EXPERIMENTAL & ANALYTICAL INVESTIGATION OF STRESSES In An I. C. Engine Connecting Rod

By
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THESIS
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ROORKEE
1963

CONTENTS

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CERTIFICATE

Certified that the dissertation entitled "Experimental & Analytical Investigation of Stresses In An I. C. Engine Connecting Rod" which is being submitted by Sri Sunil Kumar Bandyopadhya in partial fulfilment for the award of the Degree of Master of Engineering in Machine Design (Mechanical) of the University of Roorkee is a record of student's own work carried out by him under my supervision and guidance. The matter embodied in the dissertation has not been submitted for the award of any other degree or diploma.

This is further to certify that he has worked for a period of 4½...months from May 1, 1963 to Sept. 15, 1963 for preparing dissertation for master of Engineering Degree.

Roorkee,
Dated Sept. 21, 1963.

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A C K N O W L E D G E M E N T

It is with pleasure that the author takes this opportunity to express his deep sense of gratitude to Shri A.B.L. Agarwal, Lecturer in Mechanical Engineering, whose active interest in measurement problems led the author to take up this problem. His deep knowledge of the subject and continuous guidance have influenced in a most important way the author's work at this University.

The author also expresses his sincere thanks to Prof. M.V. K[illegible] for his constant encouragement and help .

Sincerest thanks are also due to Prof. H.H. Alvord for helping in the initiation of the work. Lastly the author thanks the staff of I. C. Engine. Laboratory for their cooperation .

SUNIL KUMAR BANDYOPADHYA

University of Roorkee,
September 20,1963.

GLOSSARY OF SYMBOLS

θ	Crank angle measured from I.D.C position of crank, degrees
ϕ	Angle of obliquity of the connecting rod, degrees.
P	Net gas force on piston. lbs.
F_{ip}	Equivalent piston inertia force. lbs. t
Q	Thrust on the connecting rod lbs $= \frac{P - F_{ip}}{\cos\phi}$
F_a	Axial component of the centrifugal force lbs.
F_r	Net axial load on the rod lbs.
F_n	Component of centrifugal force acting normally on the rod lbs.
M_x	Bending moment at a distance x from the wrist pin (lbs. inch.)
f_{Mx}	stress due to M_x
f_{cd}	Direct stress on the rod due to colmun action.
A	Cross sectional area in sq. inch.
S_y	Yield stress of the material of the rod in psi.
n	colmun end factor (unity for pin end)
E	modulus of elasticity psi.
K	radius of gyration inch.

—0000—

CHAPTER I

INTRODUCTION:- The design engineer is primarily concerned with the determination of stresses a part is subjected to under the actual conditions of loading . The size of the part is so designed that the stresses induced are less than the strength of the material of which the part is made.

Now these stress & strength as has been computed on paper takes into account all ideal conditions. They may include a perfect loading, a perfectly homogeneous material under ideal manufacturing conditions and an orderly stress behaviour. But our day to day experience with the performance of parts tells something which deviates far from the ideal conditions & that frequently is the reason for the failure of the parts.

Machine parts & machines as we see these days are the result of immense hit & trial method of testing and at the cost of a great amount of human effort . Experimental science has given a blow to this method. Experimental stress analysis thus aims in determining stresses & strength of a part under actual service conditions which includes deviations from all ideal assumptions made in the previous para.

Many factors make the experimental stress analysis indispensible and often the only method of solution to complex problems . A multitude of problems are met with, for wich it is a laborious job to get into a theoretical solution and a great many problems are still lying for which no theoretical solution has yet been obtained , experimental stress analysis is the answer in such cases. The advantage of the experimental approach becomes especially obvious if we consider that it is possible to determine experimentally the stress distribution in a machine part in actual operation without knowing the nature of forces acting on the part under those circumstances, which proposition is clearly in-accessible to any theoretical method of analysis.

Coming to the problem of stress analysis of a connecting rod of an engine, the conventional theoritical method takes into consideration the component of gas pressure corrected for the instia effects of piston & connecting rod & the bending stress caused by the contrifugal force acting on the rod. Usually the ~~xxxxxxxxx~~ design is based primarily on those factors only. but it can not be definitely said what effect the temperatures stress have on the rod with running of the engine or what will be the fate of the rod if the alignment is improper or some torsion acts on the rod.

The experimental method is expected to give us a graphic idea of variation of stresses & thus will definitely be a better tool for the design work. The objective of this project is to develop a method of stress analysis of engine parts when the engine is under running condition.

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LIST OF APPARATUS & APPLIANCES USED

No.	Specification.	Maker.
1.	Paper base Straingages, Type -KFP Res: in ohms = 119 ± 0.5% G.F. = 2.88 ± 2% Lot No. 3763	Rohits & Co. ROORKEE (INDIA)
2.	Bridge amplifier meter: Model BAM-1	Ellis Associates, Pelham.m N.Y.
3.	Type 502 Dual Beam Oscilloscope Serial = 008464	Tetronix U.S.A
4.	Oscillograph record camera Type 299 Serial 7323. With '23' Graphic(120 Roll Holder)	Dumont. U.S.A.
5.	'Indu' Film 200/ C° A.S.A.	
6.	Pieco Electric Pressure Pick Up PZ 14 : 3893	Kistler Inst. Corpn. U.S.A.
7.	Electrostatic Charge Amplifer S/N 386 Type 566	-do-
8.	Portable Potentiometer S. No. 27940	W.G. Pye & Co. ENGLAND.
9.	Nife Battery B 10640 Type 2152	
10.	4 Stroke Cooper Diesel Engine, 12 B.H. P. at 350 R.P.M. No.	Distributor Marshall & Sons.

CHAPTER II

EXPERIMENTAL PROCEDURE

ENGINE PREPARATION

Before the exprimentation, the first step was to convert the engine into a test unit. The work comprised of the following items:-

(1) Providing suitable exhaust water pipe to drain out the water from the cylinder jacket.

(2) Arrangement for loading the engine:- The engine had no arrangement of loading . As a first hand solution a rope-brake dynamometer with 1" dia cotton rope was mounted on one of the flywheels. (see photo:- 1)

(3) Providing suitable adapters with both male - female ends such that pressure transducer or indicater may be placed. (design of adapter is dealt with later).

ARRANGEMENT FOR STRAIN GAGES:-

Electric resistance strain gages were chosen as stress transducers in view of its light weight, ease of application, little maintenance , sucessful performance & quick availability .

In order to measure stresses it is necessary to connect the strain gauges in a conventional , wheatstones bridge.

With a 2-gage bridge having one active & the other dummy gage for temperature compensation, it is necessary that dummy gage should not sense any stress . Under these conditions the output of the bridge will be directly proportional to the stress in the active arm.

However in our problem of determining the total axial stresses at various points of a rod our aim was to install a compensating gage which is absolutely dummy to any stress and at the same time should compensate the effect of temperature of the active gage.

The requirements of the dummy gage can thus be summed up as follows:-

(1) It should be subjected to the same temperature.

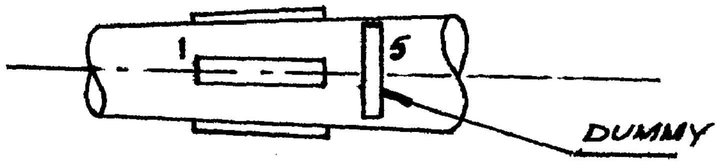
(2) It should be installed at such a place where there is no stress in its active direction.

With reference to the first point it may be said that a very reasonable temperature equality can be maintained by placing the dummy gage in the vicinity of the active one.

The second point requires a perfect strain free direction or a direction sensing very little strain. This is quite a difficult problem to solve, due to the complex nature of forces and geometry of the rod.

As a trial, the dummy gage was placed in the poisson's fashion with respect to the axial strain sensing gages. Following experements were done:-

By connecting gage (1) & gage (5) which is assumed dummy, The peak output was -2.4 cms of scope beam deflection.



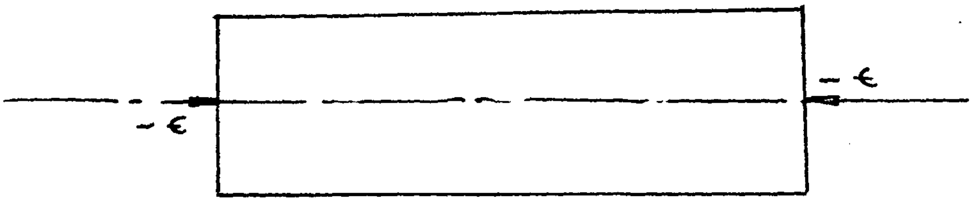
By connecting gage (1) and an external gage the peak output was -1.5 cms. & that between gage (5) & external was + 0.2 cms.

i.e. (1) & (5) = -2.4 cms.

(1) & ext. = -1.5 cms.

(5) & ext. = + 0.2 cms.

From the principles of mechanics these may be analysed as follows.



Corresponding to the peak explosion pressure the connecting rod is subjected to a maximum axial compressive strain say $-\epsilon$,

then, Radial strain = $\mu\epsilon$

Circumferential strain = $\mu\epsilon$

Now when the output of the external dummy gage is taken into account, it gives the exact value of stress to which the material of the rod is subjected, because the reference gages is absolutely unstrained. (Provided due temperature compensation has been made)

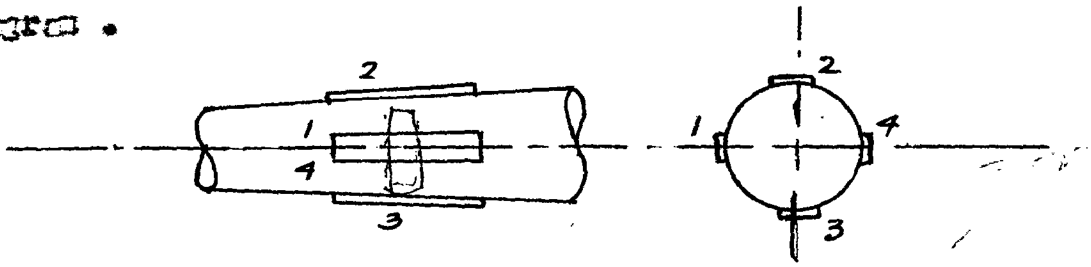
Now with gages (1) & (5) the gage (5) is strained by an amount $\mu\epsilon$ irrespective of whether there is any component of stress there or not. So when (1) & (5) are in the adjacent arms of the bridge the net output amounts to $-\epsilon-\mu\epsilon = -(1+\mu)\epsilon$ If $\mu = 0.3$ say, then output compared to (1) & ext. is = -1.3 x 1.5 = - 1.95 but actually it is = 2.4. This may be accounted for due to component of any indeterminate stress present in that direction.

So to elliminate the effect of this stress it was decided to install an external unstrained gage which will act as the dummy.

