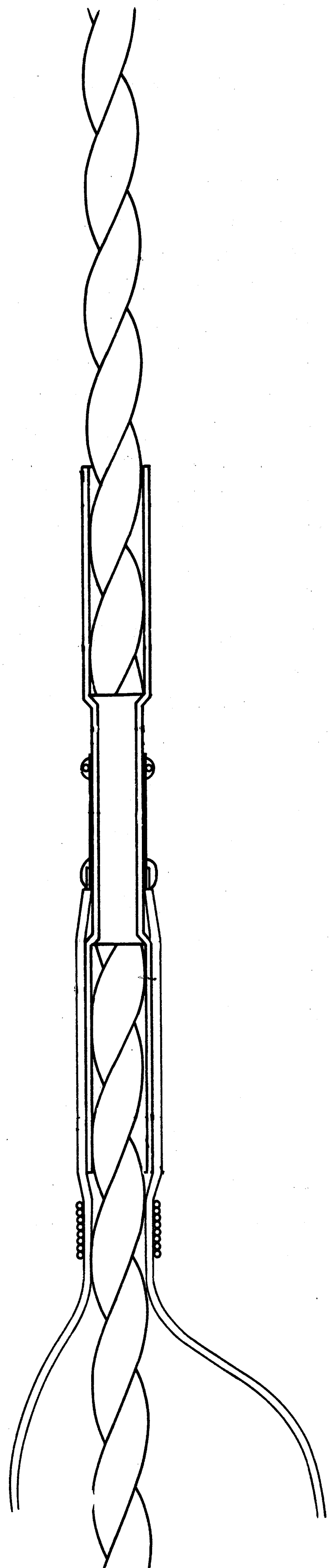

Fig. 1. Cord load transducer.

IV. CALIBRATIONS

For a transducer of the type described here to be effective, a reliable calibration procedure is needed. A number of effects which could potentially cause error were investigated in a rather thorough test program. First, consideration was given to the effects induced in the transducer output by imbedding it in rubber. This was measured in a series of tests in which load vs. transducer output were recorded both before and after imbedding the cord in rubber. The results of two such tests are shown in Fig. 2, and as can be seen, there is no appreciable difference in the response records. Based on these and similar results, all transducers were calibrated before insertion into a tire in the "bare cord" condition, and this calibration was later used to interpret output signal as a measure of cord load.

Transverse stress effects can also influence the output of such transducers. This was investigated by imbedding the transducers in rubber samples of various thickness, and then recording the results for different transverse compressive stresses. These results showed little or no transverse stress effect on the output signal.

Perhaps the most important characteristics examined in the calibration study were the linearity and reproducibility of cord load vs. transducer output. Figures 3 and 4 show the calibrations of approximately 35 transducers constructed from essentially the same materials. Some of them were inserted in existing tires, and some in tires as they were being built. Figure 3 shows the amount of scatter in such measurements and Fig. 4 is a plot of load vs. output obtained from the average of the data in Fig. 3. As can be seen from the curves, the calibration is quite linear for the loads used, and reasonably reproducible.

All of the above calibration studies were done with the cord in tension. A similar study could be made for the cord in compression, since the cord has been observed in compression under some operating conditions. However, the experimental difficulties of such a study are more severe.

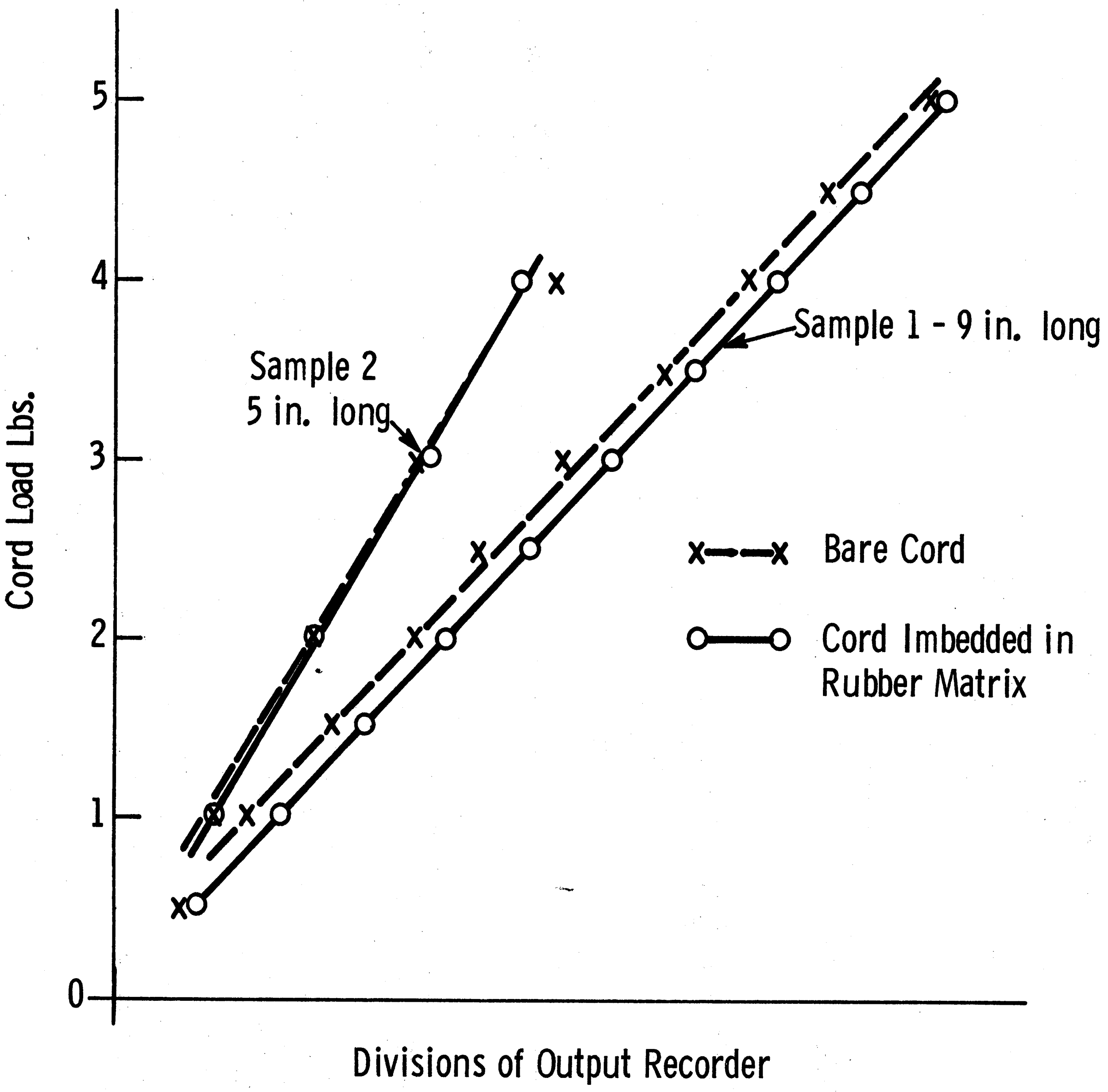

Fig. 2. Comparison of calibrations for transducers under bare cord and imbedded conditions.

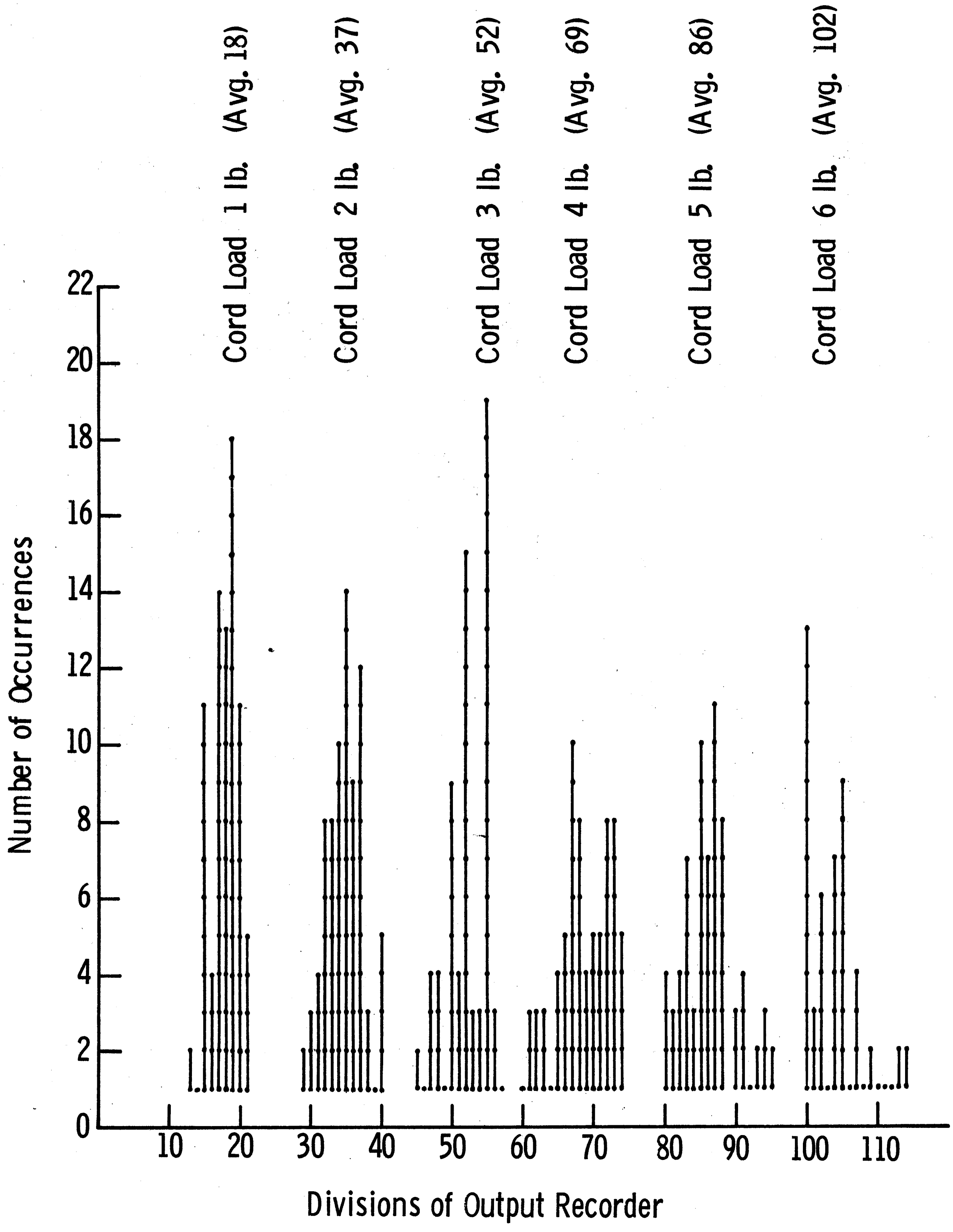

Fig. 3. Statistical calibration of transducer.

