THE DESIGN OF A REMOTE READING EXTENSOMETER

Thesis

by

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The problem of an accurate strain gage for use in the experimental determination of stresses is one of great importance. Desirable characteristics of such an instrument are:

1. Accuracy
2. Wide range
3. Maintenance of calibration
4. Lightness
5. Compactness
6. Simplicity
7. Possibility of remote reading

Mechanical, optical, and electrical means, and combinations thereof have been employed to fulfil all or part of the above requirements.

Under the heading of mechanical instruments, come the various lever and dial gage instruments, usually restricted to rather large size, and using diverse methods of attachment to the specimen. Among the most successful of such instruments is that developed by Huggenberger. It employs a 2 cm. gage length, and gives an accuracy of 1% or better at unit elongations of 0.05 to 0.07, about the elastic limit of the heat treatable aluminum alloys. At GALCIT, as well as elsewhere, these instruments have been used with considerable success in structural investigations.

The best optical instrument yet developed is possibly the Tuckerman triple mirror strain gage used by the Bureau of Standards. It is of the self columnating type, the mirrors being in the measuring head, and the reading being done through a telescope of fixed focal length containing both the light source and the scale. The telescope may be set up and the instrument read from any position in the plane of symmetry of the measuring head from which all three mirrors may be seen at once. Proper alignment of the telescope is indicated by the appearance of a secondary image of the light source in the field of view. The measuring head is quite compact, and the sensibility claimed for the instrument is 1/250,000", (1).

The disadvantage of mechanical and optical instruments is that they must be seen, and usually from a definite direction, to be read. Furthermore, their sensitivity is not readily subject to change. An instrument adapted to measuring elastic deformations is practically worthless in the plastic region. The electrical instrument, on the other hand, may be read wherever it is convenient to set up the output meter. Further, by changing the sensitivity of this meter, the sensitivity of the instrument as a whole is changed, and the same measuring head may be used in the elastic region and in at least the first part of the plastic region. All in all, the electrical instrument may have an advantage over the mechanical or optical systems under any conditions, and certainly it excells for remote reading.

Electrical instruments in general may be classified as

(1) See Trans. of A.S.T.M., Vol. 23, Part II, p. 602, 1923

resistive, capacative, or inductive. The resistive type depends on the deformation of the sensitive element producing a measurable change in the resistance of the element. For this element carbon strips or resistance wire are usually employed. For example, carbon strips cemented to the blade and connected through an oscilloscope have been used to discover vibration patterns in metal airplane propellers, (2), and a wire wound tension dynamometer, also connected to an oscilloscope, is used in impace research at the California Institute. For reasonable accuracy, however, these elements require considerable force to make them operate, and the setup becomes quite bulky. Furthermore, the carbon strips are subject to creep which renders them undesirable for static investigations.

In the capacitive type of instrument, the strain of the specimen is made to operate a variable condenser on which is impressed an alternating voltage of radio frequency. The change in current due to change in capacity may be measured with suitable instruments. In general, however, these instruments are highly sensitive to anything in their immediate or even remote neighborhood, and maintenance of calibration is practically impossible.

The inductive type of instrument, also, is excited by a source alternating current, usually of audio frequency. The sensitive element is a magnet coil with an iron core, the air gap of which is varied by the strain of the specimen. This change in the air gap changes the inductance and in turn the impedance of the coil, which is measured by a galvanometer

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(2) See Trans. A.S.M.E., Vol. 59, p. 156, 1937.

in a bridge network containing the coils of the measuring head. The coils are, of course, subject to temperature changes in resistance, but otherwise the instrument is self shielding and quite stable. As mentioned later, the temperature variations in resistance can be minimized by use of the proper circuits. By and large, for static tests, and for dynamic tests of low frequency, the inductive type of instrument seems to be the best.

The author has had some experience with a set of such instruments developed by the Material Pruefungs Anstalt of the Technische Hochschule Darmstadt. These particular instruments were developed to possess very short gage lengths (from ½ to 5 mm.) and so to be adapted to measuring strains in small reentrant corners, fillets, etc. Fig. 1 is a photograph of one of the instruments, about 2½ times normal size, in place on the calibrating bar. Fig. 2 shows the method of attachment to a pipe flange model. A schematic diagram and explanation of the circuit used is shown in Fig. 3, while Fig. 4 shows a section through the measuring head.

The instrument operates as follows: Motion of the armature causes the air gap in the magnetic circuit of one coil to increase, while that of the other decreases. As the two coils form two of the four components of a bridge network, the sensitivity of the instrument is doubled over that of a single coil instrument. Also, if the bridge network is made as nearly symmetrical as possible, variation in resistance due to temperature should be the same for both sides of the bridge, and should cause only a second order unbalancing effect. The deflection of the galvanometer is almost directrectly proportional to the strain of the specimen because: 1, the deflection of the armature is small with respect to the total air gap, and 2, the rectifiers being connected in series, carry a considerable percentage of their rated current, even when the circuit is in balance. This is important, for the response of the rectifiers is not linear, and to approximate a linear response, one must operate well out on the curve where the variation in current, due to the bridge being unbalanced by the action of the strain gage, is a small percentage of the total current.

These particular instruments possessed some undesriable characteristics. First, the zero of the galvanometer would sometimes wander up and down as much as 10% of the maximum reading, but at other times would stay perfectly steady and cause no trouble. This action seemed to be unrelated to anything which went on in or around the instrument, up to the time the author left the Hochschule, remained unexplained. Second, the flexure hinges were a bit too stiff, and the specimen had to be loaded and unloaded several times before the points of the instrument were set and would give reproducible readings for that load range, which naturally precluded using the instrument outside this load range, or above the elastic limit. The foregoing, however, do not appear to be insurmountable difficulties, or characteristics which cannot be eliminated by good design.