In order to compensate for the effect of temperature of the connecting rod, it is necessary that the dummy gage is subjected to the same temperature by heating the dummy gage externally till it assumes the temperature of the conecting rod.

INSTALLATION OF GAGES

Our object is to sense the axial stress only. So the gages are placed axially so that they may sense the required quantity. Strain gagesos are placed as shown in the following digram .



PREPARATION OF THE SURFACE:-

The rod is cleaned well with cloth first and then with acetone to remove all greasy mater from the surface. The surface is smoothed off from rust and miner seartches by rubbing emory cloth over it. Then once again the surface is treated with acetone and finally with liquor ammonia to remove any acetone.

MOUNTING THE GAGES:-

A very thin layer of strain gage cement applied on the surface where the gages need be mounted and then allowed to dry for about 2 hours. This procedure gives a better inculation resistance with respect to the earth. The final step consisted in sticking the gages with a libral amount of cement and a coat of cement applied over the mounted gage for protection against moisture or oil.

LEAD CONNECTIONS:-

The lead wire soldered withe the strain gage was a 14 strand flexible wire, the dia of each strand was 0.007" The whole set of gages were kept covered by Scotch paper tape to prevent it from mechanical damage. The soldered leads on being taken out of the gage assembly posed the problem of

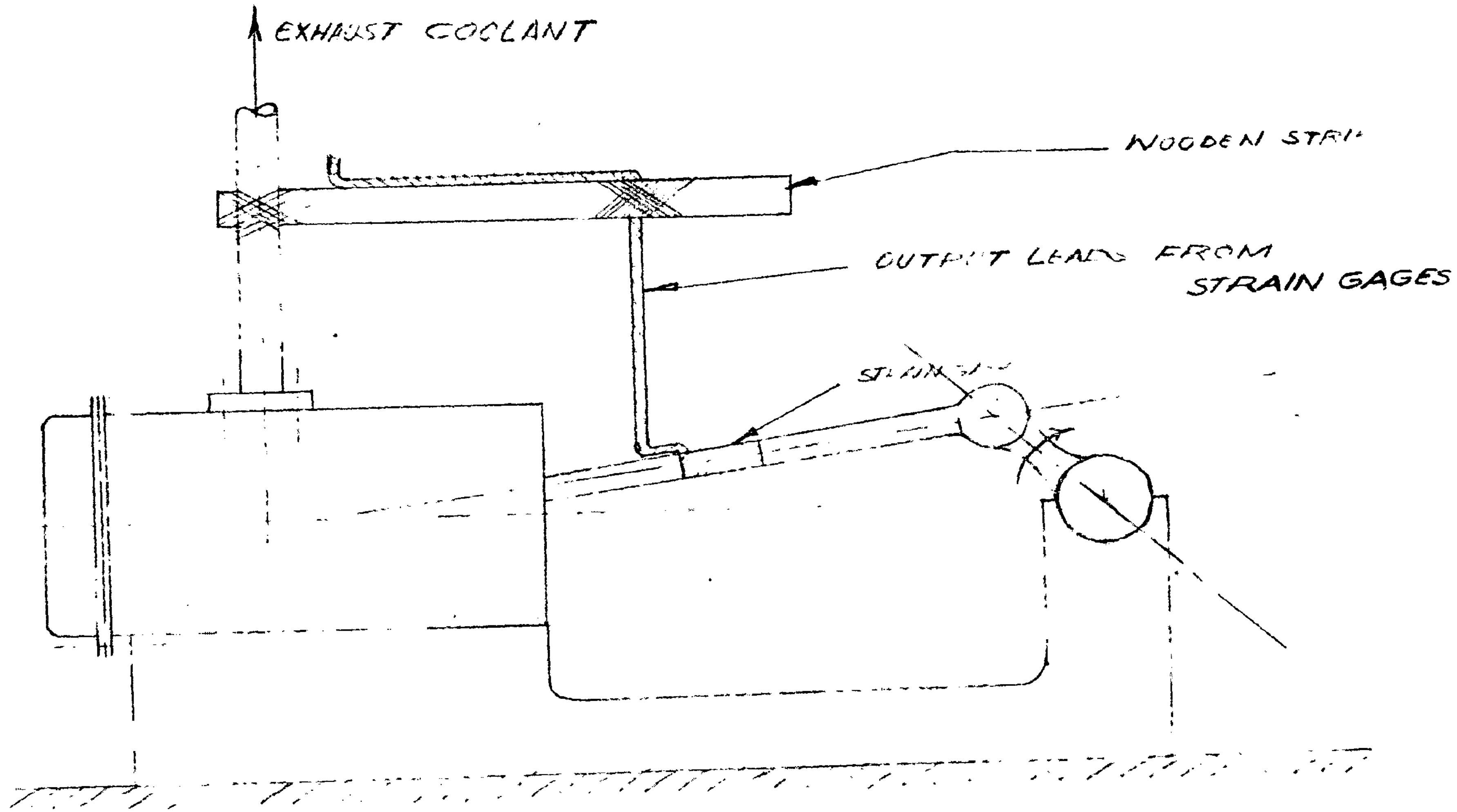


FIG-1

the fatigue failoure of the wire strands under the running conditions of the engine. The problem was solved in the following manner:-

In the first instance the lead wires were bunched out to a single unit by wrapping them with black tape and taken vertically off and attached to a wooden piece fastened to the exhaust cooling water pipe.(see Fig. 1)

The problem that arose out of this was that we had to allow an extra length of wire of the lead for the reciprocation of the rod. Due to this the free length of wire was getting twisted. The engine was running at 350 R.P.M; the wire were getting twisted and released at this rate.

Plastic being more fluxible than copper did not get damaged, but the wires inside got ruptured owing to fatigue.

This twist was reduced by having a longer lead wire fastened to the wooden piece at a much higher level. But such high speed the bunch of wires attained sufficient inertia to fly to the path of crank and foul with it. As a result of this all the strain gages were pulled off when the lead wires got wound up with the crankshaft.

The next step was to attach a piece of iron rod of about 1/4" dia to the wire bunch, which, it was hoped will prevent the wires from getting twisted when the minimum length was in action. The free length of the rod was guided through a slot provided at the end of a conduit pipe. The arrangement failed owing to the difficulty experienced in guiding the supporting rod to a proper path.

The next arrangement tried was to take up a bent conduit pipe attached in a similar fashion to the engine frame

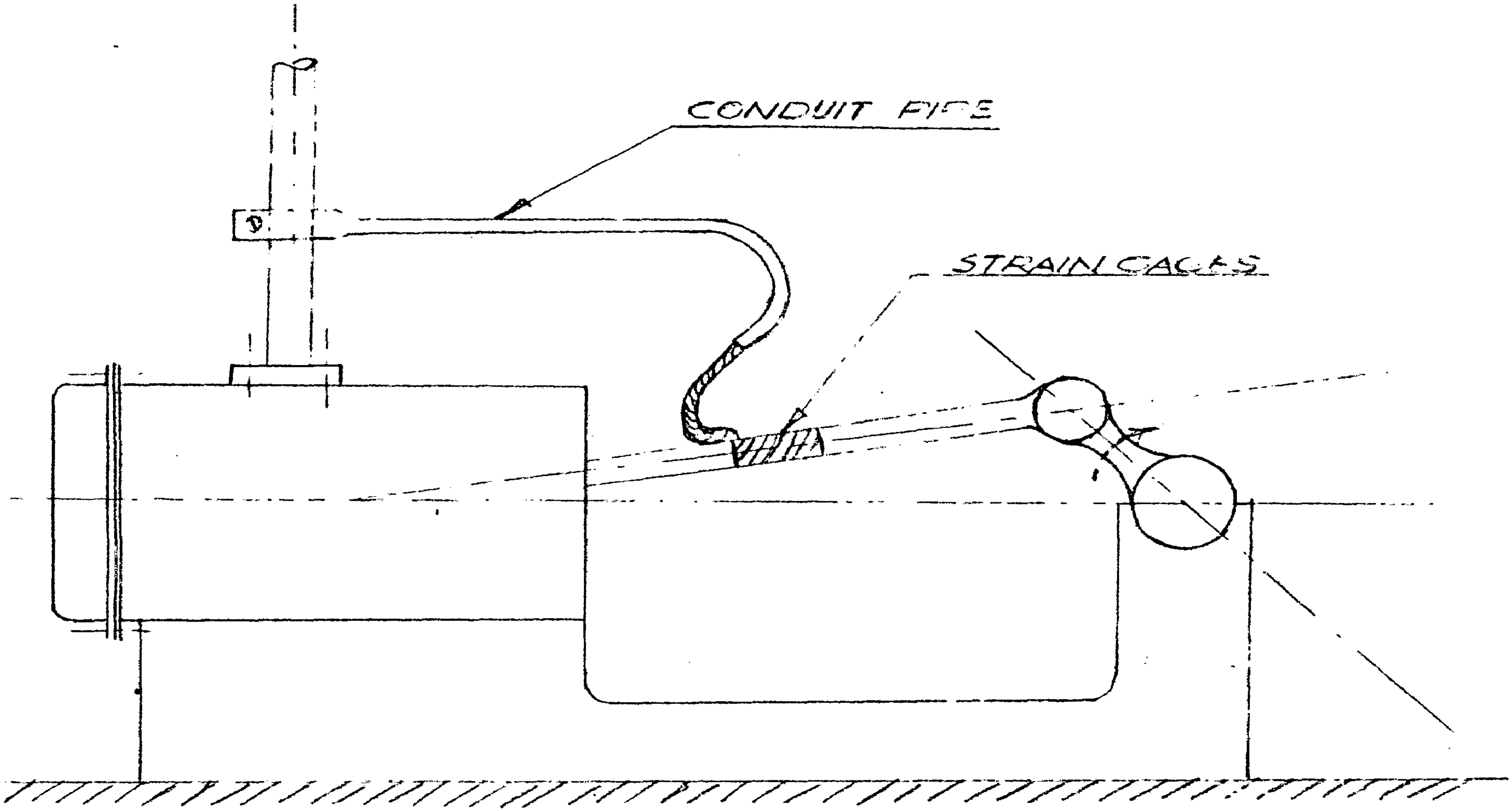


FIG-2

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and coming down very close to the path of travel of the connecting rod (see fig- 2) This also figured badly owing to the fatigue of the metal wires inside the flexible wire.

It was concluded from the above EMF failures that the wires were failing due to high frequency of reversal of stresses in the wires.

It was then decided that if the relative motion between the connecting rod and the lead wires is reduced to a minimum then we may expect a satisfactory life of the wires. The following arrangement was done which proved to be sucess even for a continuous 20 hours of running of the engine.