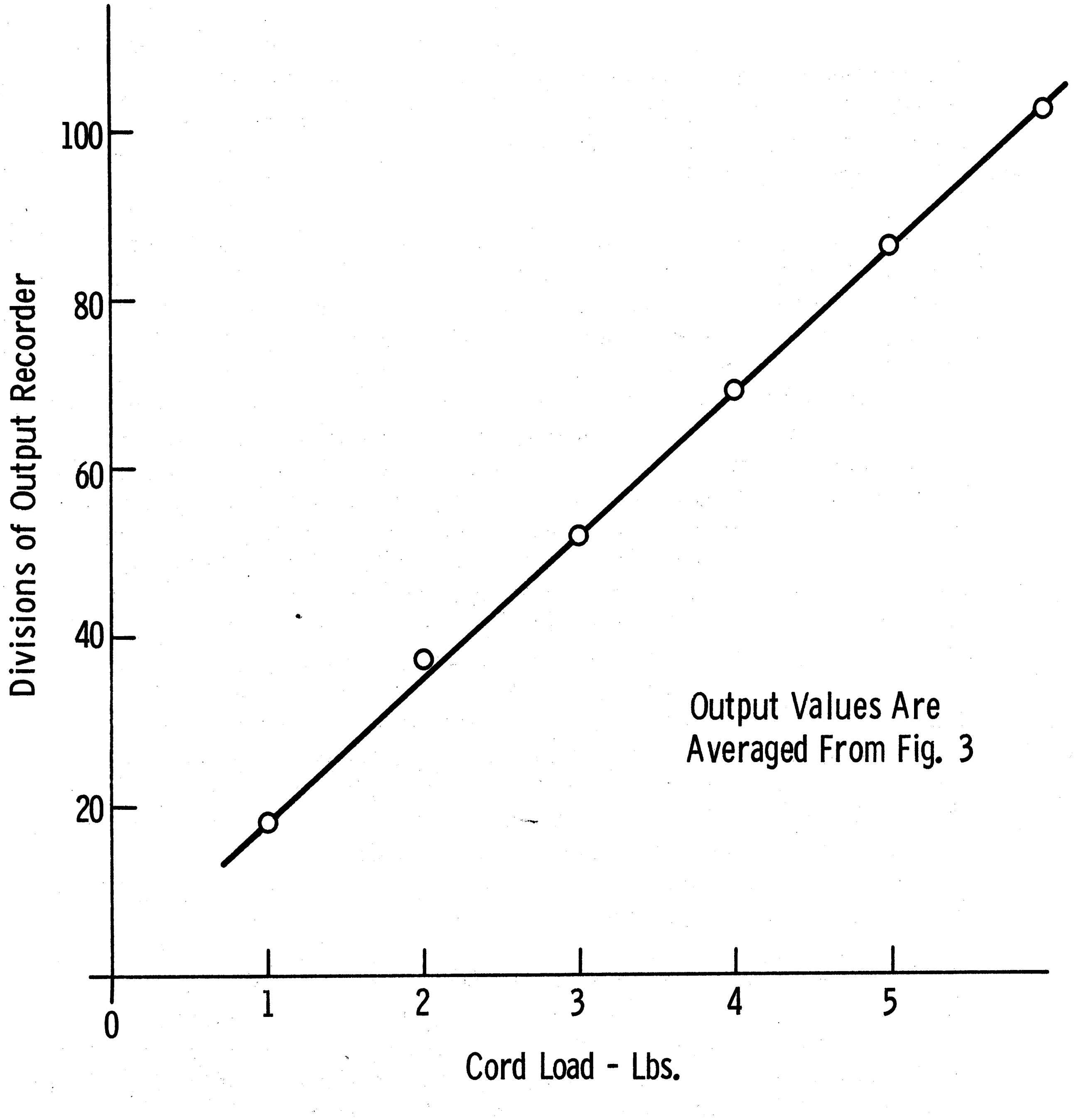

Fig. 4. Transducer calibration—averaged output.

V. APPLICATIONS TO TIRES

The ultimate goal in the development of this force transducer was to demonstrate its practical applicability to pneumatic tires. This was accomplished by inserting the transducer into existing tires as well as into tires while they were being built.

The insertion into an existing tire is begun by first removing a cord from the inside ply of the tire. A convenient method for doing this is to use a small wire buffing wheel to remove the liner rubber near the bead. Then a cord is gripped with heavy tweezers or needle-nose pliers and pulled out, from bead to bead. A cord of the same size and material as the one removed but with a load transducer attached to it, is then placed in the groove left by removing the cord. The transducer is positioned so that it lies at the desired meridianal location. Care must be taken to keep the leads from the strain gauges in an upright position. The next step is to seal the transducer in the groove. For this purpose we have used a cold setting rubber developed by Minnesota Mining and Manufacturing Company. After setting, the lead wires are soldered to terminal tabs which have been bonded to the liner of the tire. From these tabs larger leads are brought out through small holes in the rim. These are then attached to the rest of the bridge circuit.

The tire can now be inflated, loaded, and subjected to slow rolling tests. Cord load measurements may be obtained from these tests. Figures 5, 6, and 7 show typical results obtained from a 7.75 x 14, 2-ply tire subjected to several such tests. For example, Fig. 5 illustrates the load cycle experienced by the cord in the first ply near the crown for constant internal pressure with varying vertical load. As can be seen, an increase in load increases the magnitude of the load cycle but the shape remains essentially the same.

The load measured by the same transducer for a constant deflection but varying internal pressure is shown in Fig. 6. In this illustration it is again observed that the shape of the load cycle is nearly unchanged for the range of pressures investigated. Cord loads at the crown of this tire due to inflation pressure only are shown in Fig. 7. It is seen that the cord load is approximately linear with internal pressure, especially in the range of pressures used in ordinary operating conditions. This is to be expected.

These transducers may also be inserted during the tire building process. This requires somewhat greater care and planning but is a more realistic measurement. The details will be given for a two-ply tire. The process begins by building and calibrating as many transducers as needed to measure the cord loads at desired locations. In addition, full size layout drawings are made of the two carcass plies. The location of the transducers is marked on the layouts. These are then used as templates for locating the gauge positions at the time of building the tire.

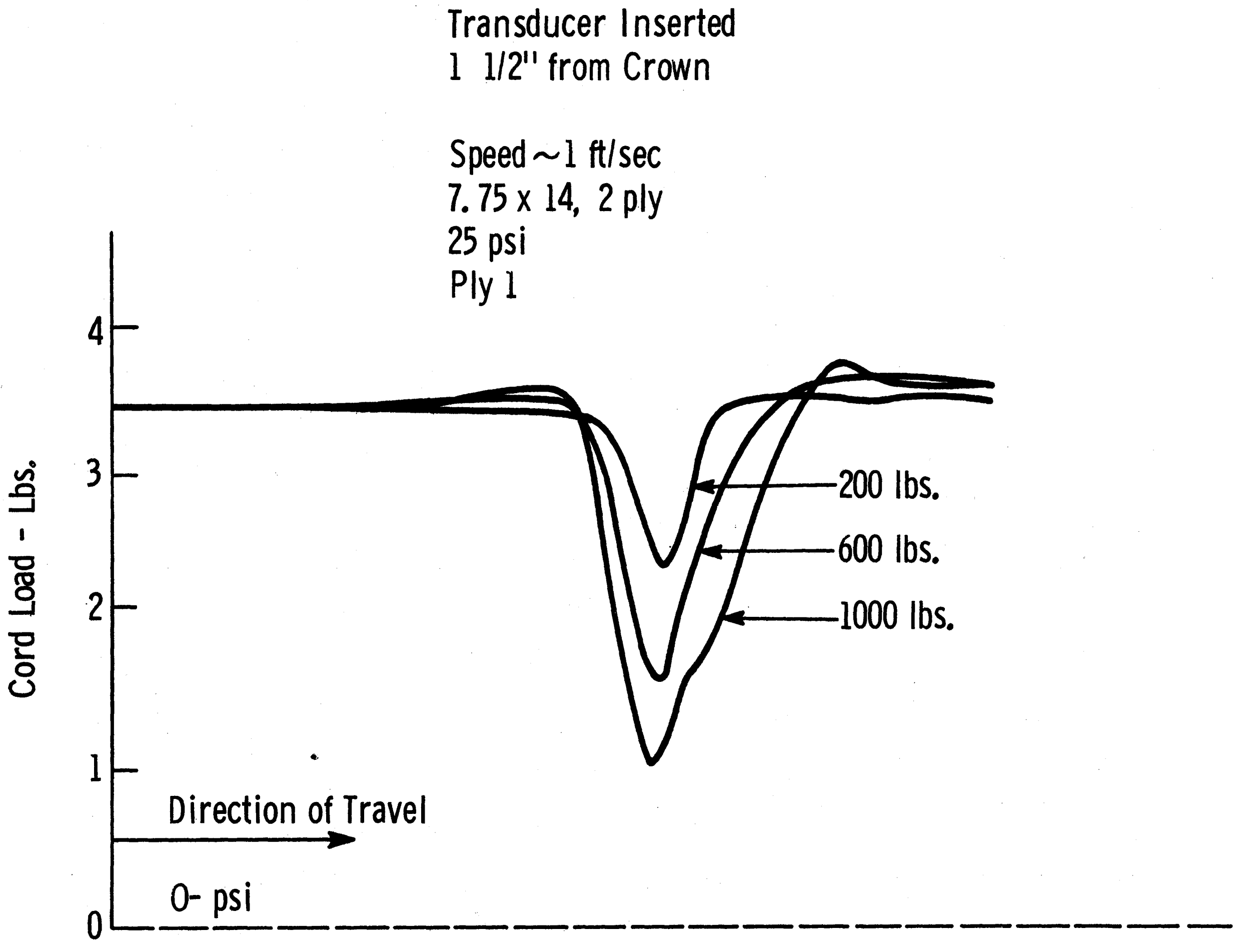

Fig. 5. Constant internal pressure—varying vertical load.