A somewhat larger instrument is being developed at present at GALCIT. Alternative designs of the measuring head are given in Figs. 5 and 6. It will be noted that the coils and their iron cores are assembled, and with the binding posts for the ends of the coil, are moulded in a transparent plastic. This provides an excellent method of insulating the coils and holding the parts firmly in place with respect to one another. To date, the core laminations have been produced from two different alloys; from silicon steel, and from a high permeability alloy. Several coils have been wound, and after the mould was redesigned two were successfully moulded in the plastic. One hinge mechanism was made on the principles shown in Fig. 5, but in an attempt to make the hinge as flexible as possible, the mechanism was broken. Another hinge mechanism is under construction on the principles of Fig. 6, and will be used to study the effect of the variables, such as frequency, current, core alloy, air gap, etc. on the response of the instrument. Much time was spent in trying to adapt aluminum wire to the winding of the coils by anodizing it instead of enameling it for insulation, and after several unsuccessful attempts, it was decided to reserve this refinement for the future. It is hoped that by using a vacuum tube circuit it will be possible to use a more rugged instrument in the bridge network than the sensitive galvanometer used in Darmstadt.

At present, no definite predictions as to the performance of the instrument can be made, save on the basis of the experience of others. It is understood by the author that the Pratt & Whitney Company has developed an instrument to take the place of a "go - no go" gage which operates quite successfully on the same principle. Furthermore, his experience with the Darmstadt instrument leads him to believe that if a reasonable gage length is used, and care is taken to see that the supposedly constant factors in the system are actually constant, the instrument should effect a reasonable compromise of the desirable characteristics set forth in the first paragraph.

APPENDIX

The specifications and dimensions of those parts of the instrument already completed are given in the appended working drawings #2-257-2 to #2-257-5 inclusive.

The coils are form wound of 300 turns of #30 enameled copper wire painted with airplane dope to prevent unravelling, and forced onto the cores over suitable insulation. To the brass inserts which have been drilled, but not tapped, are soldered the ends of the coil windings. The assembly is then placed in the mould, the core fitting into the slots in drawing #2-257-4, items 4 and 5 provided and the extra length of inserts projecting into the appropriate holes in items 3 and 6. The mould is then placed in the jig, the powdered plastic is introduced in front of the plunges, and the casting is performed at 315° F and not less than 3,000 p.s.i. The mould is cooled under pressure. The "hard" grade of Lucite is used for the moulding material.

The rough casting is chucked in the mould with the top and bottom removed and the plane surfaces are faced in the lathe. The final operations are the tapping of the brass inserts, and the drilling of the holes in the opposite bosses.

The drawings in this thesis are in the GALCIT files under job 257.