A forged steel link 1/4" x 1" x 6" having two holes of 3/4" dia at two ends was fixed to the piston through a stud which was kept welded to the piston. Suitable bearing was provided such that the link can move freely on the stud. The other end of the link was fitted to a floating link which is fixed to a movable boss carried over a pin which is again supported on a stand screwed to the engine frame. The complete detail drawing of the system is given herewith.

Now the whole bunch of wires was made into a single unit covering with Scotch pa or tape. The lead wires were changed to 23 strand flexible wire each having a dia of 0.00 inch . Banana plugs were attached to each wire end and brought out through the reducing links. (The arrangement can be seen in photo No 3 and fig No 3)

TEMPERATURE MEASUREMENT:-

As has been discussed before that the temperature of the active and the dummy gage should be the same. We need to know the connecting rod temperature . To measure this a copper constantan thermocopple was used for the purpose.

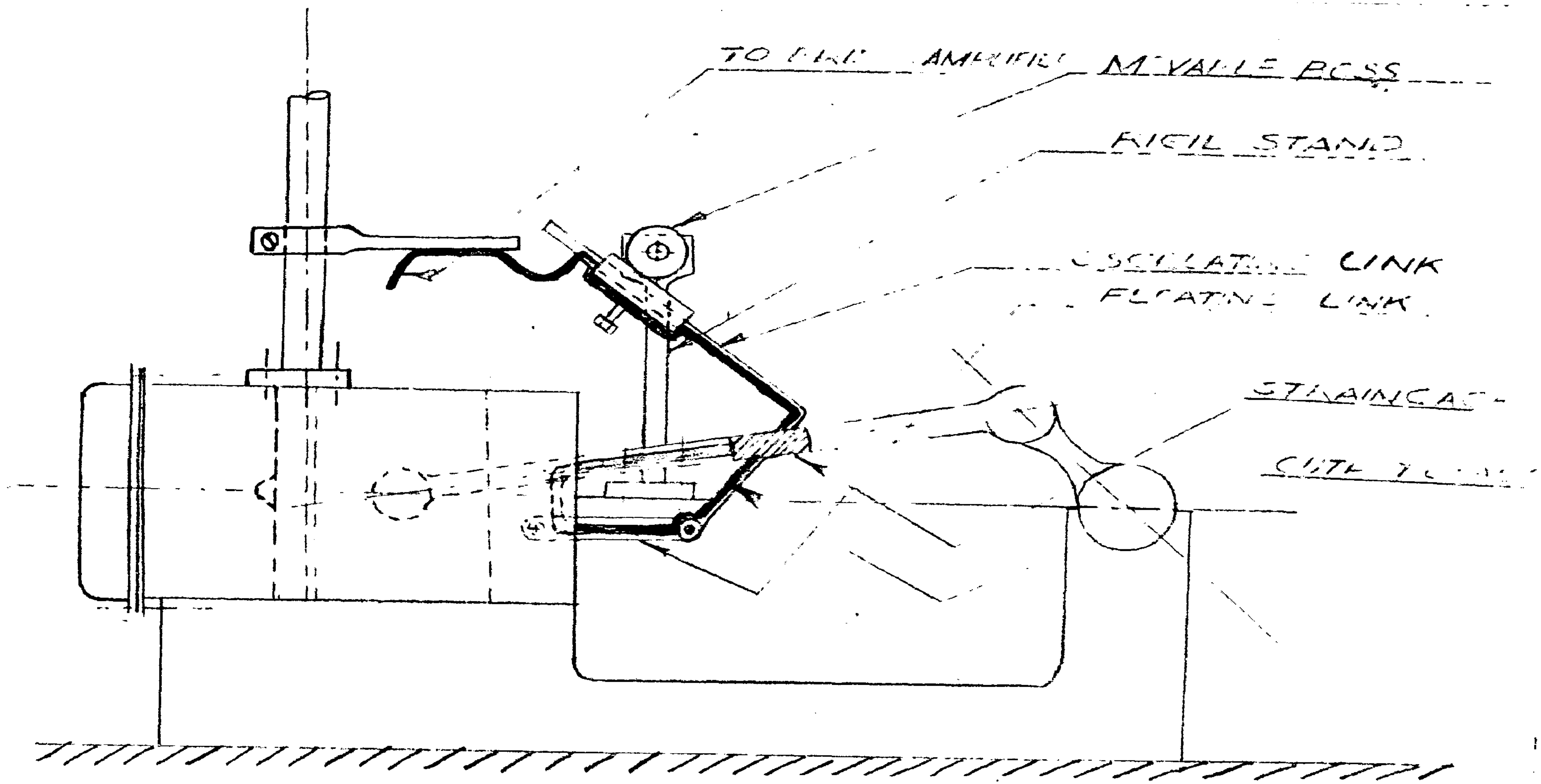

FIG-3

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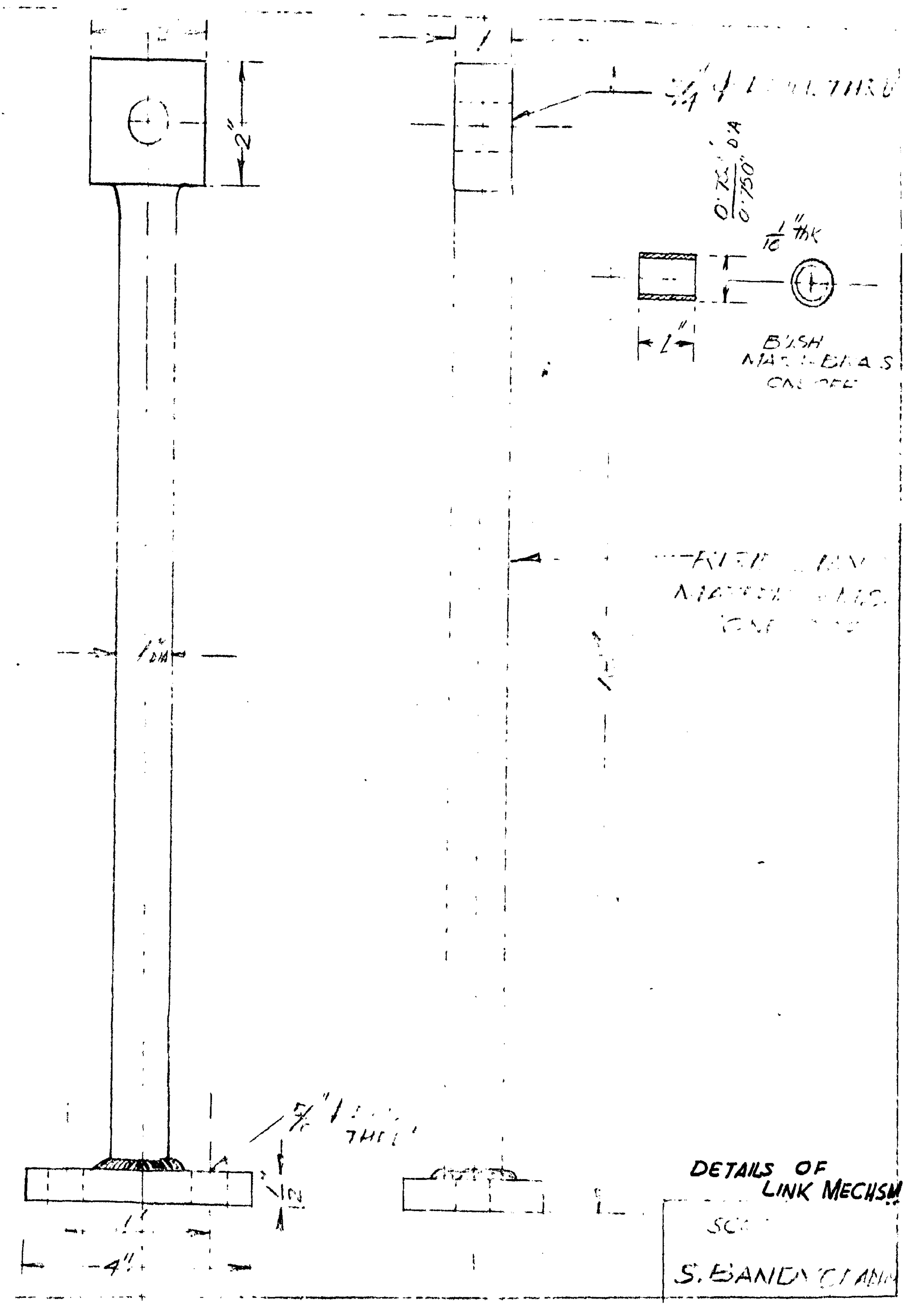
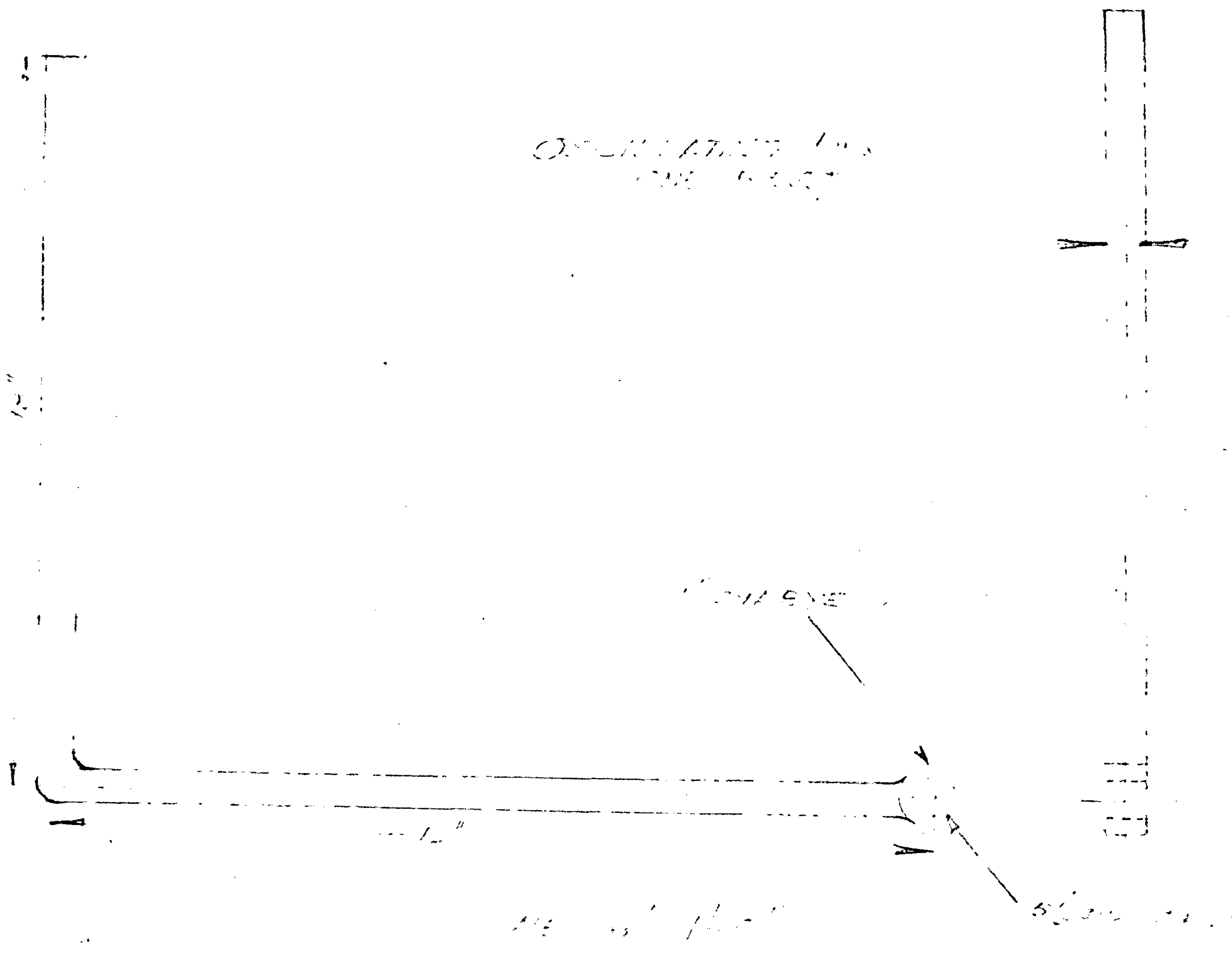
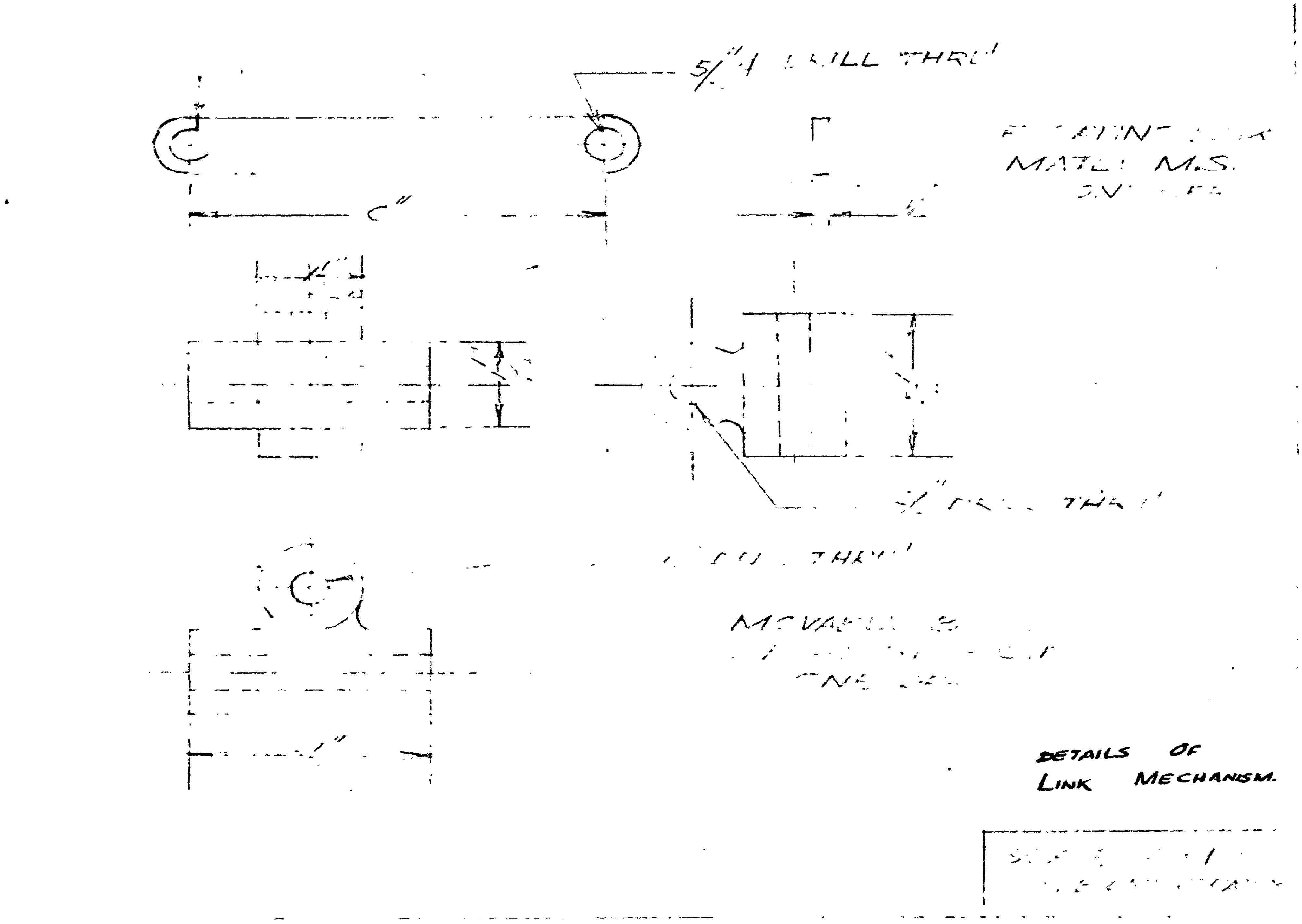