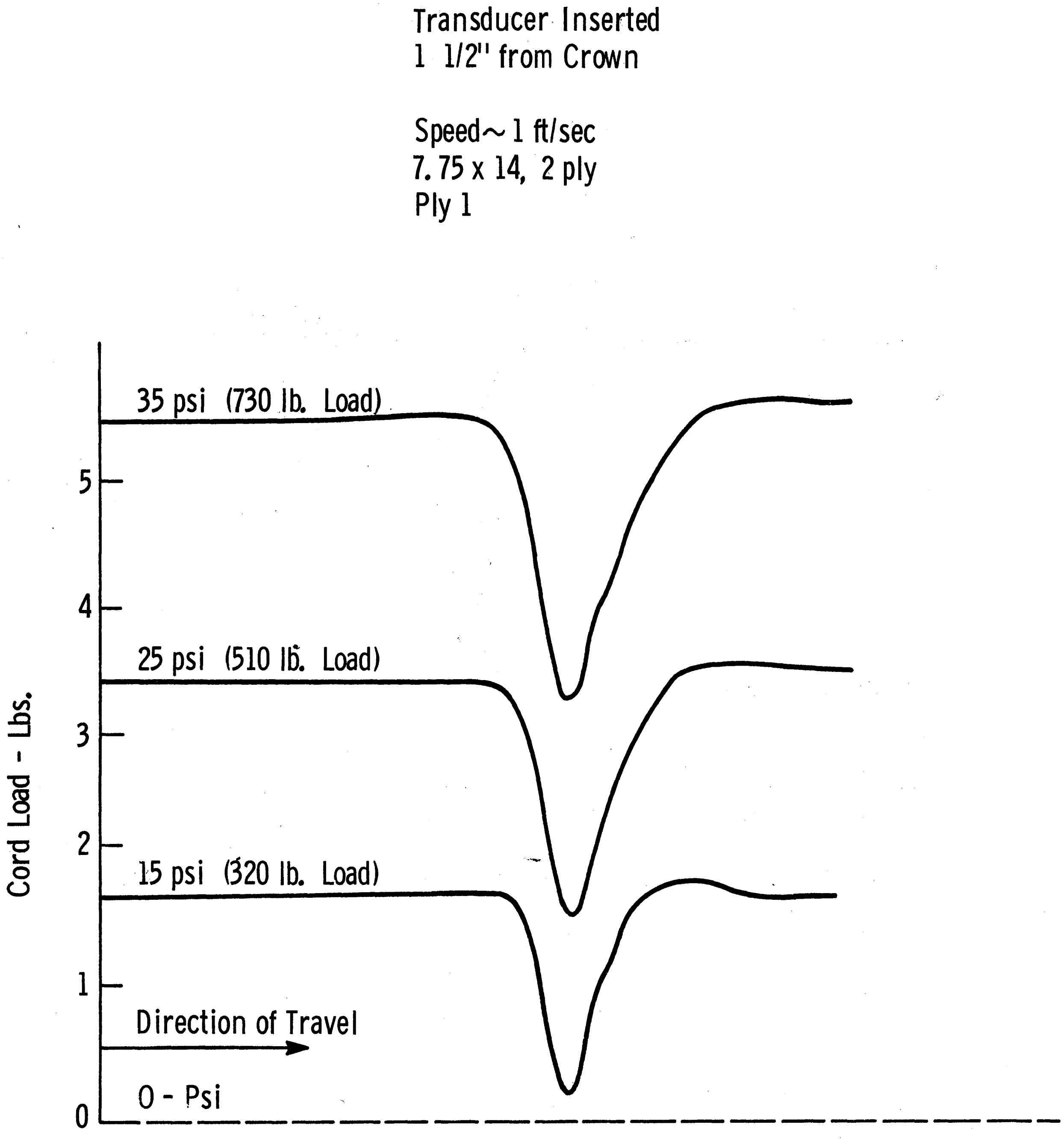

Fig. 6. Constant vertical deflection—varying internal pressure.

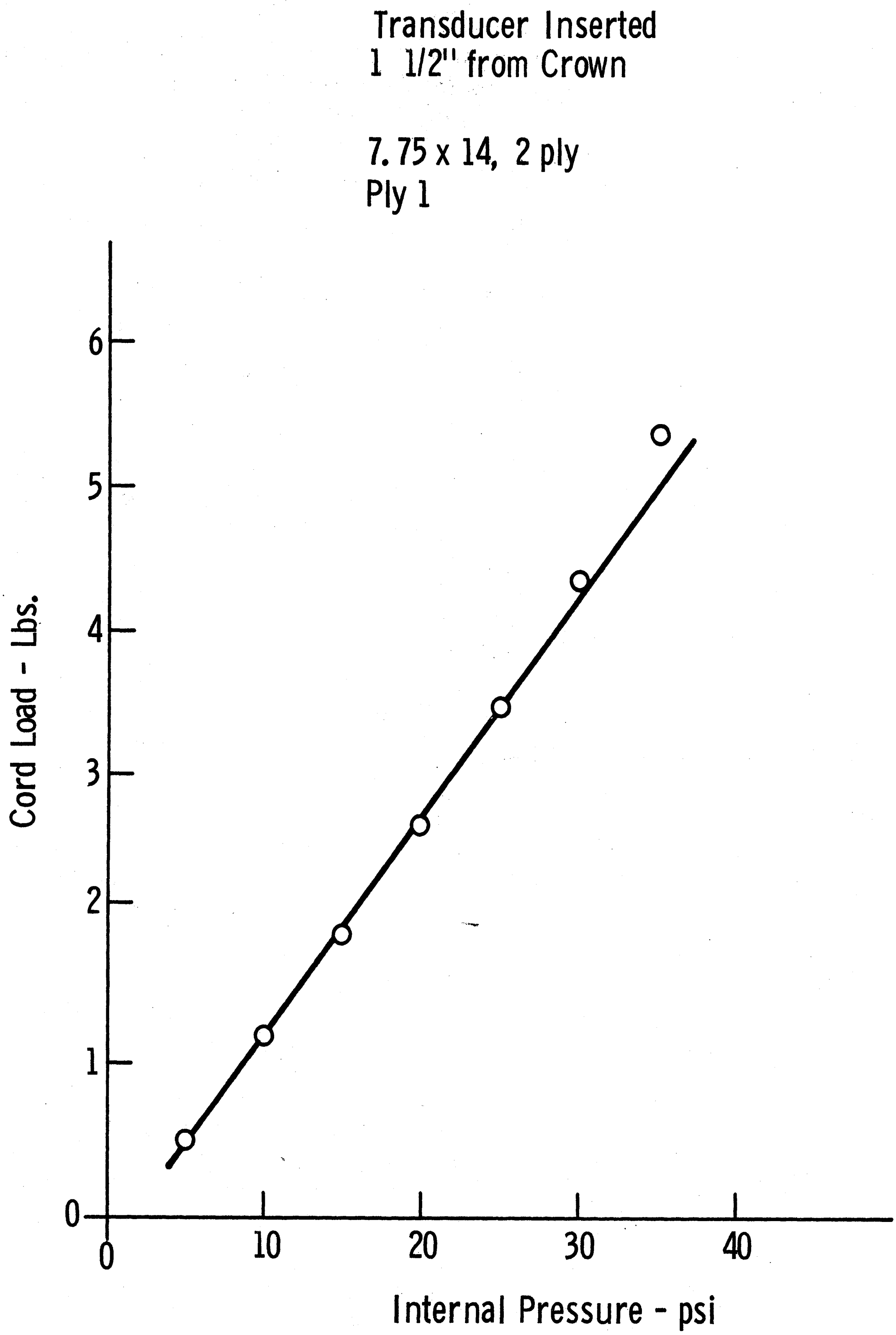

Fig. 7. Inflation loads.

The actual building process begins by cutting the ply stock to size and attaching the inner liner to ply one. The plies are then laid flat on a table, and the cords which are to be replaced by force transducers are removed. Care must be taken that the ply stock is not torn. After the cords are removed, similar cords with transducers attached are placed in the grooves formed by removing the original cords. Care must be taken to locate the transducers at the desired meridianal positions. The transducers are then covered with skim stock.

The tire building process is continued by threading the transducer leads through ply one and the inner liner. The leads are then coiled inside Mylar tape envelopes which are pressed against the inner liner. These envelopes protect the leads during the curing process.

The next step is to carefully place ply two over ply one in such a way that the transducers will be in the proper position relative to each other. This positioning must be computed before building and must be laid out on the ply layouts. This is not a trivial exercise due to the great distortion which takes place when the tire is formed. The leads of ply two are then threaded through to the inside of the liner and placed in the Mylar packages.

With both plies in position the composite (sometimes called a "pocket") is rolled onto the building drum where the splices and stitching are all carefully done by hand. Care must be taken to keep any rollers away from the transducers while attaching the beads and securing the turn ups.

The final step on the building drum is to attach the tread. It must be carefully placed relative to the gauges, so that the splice may be hand stitched as well as steam-pressed without damaging any lead wires.

The building process completed, the tire is placed in the mold and cured. No post cure inflation is used after curing, in order to minimize the time that the transducers are subjected to heat while under load.

A two-ply tire was built using the procedure just described and tested by slow rolling on a flat plank machine. Cord load measurements from these tests are shown in Figs. 8-14. The data includes readings from three different carcass locations.