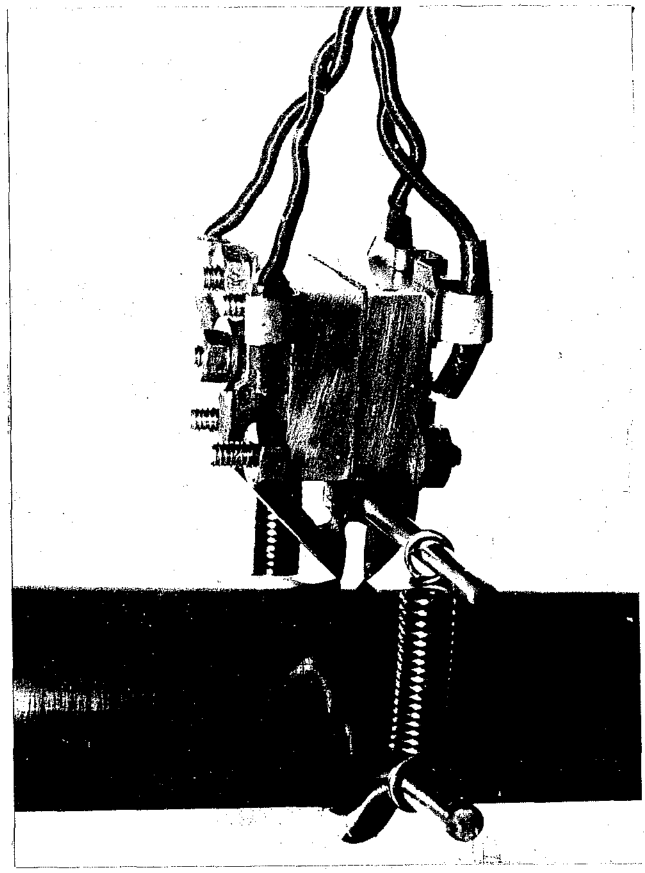


Fig. 1 Darmstadt Instrument on Calibration Bar. About 2½ Times Actual Size

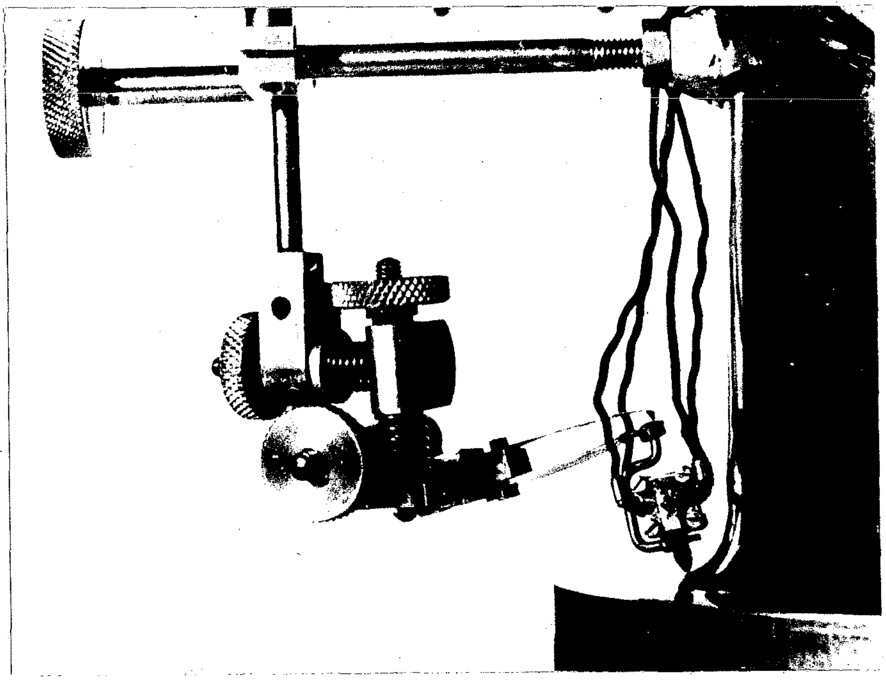
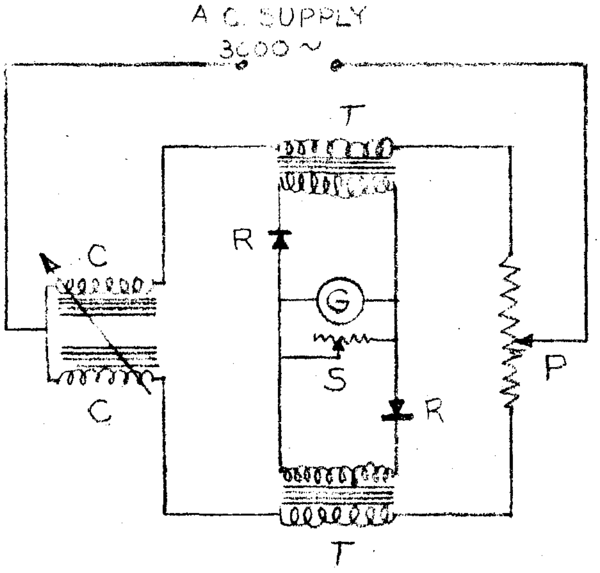


Fig. 2 Darmstadt Instrument Set up to Measure Tangential Strain in the Fillet of a Pipe Flange Model