2"
1/16" THK
BUSH
4"
DETAILS OF
LINK MECHSM



DETAILS
OF
LINK MECHANISM



MATL: M.S.
DETAILS OF
LINK MECHANISM.

The required lengths of respective wires were welded in a mercury arc. One of the junction was placed on the surface of the rod. It was held in its place by scoth paper tape. The thermocouple wires also were taken out in the same fashion as the strain gage leads.

The other junction of the thermocouple was placed inside a narrow tube filled with petrol and the whole tube was placed inside a thermosflask kept filled with ice.

The output leads of the thermocuple were connected to a portable the potentiometer. The millivolt reading of the potentiometer for a null balance gave the temperature directly in degree centigrade from a calibration curve drawn before and set in front.

PRESSURE MEASUREMENT:-

For a theoretical analysis and determination of stresses at different configuration of the rod we need to have the corresponding engine pressures. So an arrangement was provided in the set up to give a record of the gas pressure variation within the engine cylinder.

A piezoelectric pick up was available for use. It was actually a quartz crystal and is very stable and versatile in dynamic measurements. They precisely convert applied pressures to electric charge signals. They feature high linearity and repeatability over an extremely wide range of pressures and uniform charge sensitivity from very low to very high temperatures. The high natural frequency which results from the use. of rigid quartz transducer elements allows measurement of high frequency pressure variation and the fast rise-time components of explosion and internal combustion engine pressures. Initial preload on the transducer elements is greater than one atmospher permitting measurement of negative pressures to absolute zero. Though very much suitable for dynamic measurements, but with suitable amplifiers static pressures can also be measured and in fact this principle if used in static calibration of the transducer.

GENERAL INSTALLATION & MAINTENANCE PROCEDURES:-

Quartz crystal pressure transducers presents no problem in low temperature measurements. High temperature work needs careful installation because of lowering of insulation resistance of the transducer. This necessitates the use of transducer with a water -cooled adapter whereby its temperature is kept down.

In all pressure measuring installations the proper use of seals and gaskets is necessary to ensure troublefree and leakproof operation. The sealing surfaces of cavities and adaptors must also be smooth , clean and flat, so that effective seal can be made without application of excessive torque which might prove disastrars for the transducer elements and threads. Sealing is also required for good maintenance of threads.

The experimental engine has a hole tapped in the head and cylinder cover where the transducer was decided to be fitted. Suitable adaptors were designed and fabricated as per drawing attached. The points to note in an adapter design are:-

(1) That there should be no differential expansion or contraction between the adapter and the transducer due to temperature change. This becomes quite obvious when the materials of which they are made are different and a change of tempeature takes place. When such a thing happens there is every possibility of the two parts getting jammed and in severe cases of thermal stressing it might spoil the whole system. To avoid this it is always

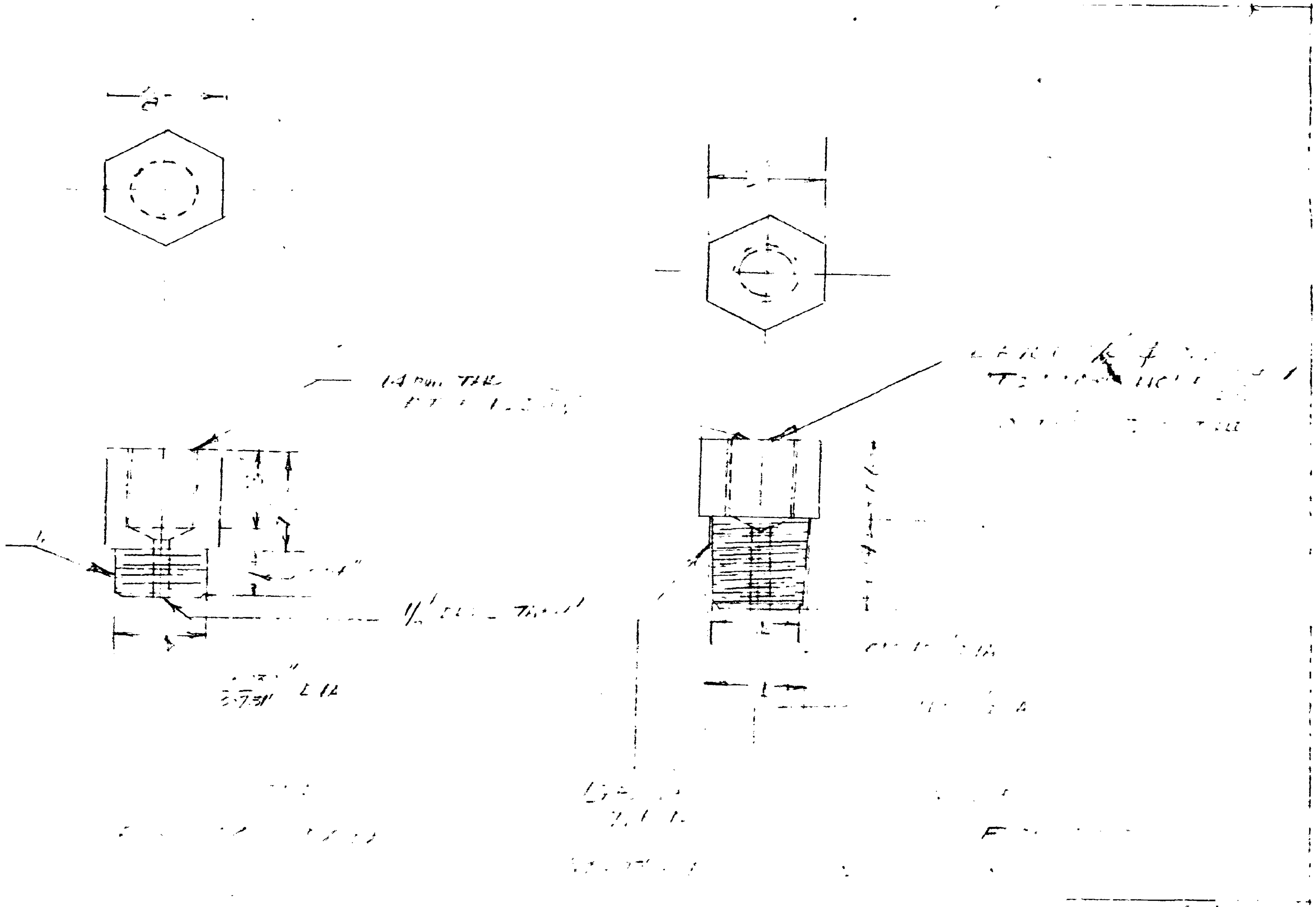


FIG-3A

preferable to have both the adaptor made of same matrial i.e. steel.