Although no analysis of the above data has been attempted, it serves as an indication of possible applications of the textile cord force transducers described in this paper.

The applications given here have all been to nylon tire cords approximately .028 in. in diameter. Such load transducers could equally well be applied to rayon cords, to polyester cords or to wire or glass. At this time there seems to be no reason for anticipating any limitation of this method from the cord material itself.

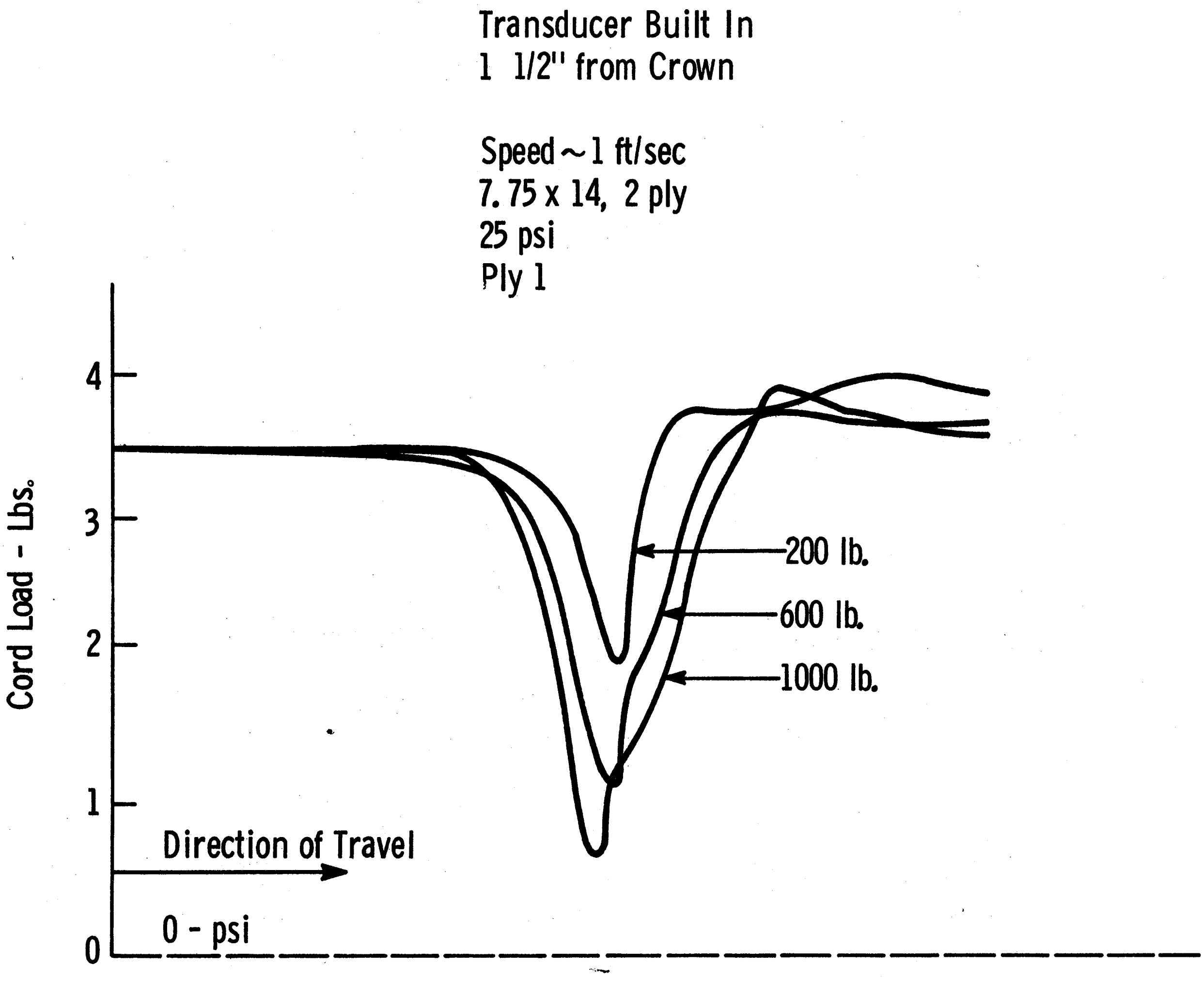

Fig. 8. Constant internal pressure—varying vertical load.

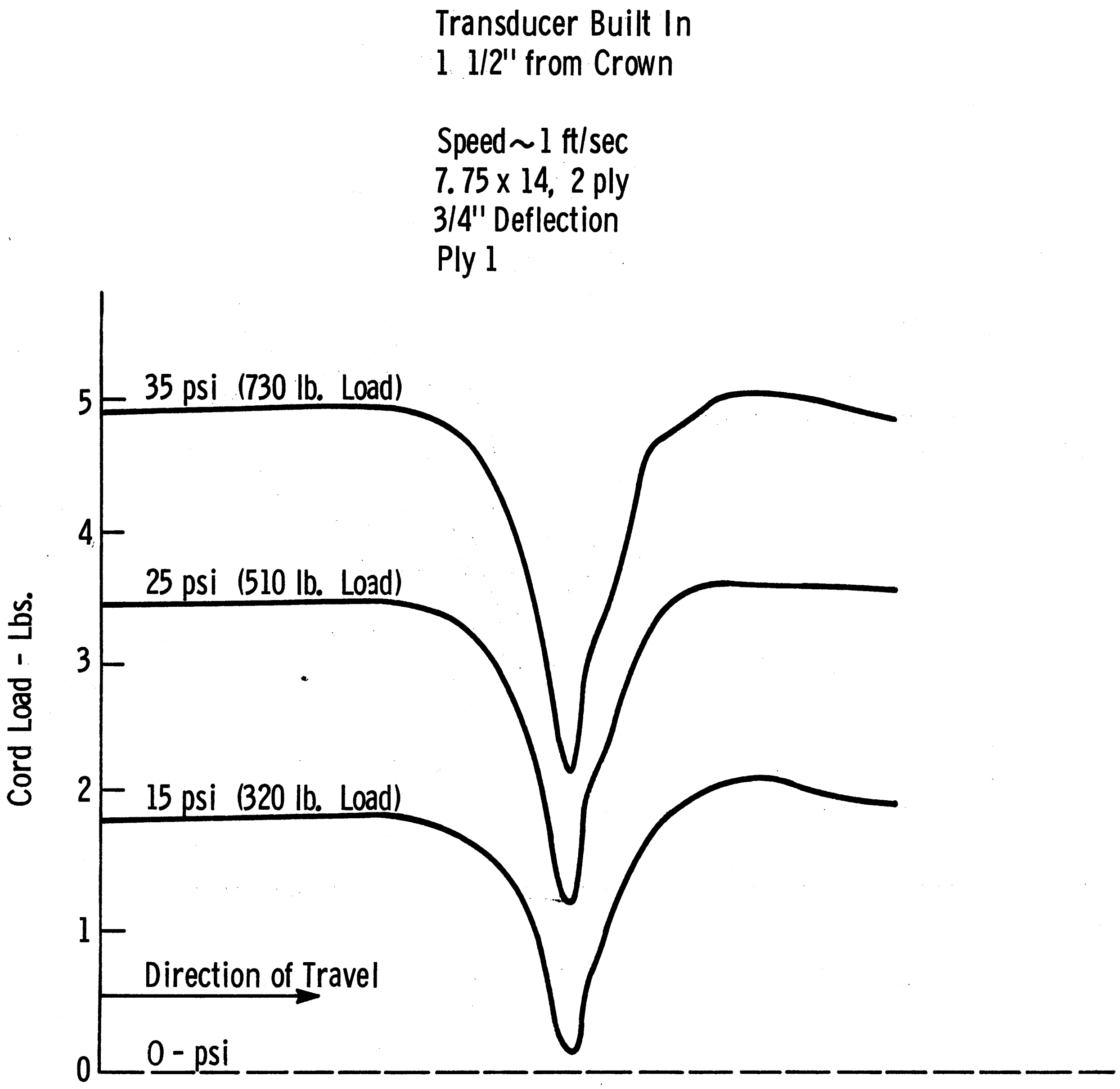

Fig. 9. Constant vertical deflection—varying internal pressure.