C ~ COILS

T ~ AUDIO TRANSFORMERS

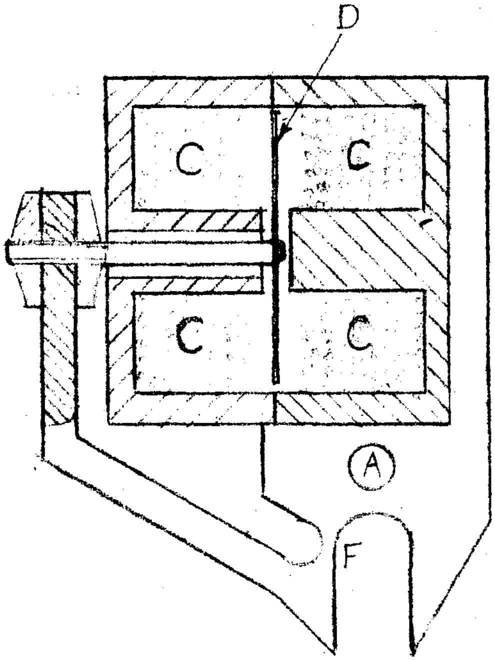
G ~ GALVANOMETER

S ~ VARIABLE RESISTANCE SENSITIVITY CONTROL

P ~ POTENTIOMETER FOR TRIMMING

R ~ RECTIFIERS

FIG 3 SCHEMATIC WIRING DIAGRAM OF DARMSTADT APPARATUS



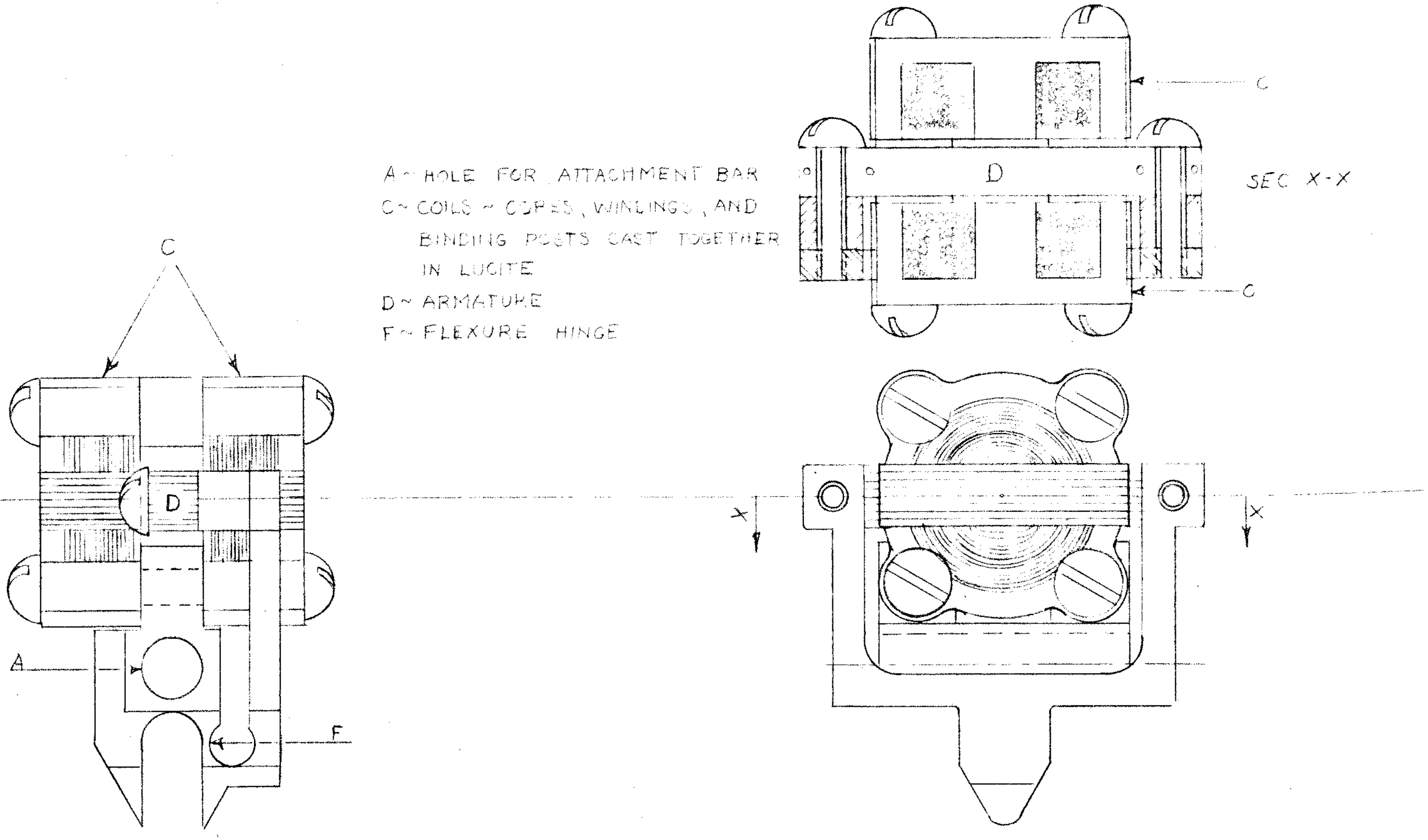
A ~ ATTACHMENT HOLE

C ~ COILS

D ~ DIAPHRAGM ARMATURE

F ~ FLEXURE HINGE

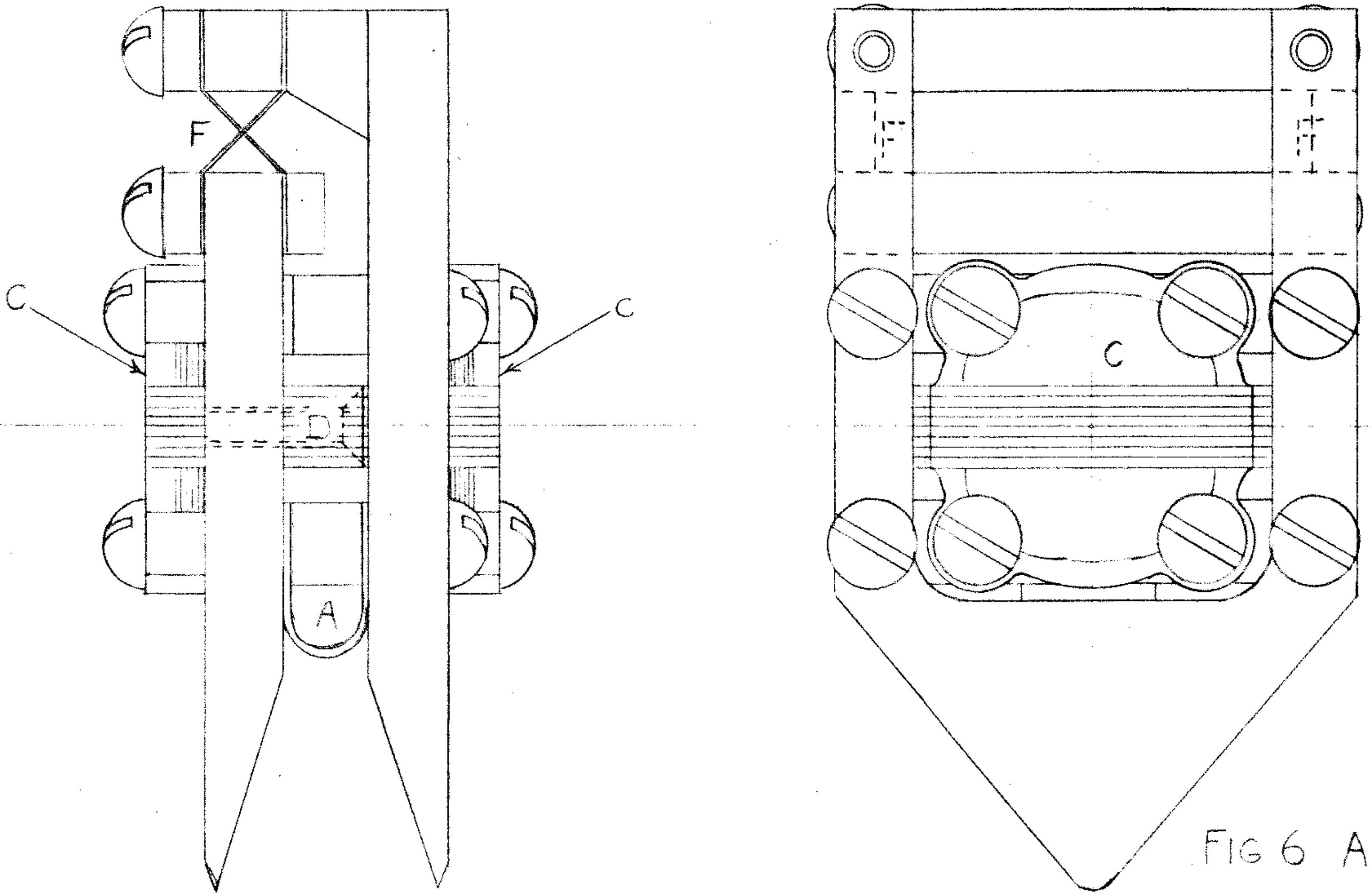
FIG 4 SECTION THRU DARMSTADT INSTRUMENT
ABOUT FOUR TIMES FULL SIZE



A ~ HOLE FOR ATTACHMENT BAR
C ~ COILS ~ CORES, WINDINGS, AND
BINDING POSTS CAST TOGETHER
IN LUCITE
D ~ ARMATURE
F ~ FLEXURE HINGE