(2) In a diesel cycle the compression ratio of the engine has a very important bearing on the efficiency of the engine, which in turn is dependent on the clearance volume at the end of stroke of the engine. This point needs that the transducer should be placed very near to the engine which infact demands the adaptor should be as short as possible. Final considerations in respect of its length is defined by having sufficient number of threads to engage with both the engine as well as the pick up.

. Quartz crystal pressure transducer are very much susceptible to moisture. Moisture lowers down the insulation resistance and sometimes it goes down to such an extent that it stops giving output. In one such instance it stopped giving output during experimentation. It was set right by baking in an over to 115 °C and keeping it in a dessicator for hours. Meanwhile an alternative arrangement was rigged up for the record of pressure.

As has been discussed before that we proivded a link mechanism to take the Bond wires out. Help was taken of that mechanism for taking a indicator diagram.

The pressure pick up adaptor was replaced by another adaptor which fits in to an indicator. A cord was taken out from the floating link and pressed over a small pully gave a rotary motion to the indicator drum. This corresponds to a linear motion of the piston on a reduced scale.

Recording of engine pressure with an indicator necessitated another observation. This was to define the crank position on the oscilloscope, so as to enable us to evaluate the stress . Corresponding to particulr crank angles. This setup is explained in the following paragraphs.

The engine is 4 and stroke disel one and completes its

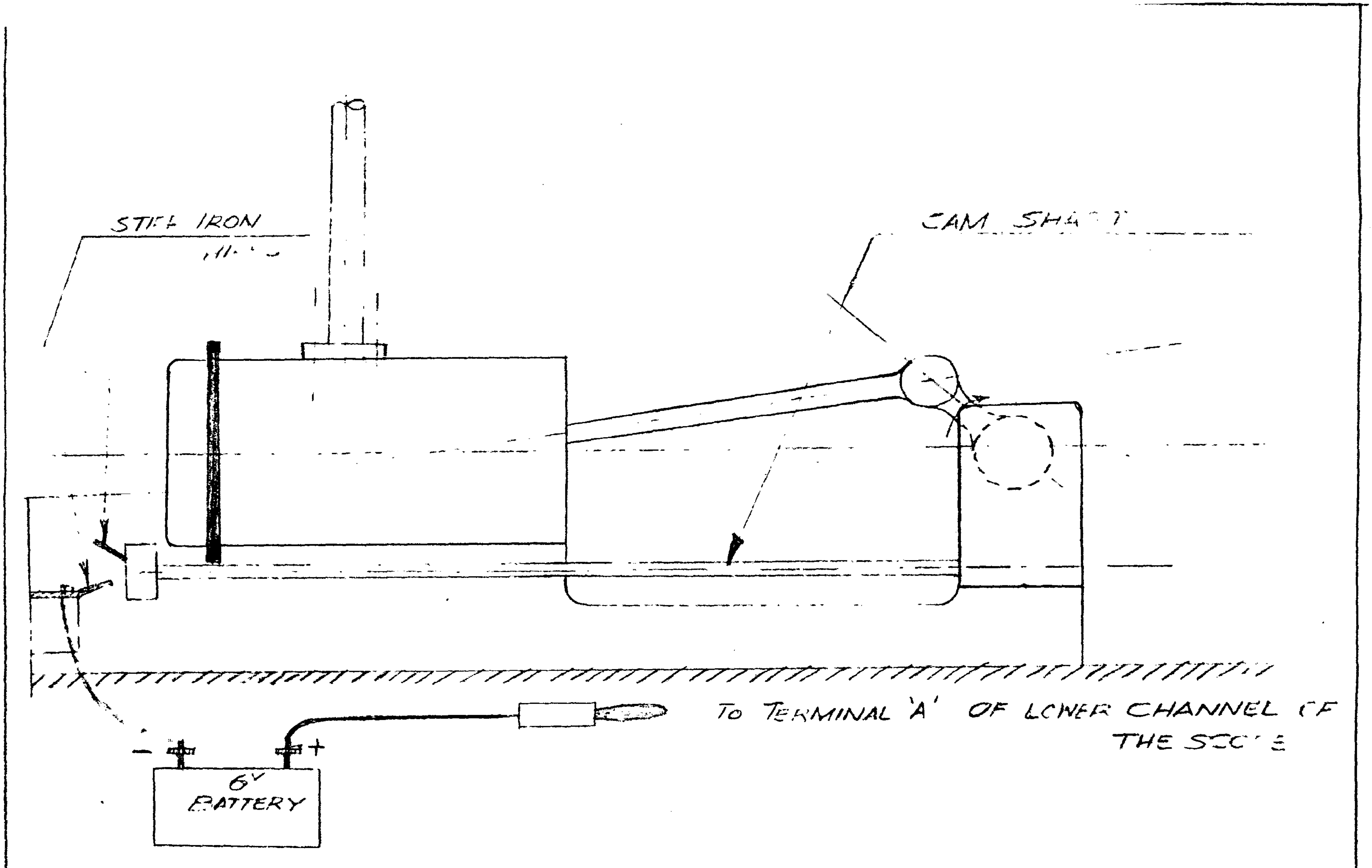


FIG-4

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cycle in every 720° of crank rotation . Now the cam shaft has its speed reduced to half by a pair of crossed helical gears. This means that when the engine runs for 720° the cam shaft runs for 360°.

As shown in the figure 4a stiff irron wire about 3/16" dia was held through screw at the end of the cam shaft. A similar wire was fixed to a wooden strip by means of screw and the wooden piece later held on the engine frame. The lead wires from the wooden insulated wire is led to the -ve of a 6^v battery the + ve of the battery was led to the terminal marked 'A' on the lower beam of the oscilloscope. The wires were so bent that they touch only when the suction stroke of the engine begins i.e. at 0° crank position for each cycle.

As the two wires touch a voltage of the battery with reference to the ground is applied to the lower beam. This gives a pip on the oscilloscope (see prints of oscillograph records) Thus between two pips is 720° of the crank revolution of the engine.

CALIBRATIONS OF STRAIN GAGES:-

Principle:- It is difficult to strain the connecting rod mechanically as the stress system in the rod is a complex one . Under such circumstances an electrical method is applied. With the Ellis Bridge Amplifier is provided a set of 10 calibrating resistors. The knob marked calibration are marked with numbers which are multipliers to respective resistances such that the product is one megohm.

The active arm of the bridge when shunted by a known resistance produces a net change in resistance, which is equivalent to a certain specific strain and hence stress. Now when such shunting occurs an output voltage results and the beam on the oscilloscope gets deflected. Then under all similar settings of the instruments, the deflection of the oscilloscope beam is proportional to that computed stress. So when a signal is fed to the same channel then with similar gain of the amplifier and sensitivity of the oscilloscope the outputs we get are all proportional and hence we may determine the respective stresses easily.

Experimentation :-

Ellis Associates give a ready formula for use with SR-4 gages and the amplifier made by them.

Thus for a 2 gage bridge:

$$\frac{400}{\text{gage factor}} \times \frac{\text{Calibration setting}}{\text{No. of active arms}}$$

= Micro inch / inch of strain.

The following example will make it clear:

Station = 3   Oscilloscope sensitivity = 20 mv/cm.

Gages = 1 & E.

Calibration setting = 2.

Defln. of the beam = 2.8 cms.

Therefore strain $= \frac{400}{2.88} \times \frac{2}{1}$

= 278 microinch/ inch

So , a stress $= 278 \times 10^{-6} \times 30 \times 10^{-6}$ psi

= 8340 psi.

Now 2.8 cms. defln. = 8340 psi.

Hence 1 cms. defln. = 2970 psi

The final step thus provides a handy tool for interpreting the signals from this pair, of gages with similar gain setting and sensitivity adjustment.

CALIBRATI N

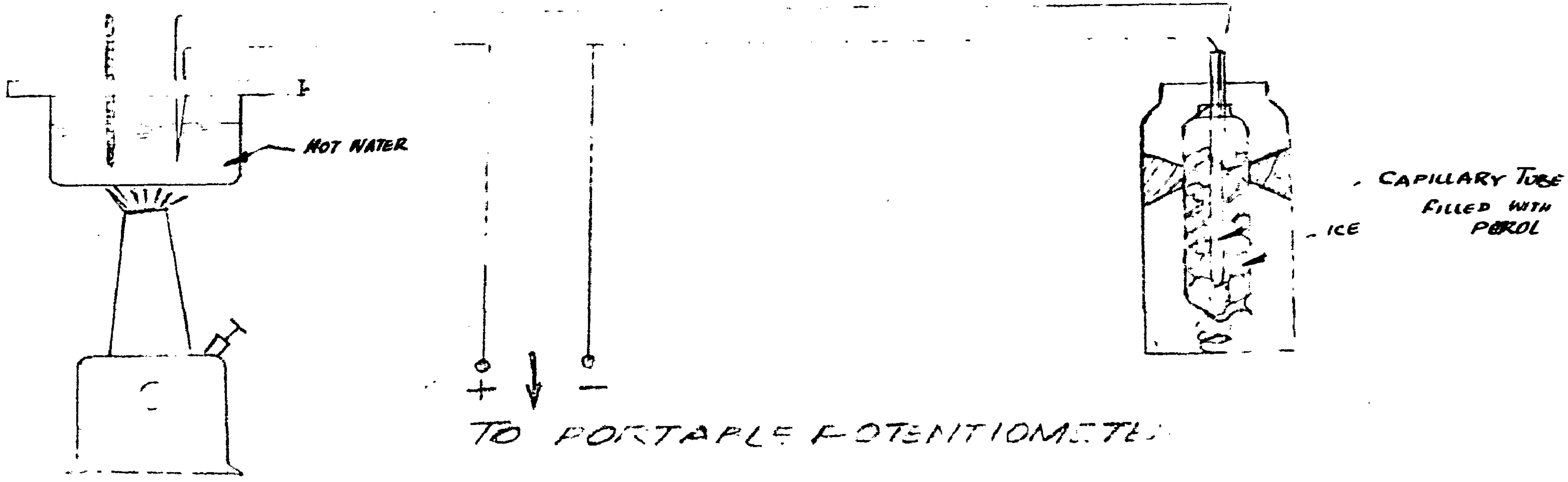


FIG. 5

CALIBRATION OF THE THERMO COUPLE :- (see Fig 5)

The copper constantan thermocouple which was used for measuring rod temperature was calibrated before use .