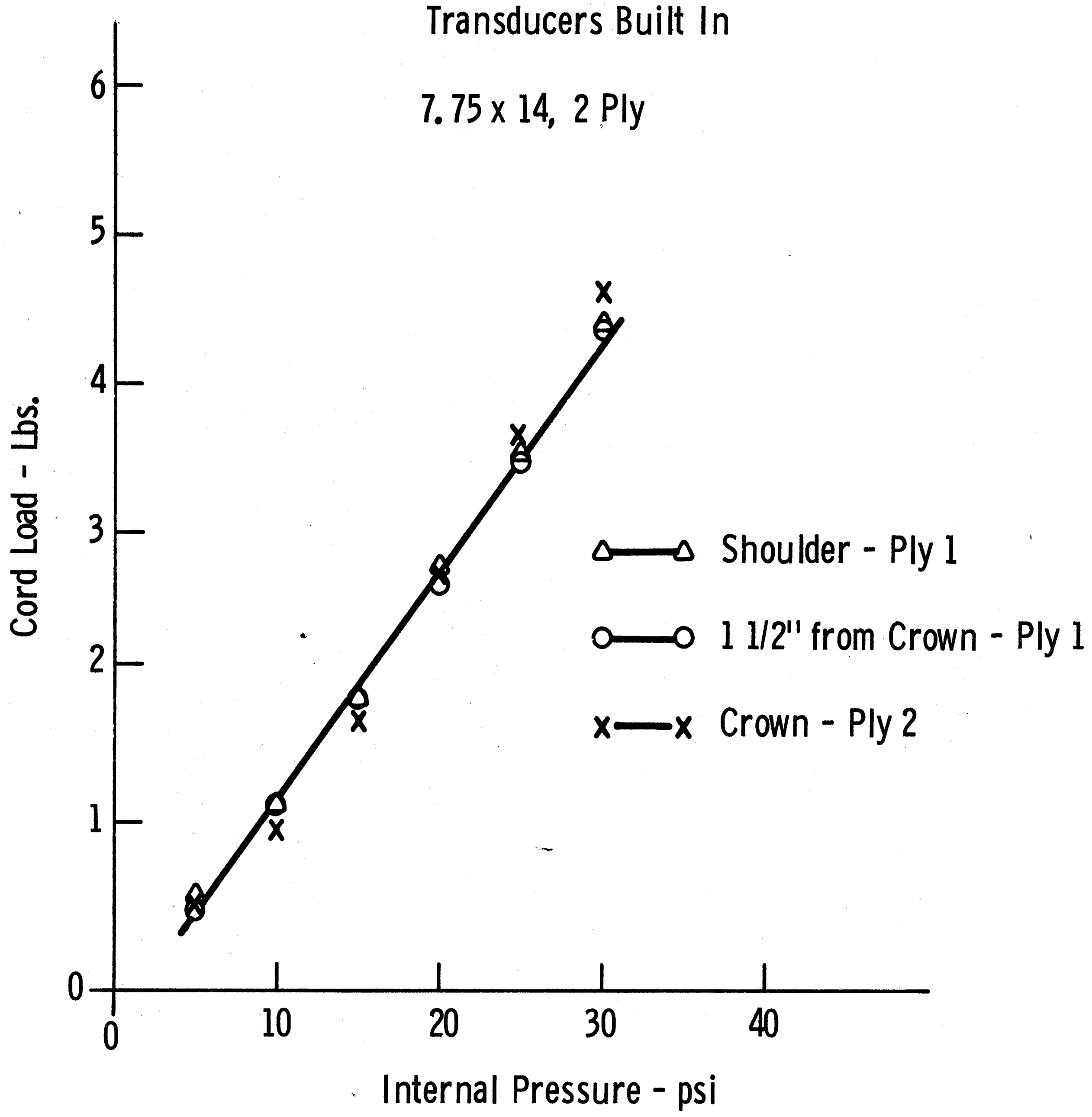

Fig. 10. Inflation loads.

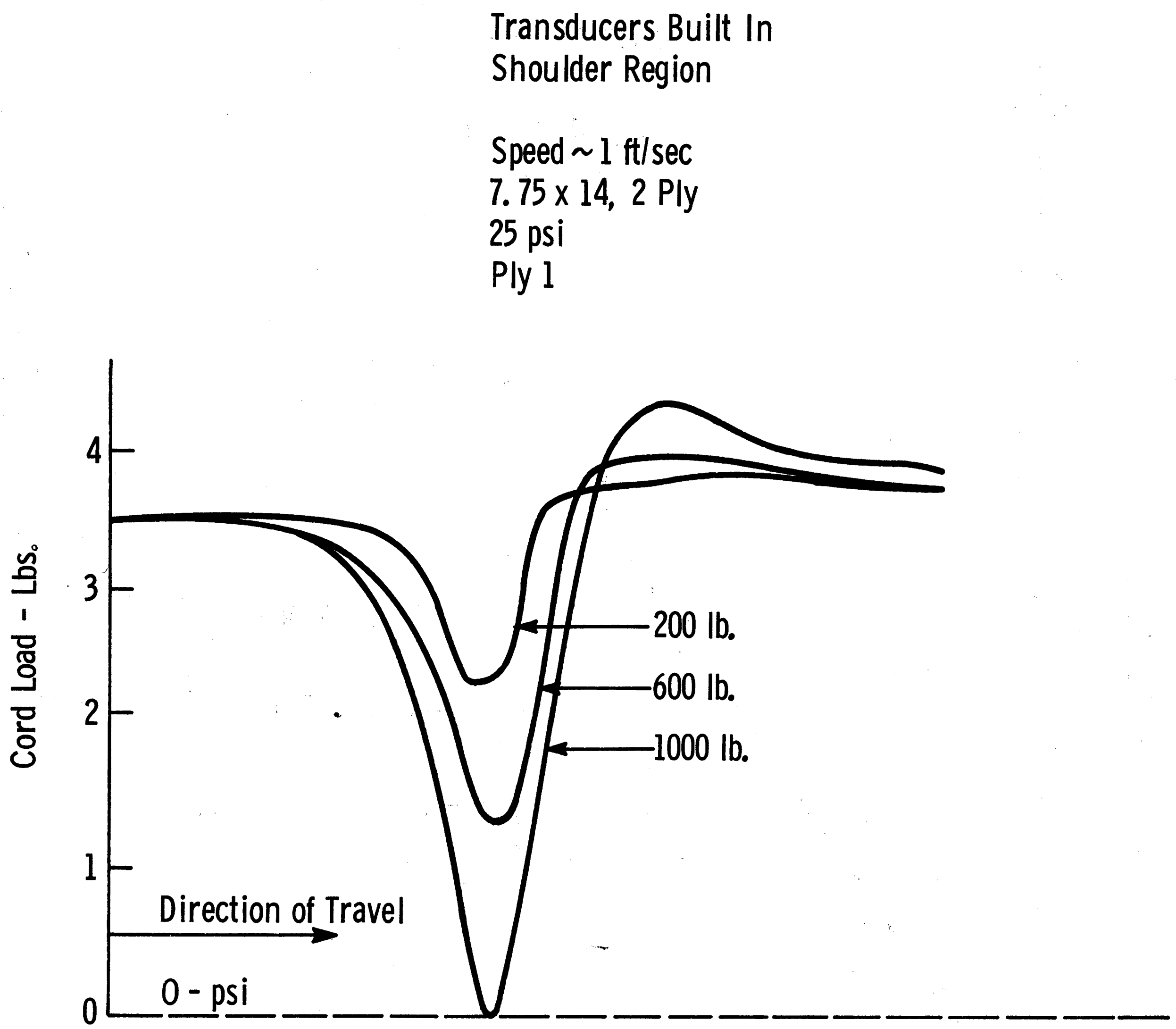

Fig. 11. Constant internal pressure—varying vertical load.

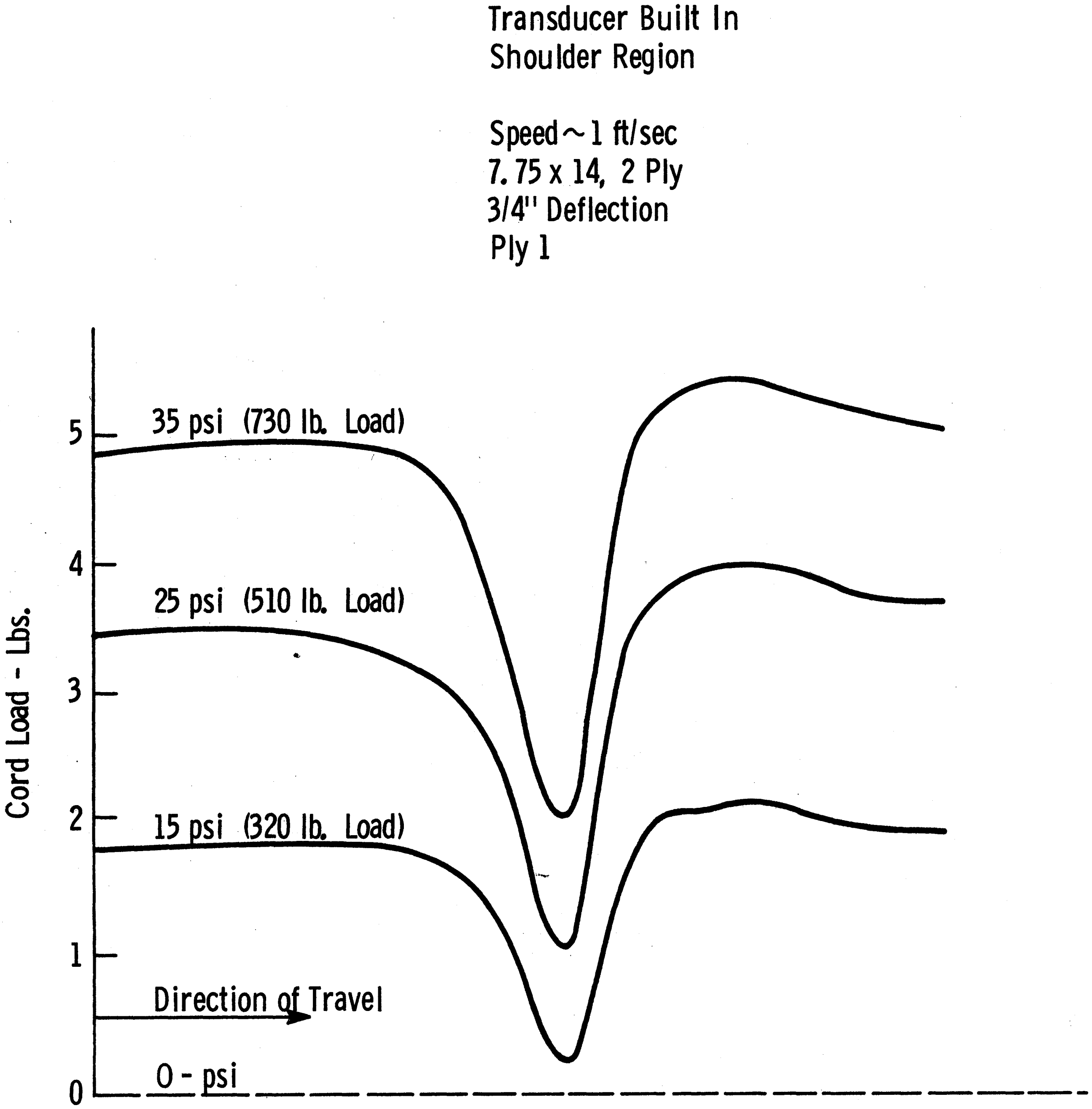

Fig. 12. Constant vertical deflection—varying internal pressure.