FIG 5 COIL AND FLEXURE HINGE ASS'Y

FOUR TIMES ACTUAL SIZE



A ~ HOLE FOR ATTACHMENT BAR

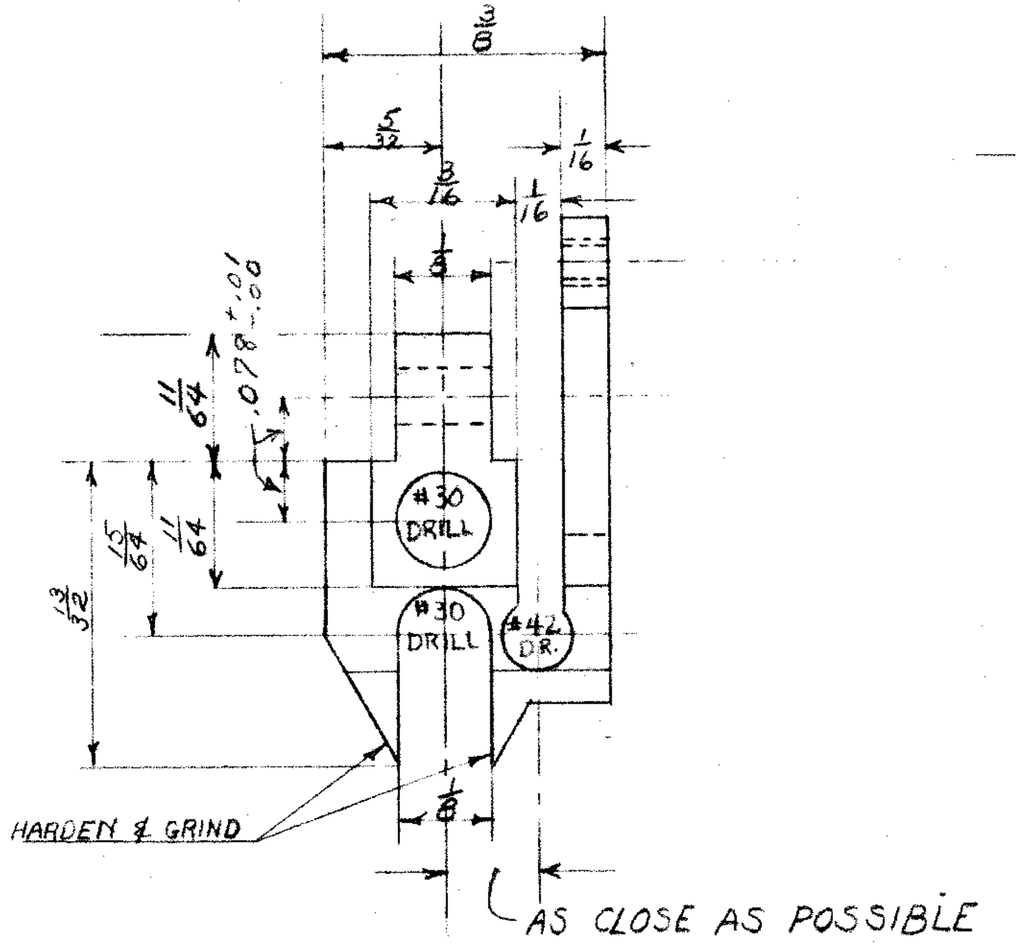
C ~ COILS ~ SAME AS IN FIG 5

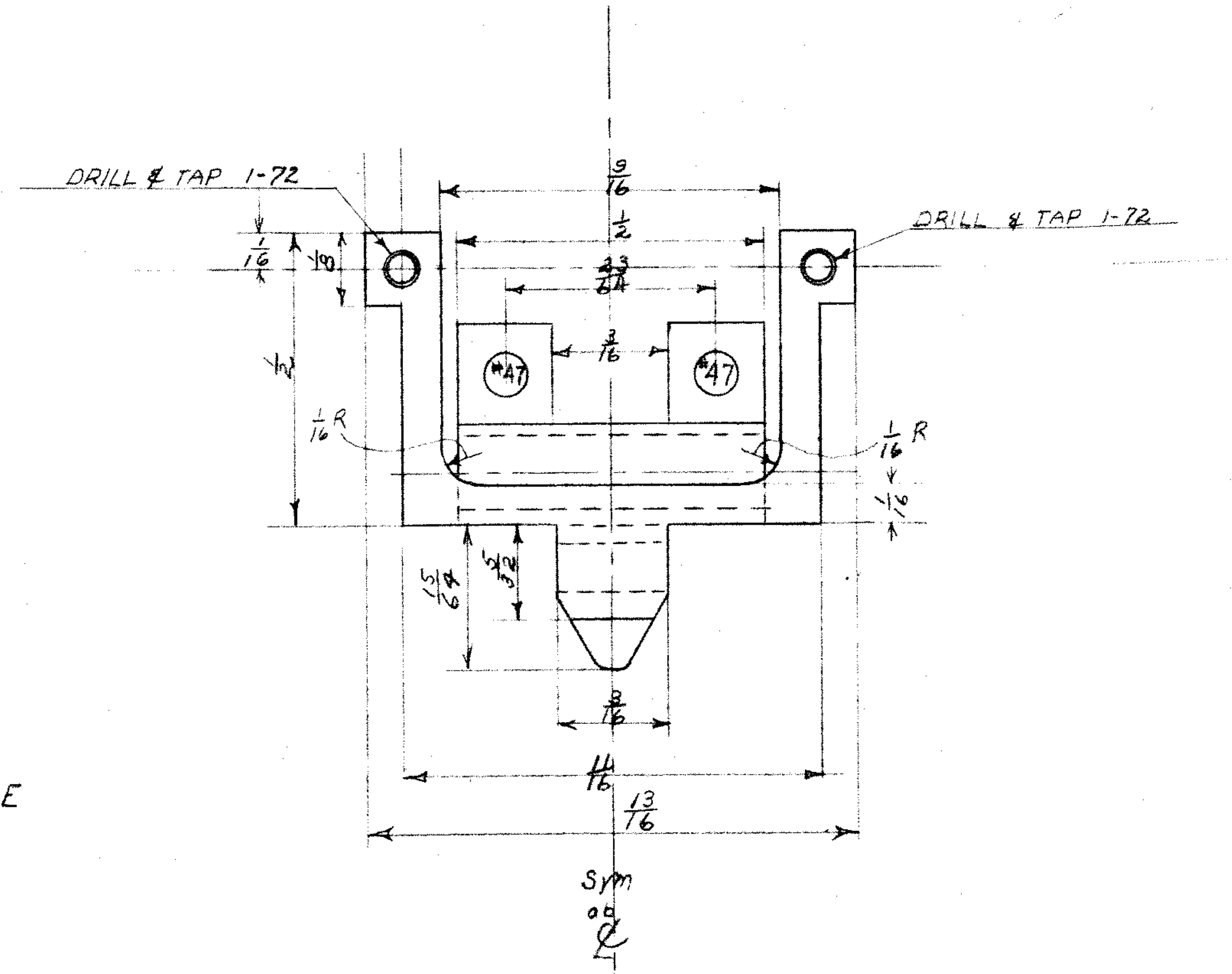
D ~ ARMATURE

F ~ FLEXURE, HINGE ~ FIXED CENTER OF ROTATION

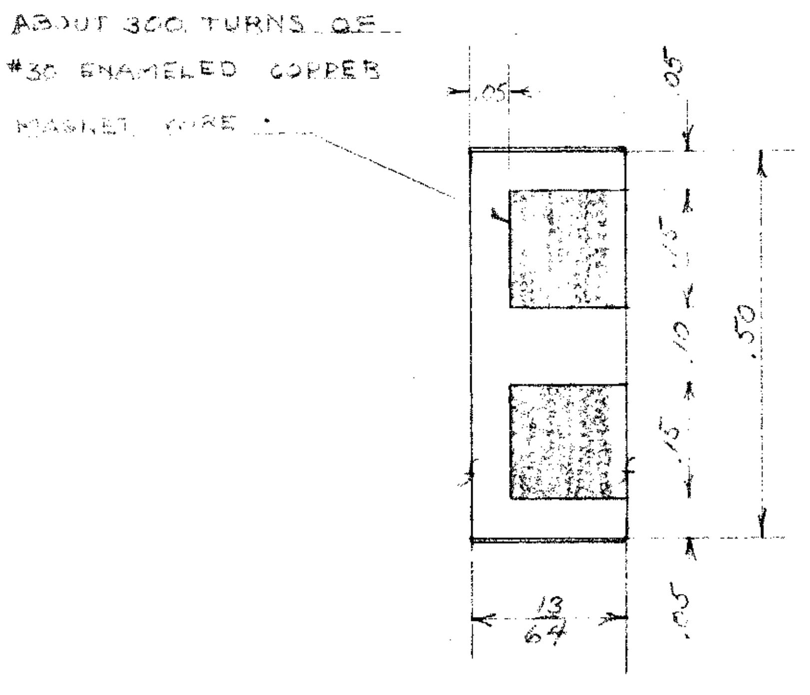
FIG 6 ALTERNATE COIL AND FLEXURE HINGE ASS'Y

FOUR TIMES ACTUAL SIZE