One junction of the thermocouple was placed in hot water raised little more than 80°C and then allowed to cool. The cold junction was maintained at 0°C.

The following observations gave the calibration curve attached herewith. (see next page) Fig-6

Temp. in °C	Emf. in mV.	Temp. in °C	E. m. f. in mV.
80	3.43	50	2.02
78	3.34	48	1.95
75	3.17	45	1.80
72	3.03	42	1.70
70	2.97	39	1.60
69	2.90	36	1.45
68	2.85	33	1.40
67	2.80	30	1.25
65	2.71		
63	2.61		
60	2.49		
58	2.39		
55	2.26		
53	2.12		

CALIBRATION OF COPPER CONSTANTAN THERMOCOUPLE

REFERENCE JUNCTION = 0°C

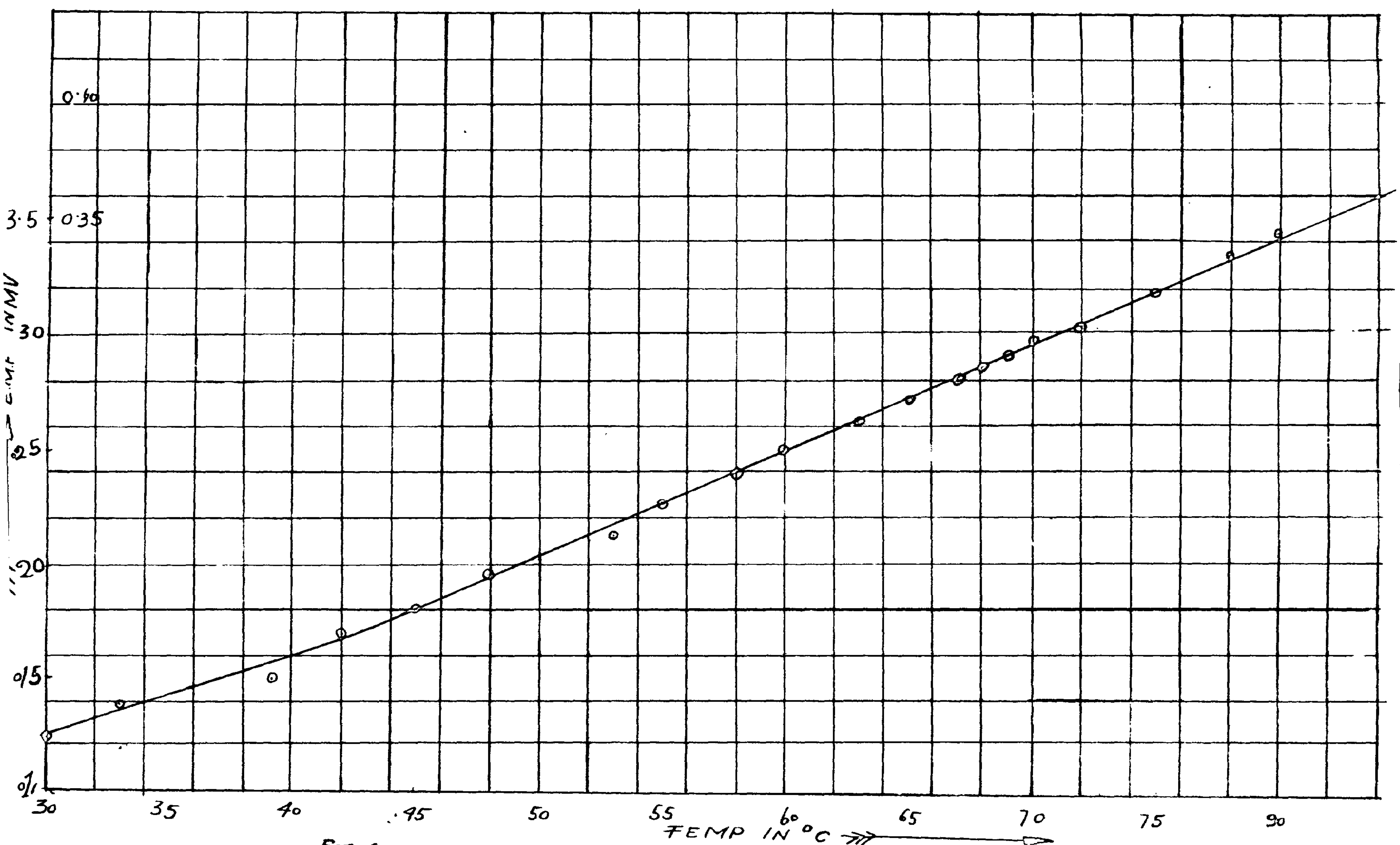


FIG. 6

CALIBRATION OF PRESSURE PICK - UP :- (see Photo-4)

The piezo electric pressure pick up needs calibration each time before use. It is because the insulation resistance of the pickup changes from time to time owing to permeation of moisture.

The procedure adopted was to place the pickup on a Dead weight gage tester. An adopter was to be made for use with it (see fig- 3A)

Weights were placed to note the defln. of the scope beam. During calibration the time constant of the charge-amplifier used with it should be in the 'Long ' position. It is always desirable to use a lower sensitivity on the charge amplifier and a higher sensitivity on the scope.

Respective sensitivities were recorded. The following observations led to calibration curve (see fig-7 5A).

Oscilloscope sensitivity = 1 V/cm. time = 0.5 m.sec/cm.

Charge amplifier = 2 mv/pcb.

No.	Pressure	Output
1.	25 psi.	0.1 cm.
2.	50 "	0.2 "
3.	100 "	0.4 "
4.	200 "	1.0 "
5.	300 "	2.5 "
6.	400 "	4.0 "

CALIBRATION OF PRESSURE PICKUP

SCOPE SENSITIVITY = 1V/CM

SWEEP RATE = 0·5 MSEC/CM.

CHARGE AMPLIFIER SENSTIVITY = 2MV/PCb

TIME CONST. = LONG

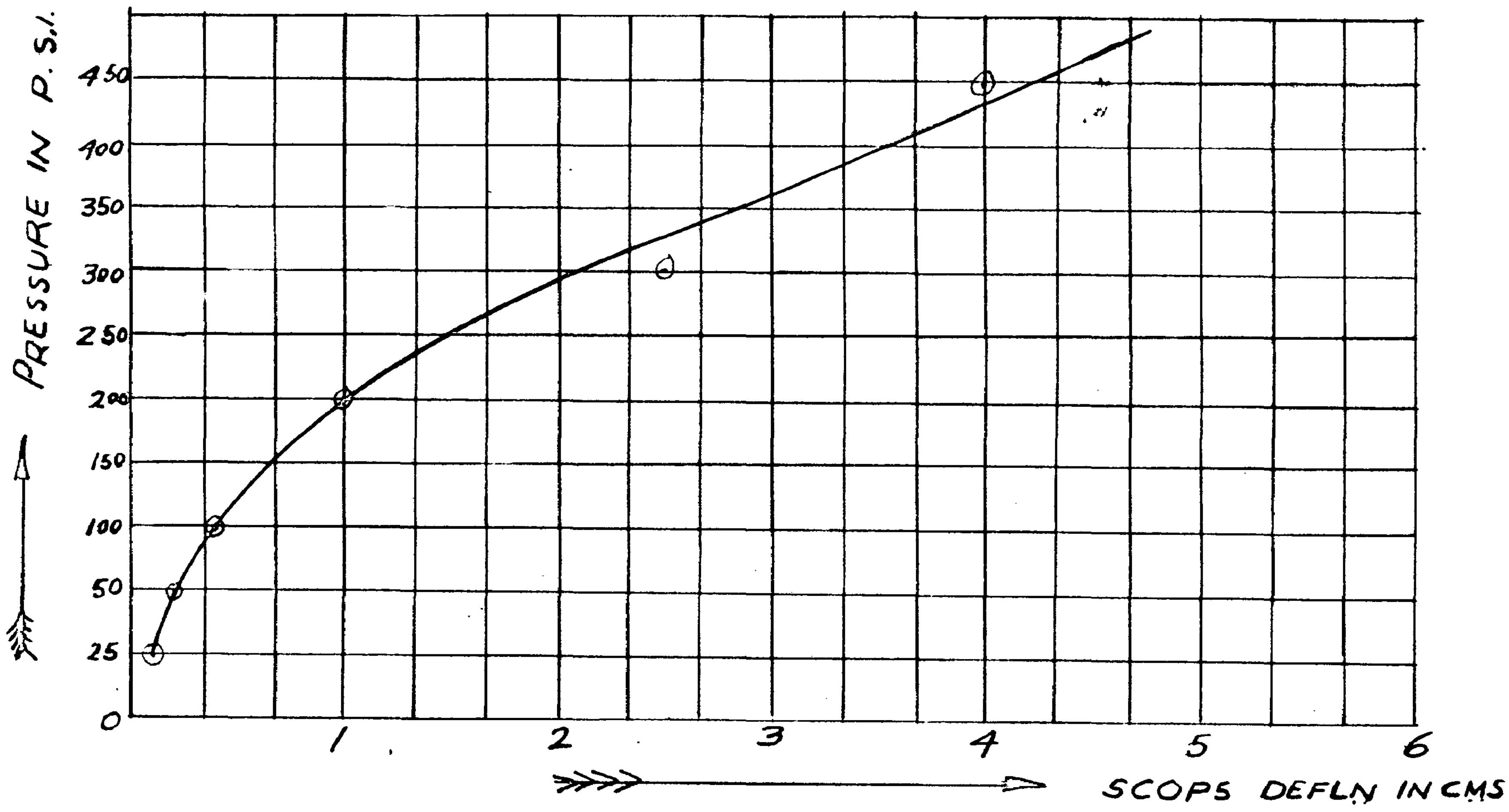
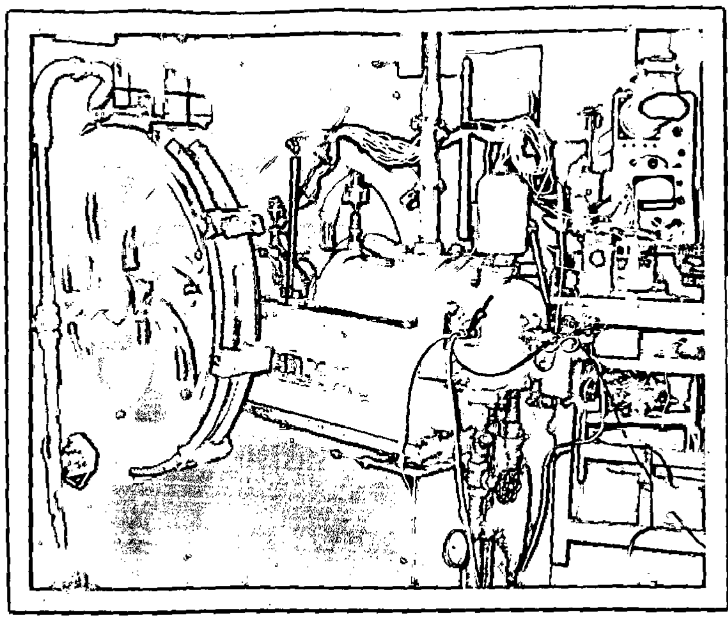