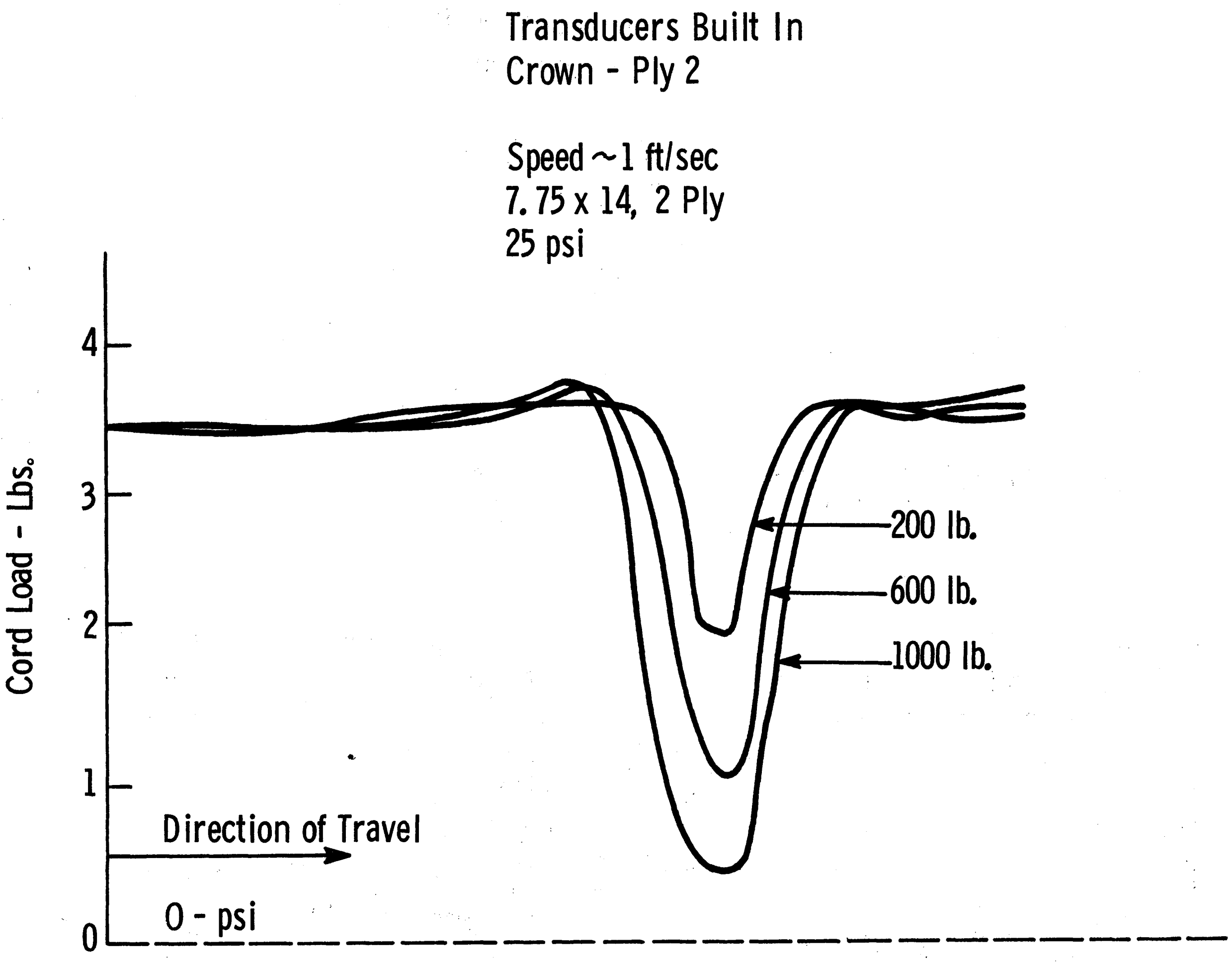

Fig. 13. Constant internal pressure—varying vertical load.

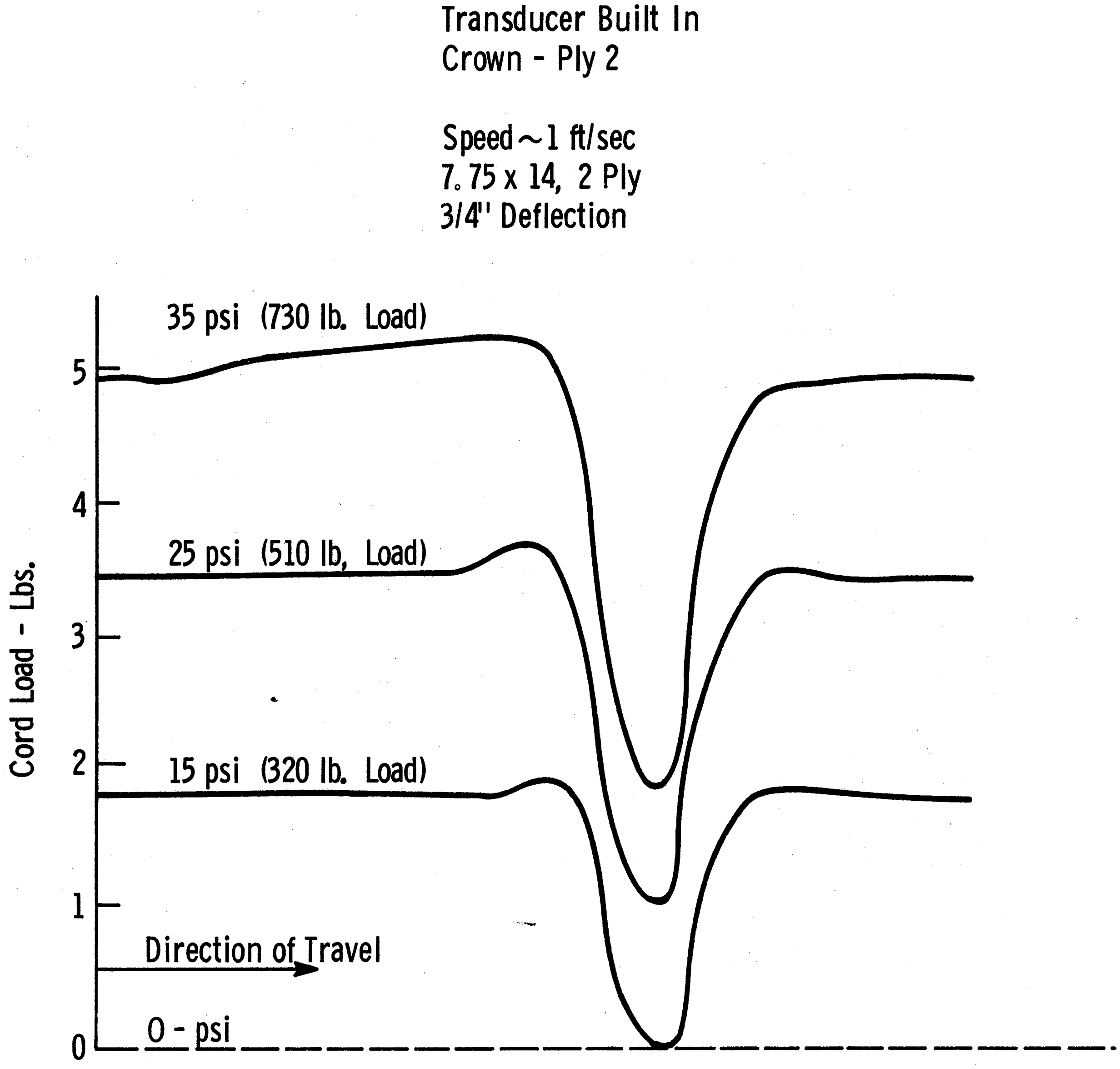

Fig. 14. Constant vertical deflection—varying internal pressure.

VI. ACKNOWLEDGMENTS

Acknowledgment should be made of the very skillfull manufacture of the transducers described in this report by Mr. Ben E. Bourland of the staff of the Department of Engineering Mechanics. His work has contributed significantly to the success of this idea.

Thanks also should be given to the Textile Fibers Laboratory, E. I. Dupont de Nemours Company, Wilmington, Delaware, and to Messrs. John Hannell, Ralph Patterson, and Jal Kerawalla of that laboratory for their enthusiastic cooperation and assistance in building instrumented tires in their facilities.

Finally, thanks should go to Mr. Frederick Reid for setting up instrumentation and collecting data for this report.

VII. REFERENCES

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APPENDIX

A force transducer developed for measurement of cord loads in pneumatic tires is illustrated in Fig. A-1. An enlarged photograph of the transducer is also shown in Fig. A-2. It is constructed by inserting the two halves of a cut cord into the ends of a small metal tube to which small foil strain gauges have been attached on the outside surface. The details of construction are described in this section. This description is for a specific transducer made for Dupont Nylon 1260/2 cord and half hard beryllium copper tubing. The various dimensions pertinent to this transducer are included in Fig. A-1.

A. TUBE PREPARATION

<u>Step 1</u>. The beryllium copper tubing is cut into 7/16 in. lengths. This can be done by holding a sharp razor blade on top of the tubing and rolling back and forth until a score mark appears around the diameter. The tube can then be broken easily at this mark. This piece is then machined to a length of $.400 \begin{smallmatrix}+.002\\-.002\end{smallmatrix}$ by holding in a split reduction collet in a lathe, as shown in Fig. A-3. A speed of 1500 rpm is used, and a very sharp cutting tool is recommended. These precautions are necessary to prevent collapse of the tube as the machining process ends. The burrs are removed from the inside diameter using any small chamfering tool.

<u>Step 2</u>. This step consists of expanding each end of the tube to an inside diameter of .0292 in. To do this the tube is positioned in a special tool, Fig. A-4, designed for this particular operation. This tool incorporates two concentric plungers in a brass frame. The swaging portion of the plungers is a #69 drill shank cut off and inserted in a hole. The protruding length of this shank is controlled by a set screw. This means that when the plungers are pressed forward both the inside diameter and depth of the swaged portions of the tube can be controlled. The total length of the tube may vary slightly. This is corrected by inserting the tube in a .041 in. hole drilled in a small metal disk and sanding on a piece of 400 grit emery paper. Pressure is applied with the index finger by rotating in a circular motion. The same amount of stock is sanded from both ends, thus keeping the ends uniform in length.