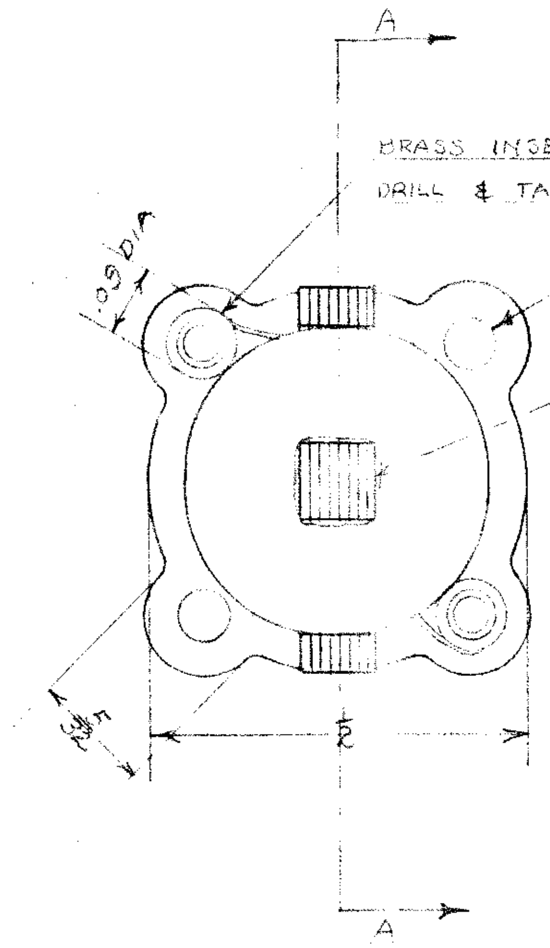




STEEL SAE 1095 OR BETTER	SM. MACH	NOTED	P.H.S. 4/23/39			P.H.S.	TOLERANCES ± .010 OR 1/64 UNLESS OTHERWISE NOTED FOUR TIMES FULL SCALE
MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	
GUGGENHEIM AERONAUTICAL LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY			INDUCTIVE EXTENSOMETER FLEXURE HINGE MECH.				2-257-2
			NAME				DRAWING NO.