FIG-7



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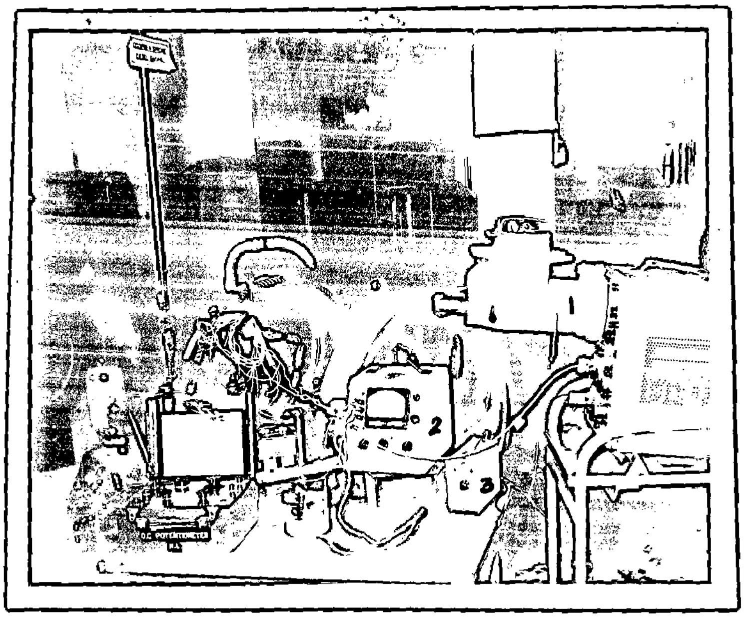
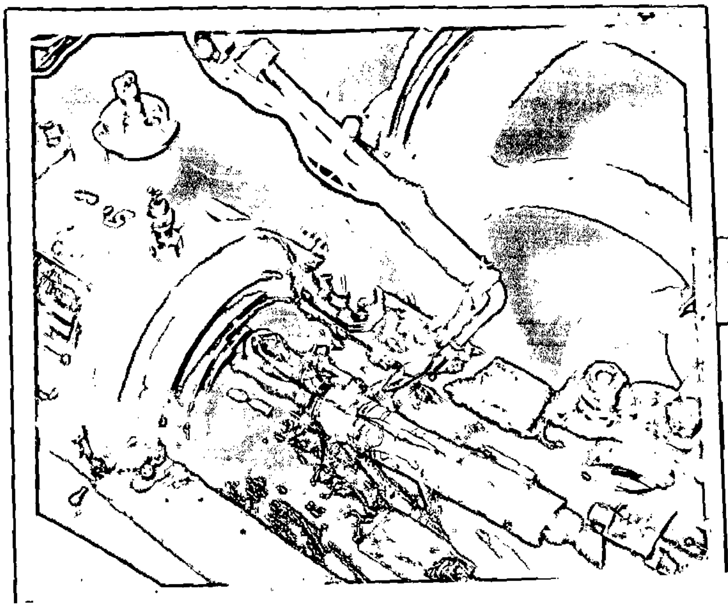




2. [illegible]

EXPERIMENTAL PROPER

Each run during experimentation consisted of the following steps:-

1) Checking the lubrication system .

2) Checking the coolant system.

3) Checking of the fuel passage and pump .

The engine was started. After it had attained a steady speed, the lead wires were formed into a requisite bridge with necessary connections and fed to the Ellis Bridge amplifier. The output of the bridge amplifier is fed to the upper beam of a dual beam Oscilloscope. Sensitivity was adjusted till we get a reasonable output. This is indicated by the area the signal covers on the scope screen . Adjustments of different knobs of both the bridge amplifier and the oscilloscope were made till we get a repeating signal.

Strain Recording:-

The Dumont oscilloscope camera provided with a (120) film holder was used for recording . The film used was 'INDU' 200/6 ° ASA. In each case the aperture setting was f8. With a reasonable intensity setting of the light beam, and maximum scale illumination of the oscilloscope the photographs were taken . The time for which the shutter was left open was based on the following simple calculation.

The sweep rate on the oscilloscope was 50 m.sec/cm. and for a spot of light to travel from one end to other end of the screen it has to cover 10 cm. Then total time for which the shutter has to remain open is equal to 50 x 10 = 500m.sec i.e. 1/2 sec. such that we got only one trace. This is irrespective of the position and instant where the shutter opens.

Before taking each photograph the temperature of the reference gage was equalised with that of active one by adding hot water and allowing some time to let the whole bath in which reference gage was immersed to attain the same temperature.

Immediatly after each photo-graph the engine was stopped to record the zero level of strain. Care being taken once again to see that the temperature in both active and reference gage was equal. Simultaneously with it calibration was also done.

A schedule of photographs with indicator diagrams is maintained and it was also recorded which gages correspond to which photo and indicator diagram.

After completing each run, the set of photos (negatives) kept in marked covers for further use and analysis.

The experiment was conducted for 3 such stations.

CHAPTER III

EXPERIMENTAL OBSERVATIONS

Strain gage station - 1

No.	Gages	R.P.M.	mv.rdg. from pot.	Photo No.	Ind. diag No.	Load	Sensitivity.	Defln.of scope	cal. setting	Zero level
1.	1 & E	340	1.40	1	x	0	100mv/cm.	4.0cm	6	2.8cm.from top
2.	1 & E	330	1.45	2	x	45lbs.	" "	"	"	"
3.	4 & E	340	2.2	7	x	0	"	"	"	3.4cm. " "

Station - 2

No.	Gages	R.P.M.	mv.rdg. from pot.	Photo No.	Ind. diag No.	Load	Sensitivity.	Defln.of scope	cal. setting	Zero level
1.	1 & E	360	1.56	2	1	0	20 " "	2.5cm.	2	4 " "
2.	" "	350	2.1	3	2	45lbs	"	" "	"	4.8 " "
3.	2 & E	350	2.5	4	3	"	10 " "	5.5cm.	"	2.5 " "
4.	" " "	360	2.72	5	4	0	" " "	" " "	"	3.7 " "
5.	3 & E	350	2.4	6	5	45lbs	" " "	" " "	"	2.8 " "
6.	" " "	360	2.45	7	6	0	" " "	" " "	"	3.6 " "
7.	4 & E	360	2.3	8	7	0	" " "	" " "	"	2.8 " "

Strain gage station-3

No.	Gages	R.El.	Dv.rdg. from pot.	Photo No.	Ind.dial No.	Load	Sensitivity	Defln of meter	Cal. setting	Zero level
1	1 Δ B	350	1.4	1	1	0	20mv/cm	3	2.8cm.	2.8cm f t
2.	3 Δ B	350	1.8	2	2	45lbs	" "	"	" "	4 cm "
3.	2 Δ B	360	2.0	3	3	0	10mv/cm	1	2.0cm	4 cm "
4.	" " "	"	2.4	4	4	45lbs	"	"	"	1.6 cm
5.	2 Δ B	350	2.0	5	5	0	"	1	2.7	2.6cm
6.	" " "	350	2.2	6	6	45	"	"	"	" "
7.	4 Δ B	350	2.5	7	7	0	"	1	2.8	2.5 "
8.	" " "	350	3.0	8	8	45	4	1	1	5 cm.

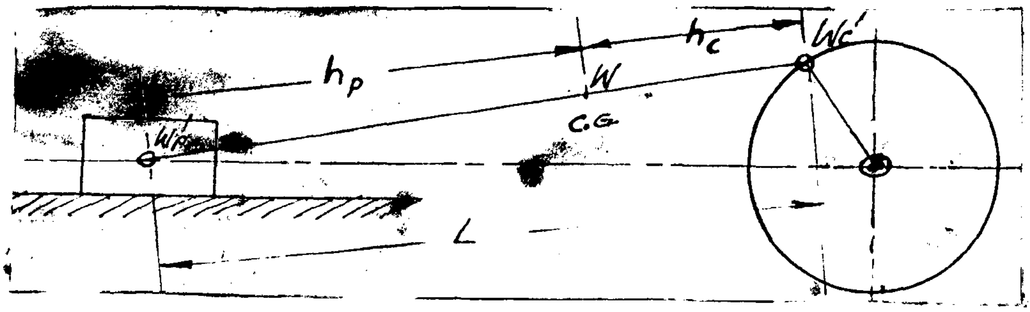
PRINCIPAL ENGINE DIMENSIONS

1. diameter of piston = 6.5"
2. length of the connecting rod = 25.25" (center to center)
3. length of crank = 6"
4. 1st straingage stn. dia of the rod = 1.625"
   length from bigend = 9.25"
5. 2nd strain gage stn. dia of the rod.= 1.625"
   length from big end = 12.625"
6. 3rd strain gage stn. dia of the rod = 1.6625"
   length from big end = 18.125"
7. Weight of the piston = 36.75 lbs.
8. Weight of the connecting rod = 34.0 lbs.
9. Crank pin diameter = 2.75"
10. Crank pin length = 2.75"
11. Crank shaft diameter = 2.5"
12. Diameter of the flywheel = 36.5"
13. Diameter of rope = 1"
14. Piston pin diameter = 1.75"

CHAPTER IV

ANALYTICAL PROCEDURE.

Connecting rod replaced by a kinetically equivalent system:-



Let the weight of the connecting rod considered as concentrated at the crank pin = W_c'

the weight of the connecting rod considered as concentrated at the piston pin = W_p'

then if W be the total weight of the connecting rod

then $W_c' = W \frac{hp}{L}$

$W_p' = W \frac{hc}{L}$

where hp = the distance from the center of gravity of the connecting rod to the center of piston pin.

hc = the distance of the center of gravity of the connecting rod to the center of the crank pin .

L = length of the connecting rod.

W_c' = $= \frac{35 \times 14.406}{25.25}$

= 19.95 lbs.

Wp' = = 15.05 lbs.