<u>Step 3</u>. The transducer is tapped to improve the adhesion characteristics between the nylon cord and tubing. A #90 jeweler's tap (.0354 in. outside diameter) and a holding fixture, Fig. A-5, are used in the tapping operation. Caution is taken that the tap is sharp and in good condition. The tap is revolved only one or two turns before removing and cleaning off chips. Liberal use of a tapping fluid minimizes tap breakage. The tapping takes place only to the bottom of the swaged portion. Upon completion of tapping the tube is

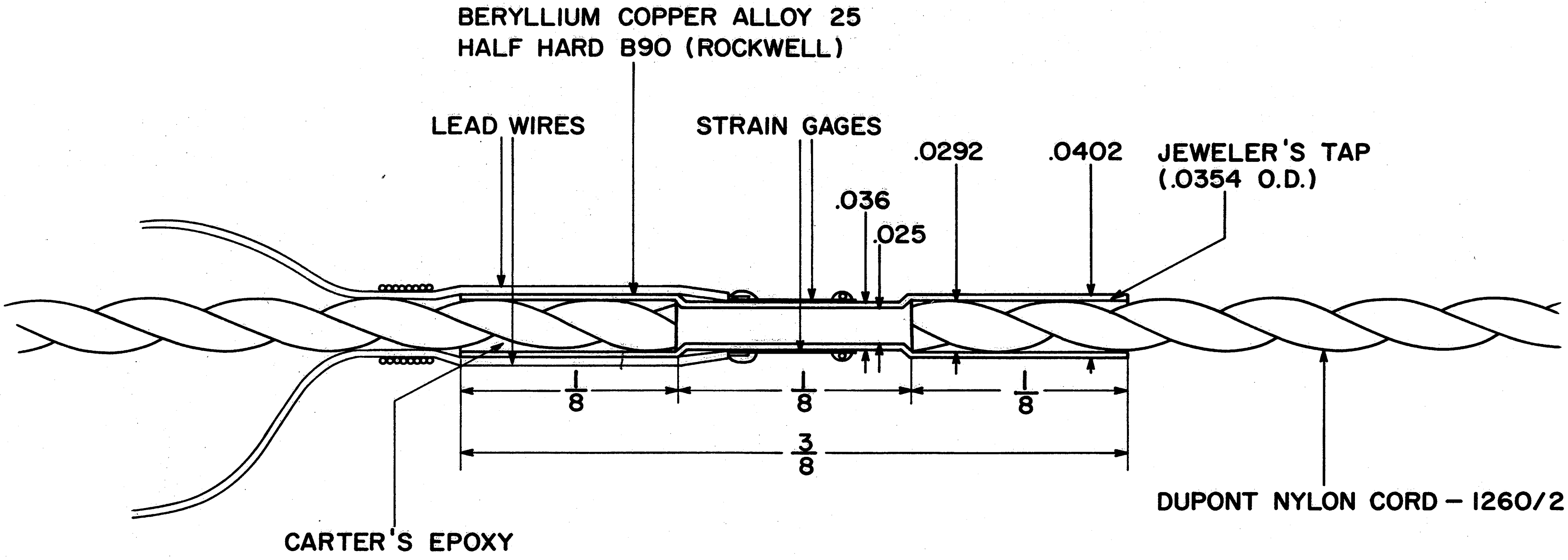

Fig. A-1. Cord load transducer.

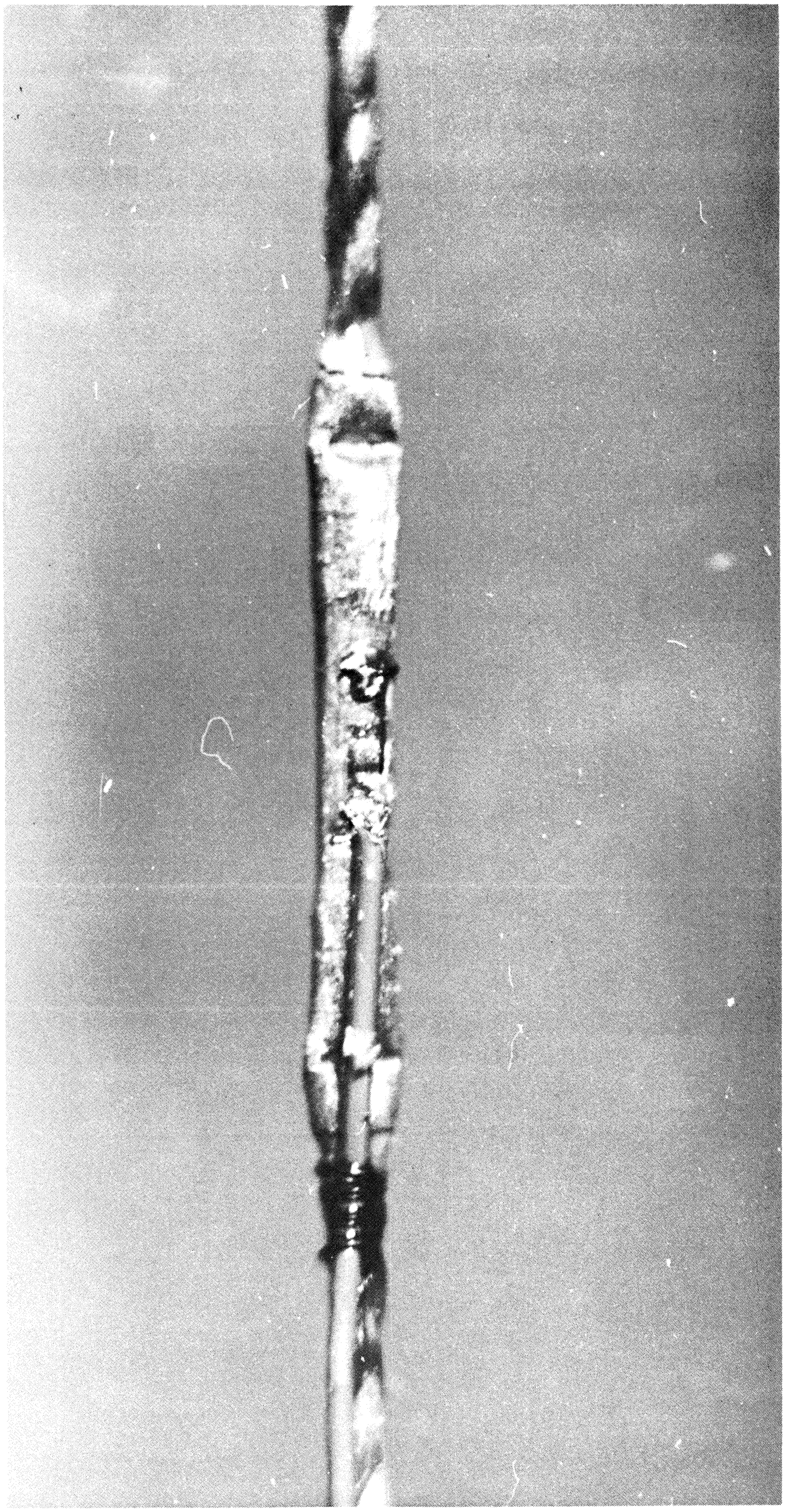

Fig. A-2. Enlarged photograph of force transducer.

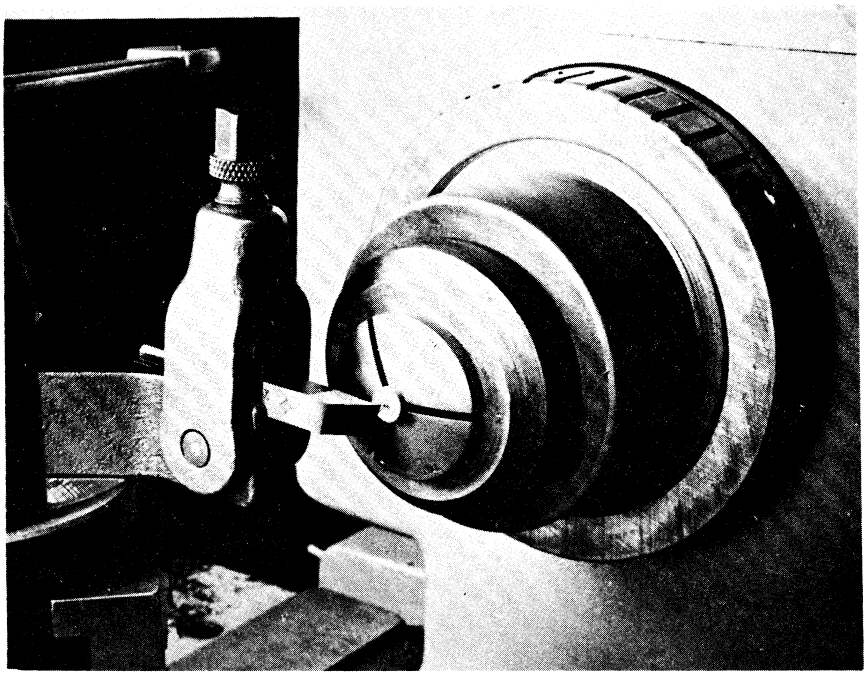

Fig. A-3. Machining of tube.