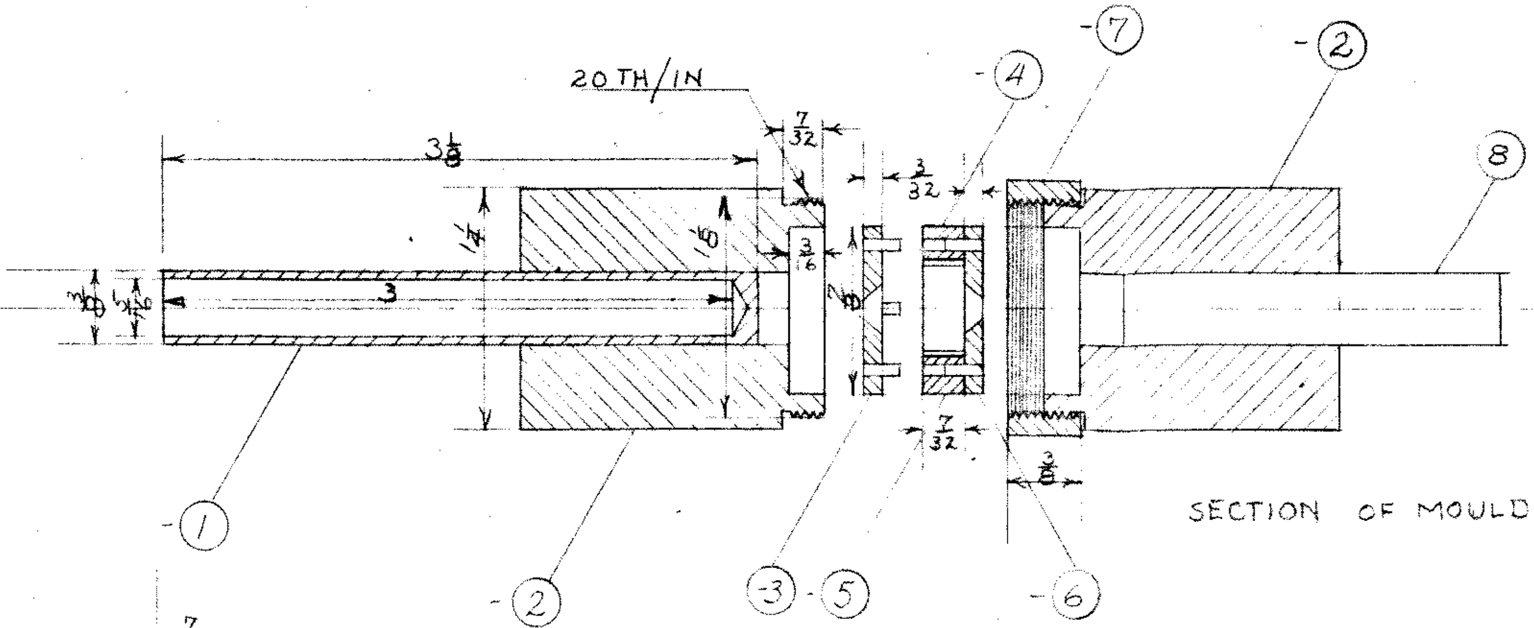
SEC A-A



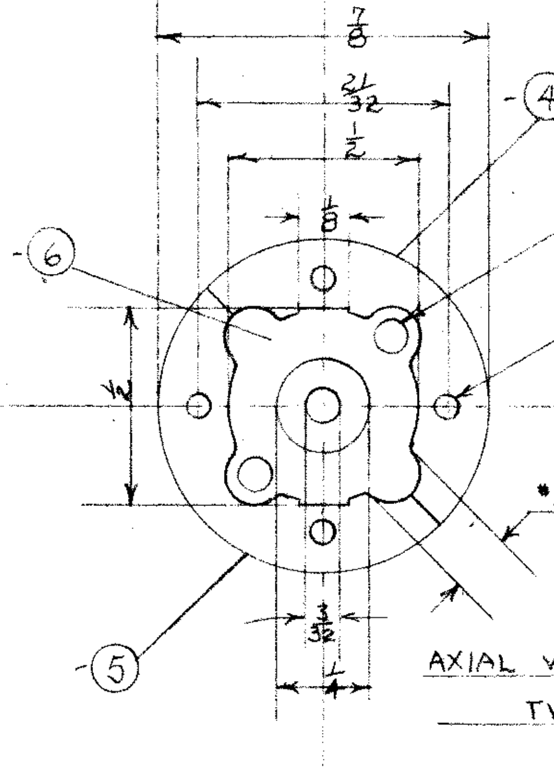
NOTE.

CORE COIL AND INSERTS CAST IN LUCITE

NOTED	f= SM. MACH. FIN.	NONE	PDH 5/31/39				TOLERANCES ± .010 OR $\frac{1}{64}$ UNLESS OTHERWISE NOTED FOUR TIMES FULL SIZE
MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	
GUGGENHEIM AERONAUTICAL LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY			INDUCTIVE EXTENSOMETER INDUCTANCE COIL				2-257-3
			NAME				DRAWING NO.



SECTION OF MOULD & CASTING JIG



#43 DRILL IN -③ & -⑥ TO PROVIDE ALIGNMENT FOR BRASS INSERTS SHOWN IN 2-257-3 ~ CENTERS ON 1/2" CIRCLE ~2 HOLES

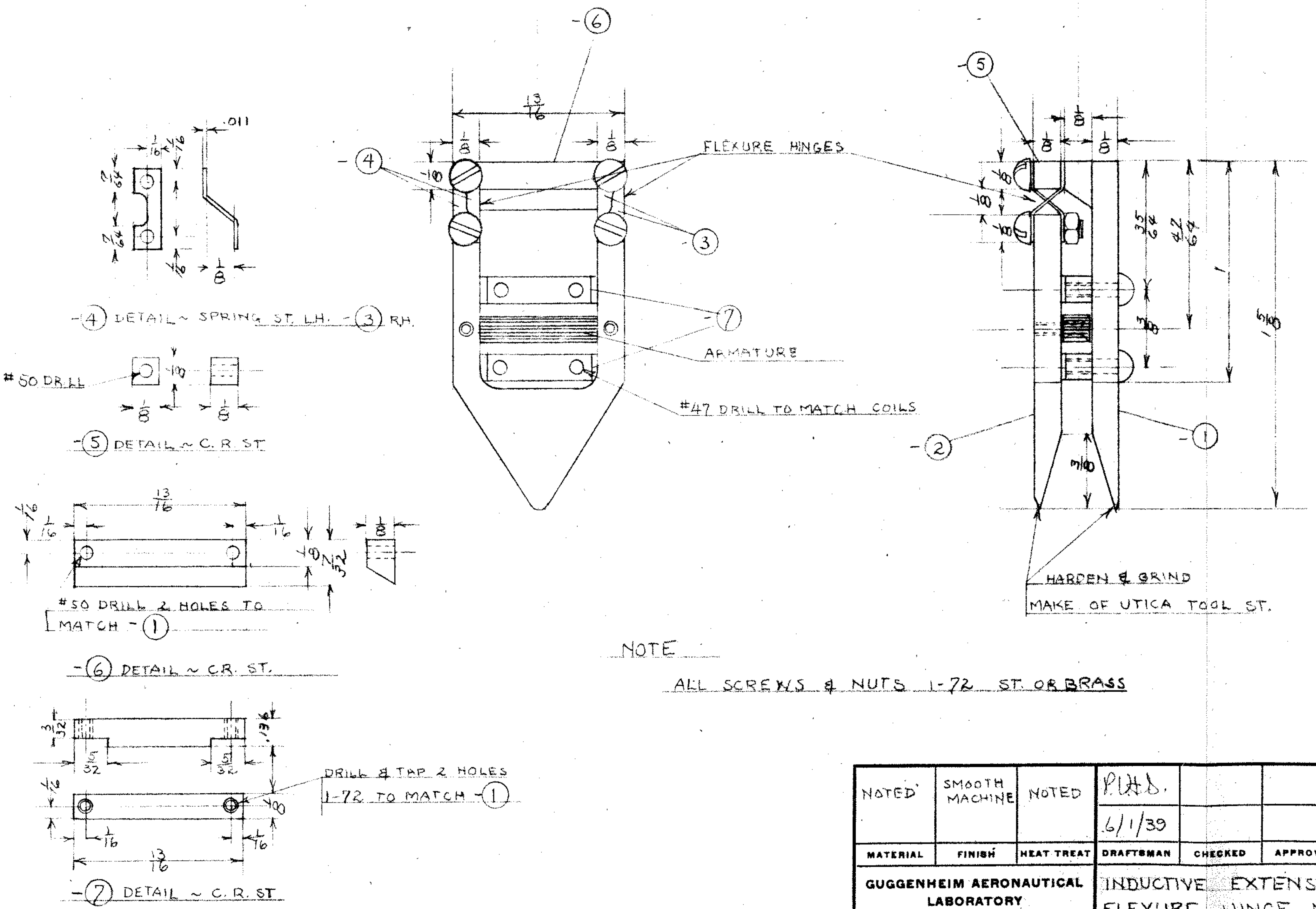
#52 DRILL FOR DOWEL PINS ~4 HOLES
PINS IN -③ & -⑥

#22 DRILL ~ SPACE 90° ~4 HOLES

AXIAL VIEW OF -④, -⑤, & -⑥
TWICE SIZE

-① PLUNGER DRILLED FOR THERMOMETER ~ PUSH FIT WITH -②
-② BODY OF JIG
-③ TO -⑥ INCL. 4 PART MOULD ~ BRASS
-⑦ CONNECTOR NUT FOR JIG ~ FROM STD. 1" NOM. DIAM PIPE
-⑧ PLUNGER

C.R. ST. & NOTED	SMOOTH MACHINE POLISH INSIDE OF MOULD	NONE	P.H.S. 5/31/39				TOLERANCES $\pm$ .010 OR $\frac{1}{64}$ UNLESS OTHERWISE NOTED FULL SCALE & NOTED
MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	
GUGGENHEIM AERONAUTICAL LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY			INDUCTIVE EXTENSOMETER MOULD & CASTING JIG				2-257-4
			NAME				DRAWING NO.



NOTE

ALL SCREWS & NUTS 1-72 ST. OR BRASS

NOTED	SMOOTH MACHINE	NOTED	P.H.D. 6/1/39				TOLERANCES ± .010 OR 1/64 UNLESS OTHERWISE NOTED TWICE SIZE
MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	
GUGGENHEIM AERONAUTICAL LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY			INDUCTIVE EXTENSOMETER FLEXURE HINGE MECH #2 NAME				2-257-5 DRAWING NO.