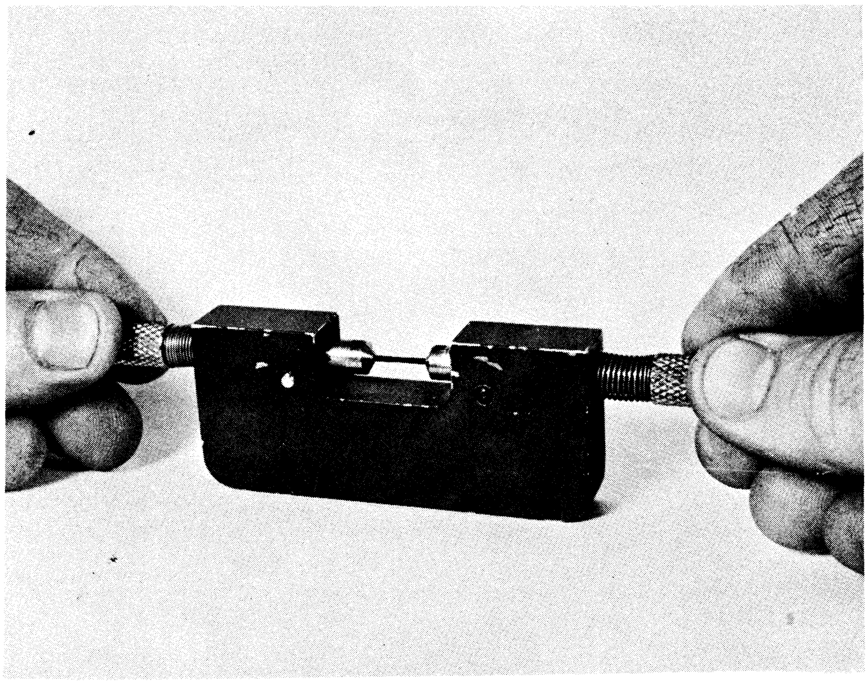

Fig. A-4. Expanding of tube.

Fig. A-5. Fixture for tapping tube ends.

cleaned with acetone, making sure all chips are removed from the inside diameter. The tapped tube is then soaked in a neutralizer* for 1 min, followed by a thorough air drying.

B. CORD PREPARATION

The cord preparation is intended to improve adhesion characteristics. The step by step procedure is as follows:

Step 1. Dip 1/4 in. of the end of the cord in BR-600* strain gage adhesive for 2 min. Keep bottle top closed by passing cord through a slit in a piece of cardboard.

Step 2. Air dry 15 min.

Step 3. Pre-cure cord 1 hr at 150°-200°F.

Step 4. Cut 1/8 in. off dipped end of cord with sharp razor blade to square.

Step 5. Brush cord with small wire brush to remove dip coating and improve adhesion.

C. TRANSDUCER ASSEMBLY

Having completed steps A and B, the transducer is ready for assembly. The step by step procedure for this assembly is described below.

Step 1. A small amount of epoxy cement is mixed just prior to assembly of the cord to the transducer.

Step 2. Using a pointed probe (sharpened end of a Q-tip) the epoxy is applied to the inside diameter of the tube.

Step 3. The solid end of the cord is dipped into the epoxy and inserted into one end of the tube. The cord is screwed into the tapped end, aiding the spreading out of the epoxy as well as eliminating trapped air pockets.

Step 4. This procedure is repeated for the other end of the cut cord. Caution must be used so that the other end of the tube remains in contact with the epoxy.

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*See list of trade names.

Step 5. The force transducer is placed on the crimping fixture, Fig. A-6, taking care to center it exactly over the two piano wires. Each end is fastened with a piece of masking tape.

Step 6. The top half of the fixture is placed over the dowel pins and tapped lightly with a hammer. The two washers serve as a positive stop and control the depth of the crimp, Fig. A-7.

Step 7. The transducer is cured in an oven for 1 hr at 200°F.

D. STRAIN GAUGE INSTALLATION

Step 1. Gauge Preparation. Micro measurement strain gauges (No. MA-09-015DJ-120)* are used for the load measurements. These gauges are received from the manufacturer with varying sizes of a general purpose epoxy resin film backing which must be trimmed to a uniform size. The actual size of the grid portion of these gauges is .015 in. long by .020 in. wide, plus a soldering tab on either end making the overall size .015 in. by .100 in.

(i) The surplus foil is trimmed away with a sharp razor blade, working on a piece of plate glass. A margin approximately .005 in. wide is left around the boundary of the gauge. A source of intensified light directed behind the razor blade, and a white paper beneath the glass, improves visibility during the trimming procedure. It is advisable not to saw back and forth with the blade, but instead press straight down. A straight cut prevents tearing the gauge. Care must be taken at this point not to drop the gauge since, due to the static electricity in the foil, the gauge will tend to repel itself from the blade each time a side is trimmed. This can be prevented by holding the gauge very gently on one tab with a fine probe.

(ii) The gauge is laid face up (silvery side) on a glass plate. A piece of Mylar tape (3-M #850)* 1/8 in. wide by 3 in. long is placed over the gauge at right angles to the length of the gauge. The tape is pressed firm with the finger and then peeled back, leaving one end attached to the glass plate. The back of the gauge is cleaned with cotton applicator slightly moistened with neutralizer.* This is then set aside to dry while the next step is completed.

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*See list of trade names.

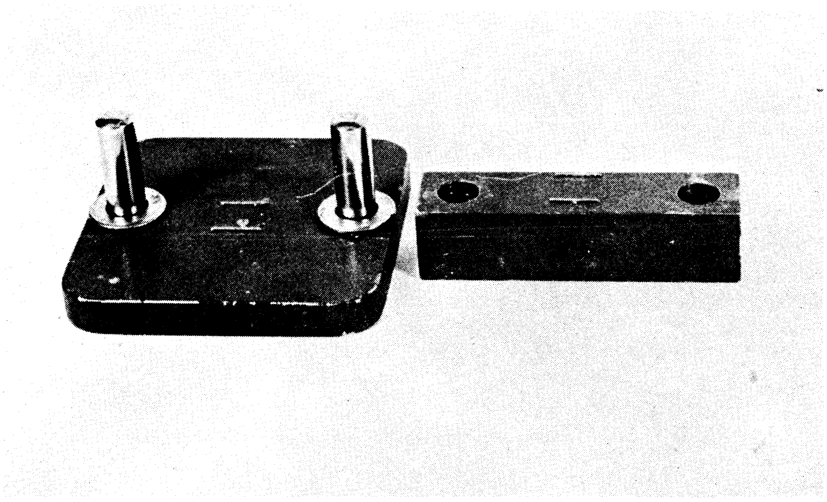

Fig. A-6. Components of crimping tool.

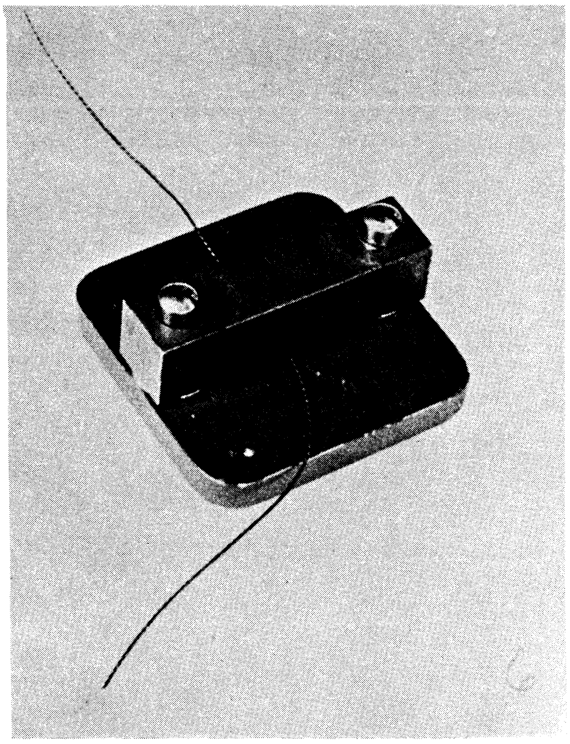

Fig. A-7. Assembled crimping tool.

Step 2. Surface Preparation (For copper alloys)

(i) Clean surface with gauze saturated with solvents such as trichloroethylene, toluene, acetone, methyl ethyl ketone, alcohol, etc.

(ii) Be sure surface is dry and at a temperature of 70°F to 100°F.

(iii) Dip 1 in. strip of silicon carbide into metal conditioner, lap surface and remove with clean tissue.

(iv) Apply metal conditioner to surface with cotton swab and remove with one stroke of clean tissue.

(v) Apply isopropyl alcohol to surface with cotton swab and remove with one stroke of clean tissue.

Step 3. Gauge Mounting

(i) Remove gauge and Mylar tape package from glass plate and apply a thin coat of adhesive to the gauge portion of specimen. Air dry a minimum of 5 min at 75°F. Do not air dry more than 15 min.

(ii) Place the gauge in position on the specimen (the tape will hold the gauge).

(iii) Cover the gauge with sheet Teflon* (.003 in. thick) and hold in place with a piece of Mylar* tape.

(iv) Clamp the gauge to the surface (5 to 50 psi) utilizing silicone gum backed up by a small metal plate to equilize pressure. (Be sure Teflon extends beyond the silicone gum.)

(v) Cure adhesive 1 hr at 200°F.

(vi) Cool and remove the clamp and tape. Clean the tape mastic from the gauge with cotton applicator and rosin solvent.

(vii) Tin gauge tabs and terminals and install suitable lead-in wires.

(viii) Dissolve solder flux with rosin solvent and blot with tissue.

(ix) Check gauges with VTVM for correct resistance.

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*See list of trade names.

(x) Apply suitable protective coating.

(xi) For transducer applications, post-cure installation for at least 2 hr at a temperature of 50°F to 100°F above the maximum operating temperature.

LIST OF TRADE NAMES AND MANUFACTURERS OF THE FOLLOWING ITEMS USED IN THE TRANSDUCER WORK

Common Name	Trade Name	Manufacturer
A. Cold setting rubber	Base compound EC-801 Class A, 2 accelerator EC-1031	3M Company Adhesives, Coating & Sealers Divn. Box 119 Bristol, Pa.
B. Copper tubing	Seamless beryllium copper tubing .025 x .036 - half hard	Uniform Tubes, Inc. Collegeville, Pa. 19426
C. Epoxy	Carter epoxy (general purpose)	The Carter's Ink Co. Cambridge, Mass.
D. Neutralizer	Neutralizer	
E. BR-600	BR-600	W. T. Bean, Inc. 18915 Grand River Ave. Detroit, Mich. 48223
F. Metal conditioner	Metal conditioner	
G. Lead wire	9A-#36 Teflon coated	
H. Gage coating	Gagekote #4	
I. Strain gage	MA-09-015DJ-120	