Now reciprocating mass = weight of piston + Wp'

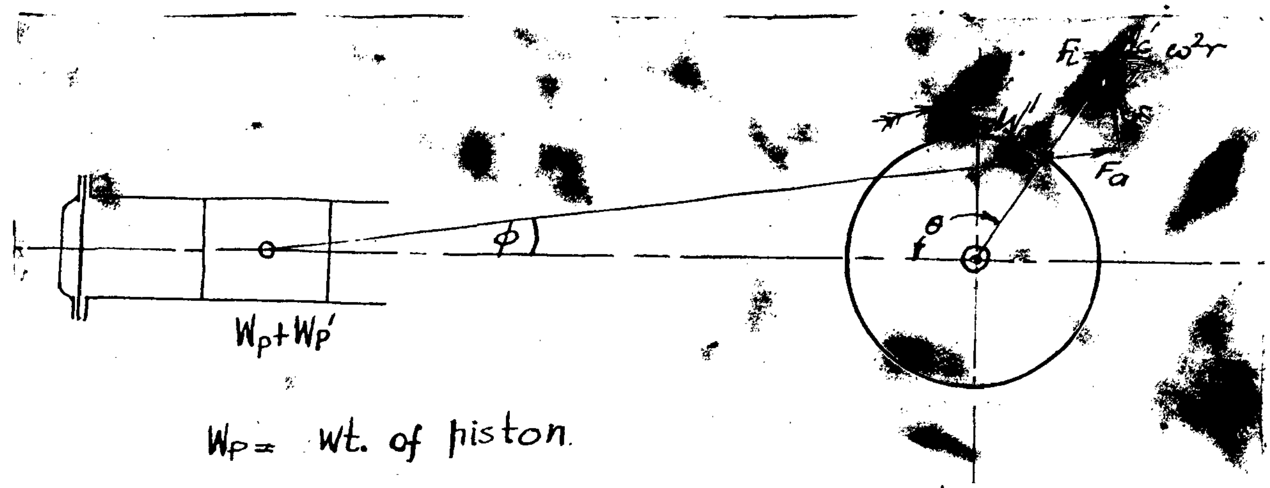
= 36.75 +15.05

= 51.80 lbs

mass revolving = 19.95 lbs.

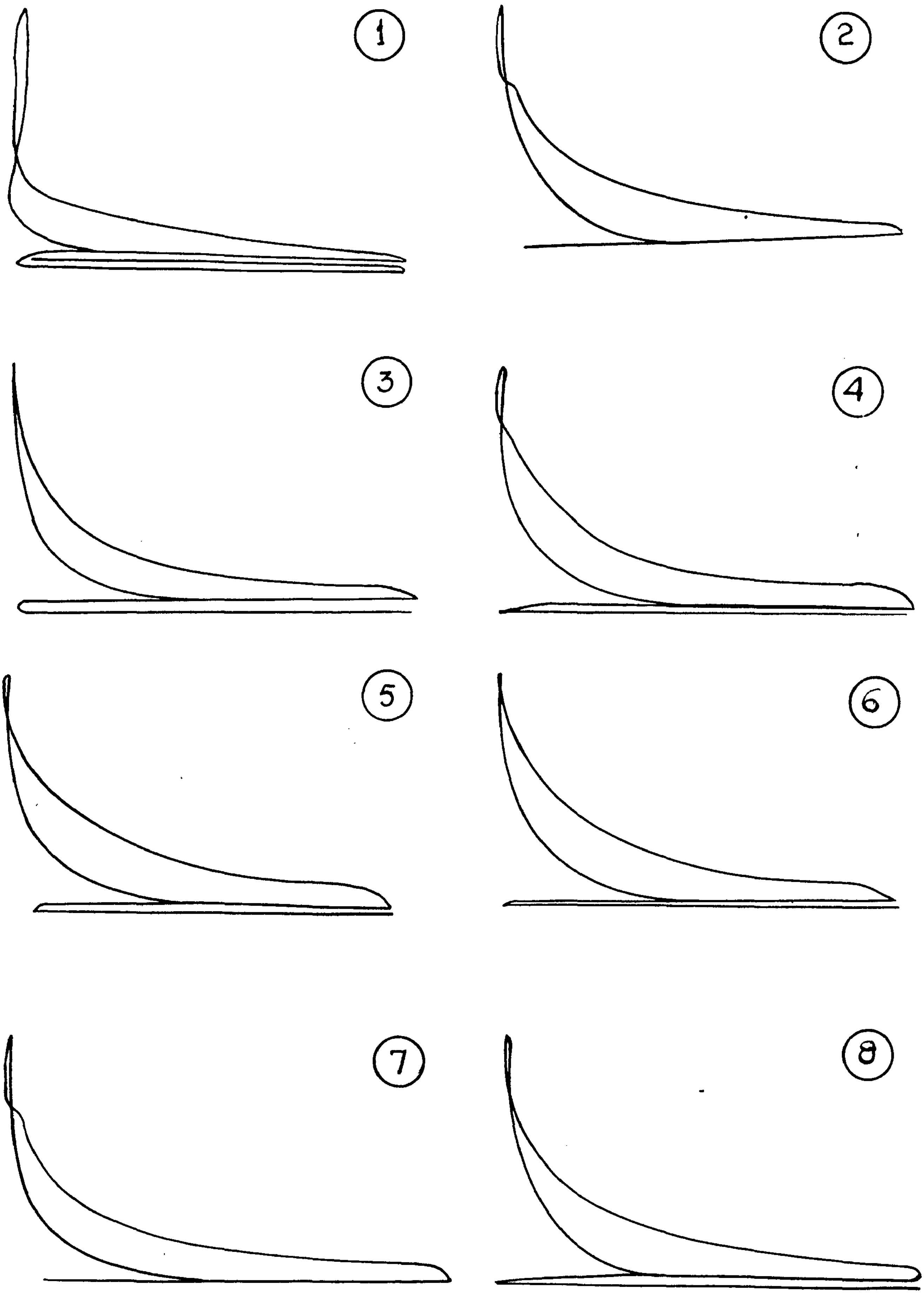
The following table gives Reciprocating inertia force in lbs. corresponding to different engine speeds.

No	Angle in Degrees	360 R.P.M.	350 R.P.M.	340 R.P.M.	330 R.P.M.	320 R.P.M.
1.	0	1416	1336	1267	1190	1117
2.	60	435	410	388	365	342
3.	120	-707	-667.5	-632.5	-595	-556
4.	180	-875	-825	-780	-735	-688
5.	240	-707	-667.5	-632.5	-595	-556
6.	300	435	410	388	365	342
7.	360	1415	1336	1267	1190	1117
8.	420	435	410	388	365	342
9.	480	-707	-667.5	-632.5	-595	-556
10.	540	-875	-825	-780	-735	-688
11.	600	-707	-667.5	-632.5	-595	-556
12.	660	435	410	388	365	342
13.	720	1415	1336	1267	1190	1117

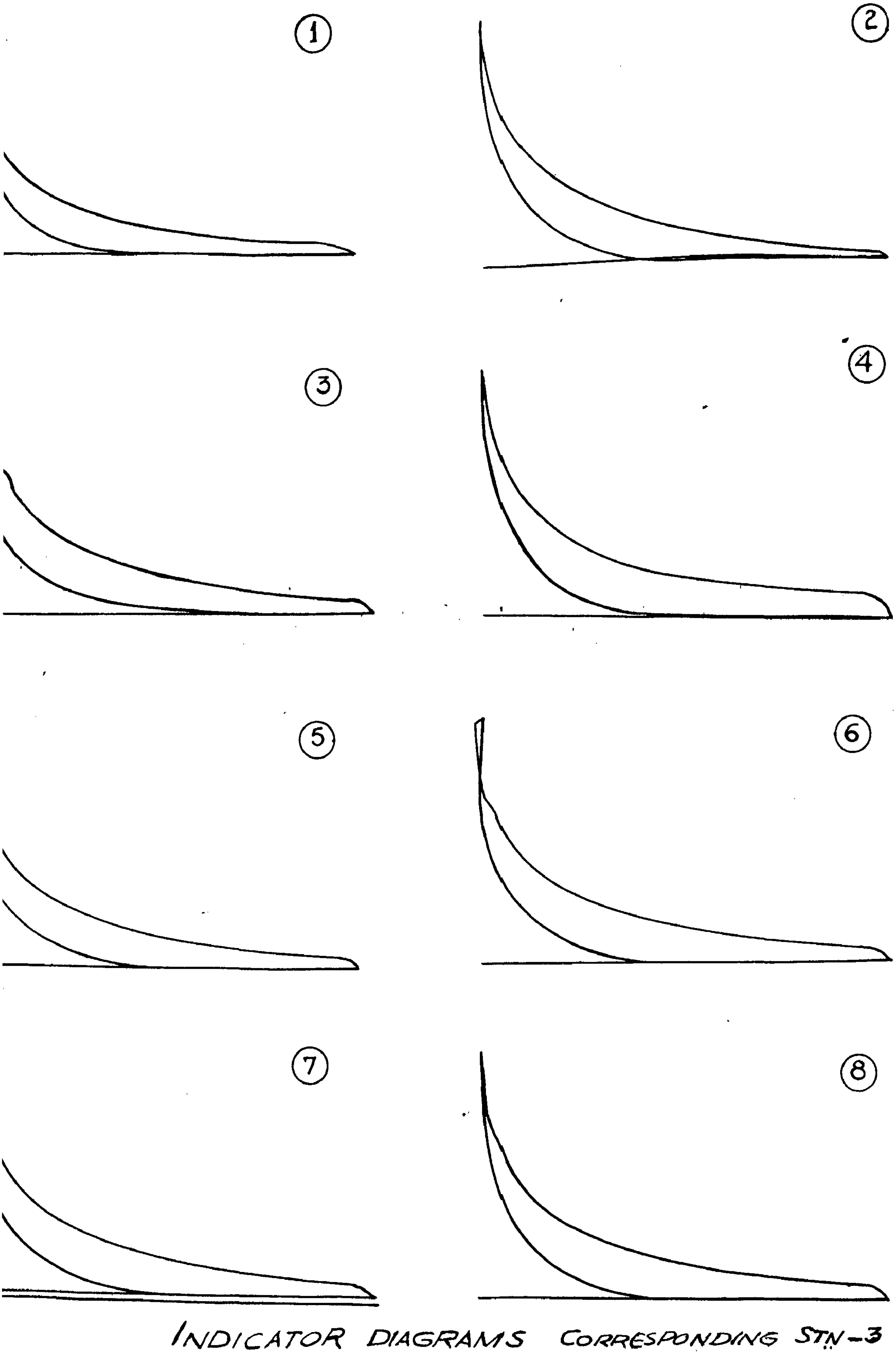


With reference to above fig. the following table gives the values of Fn and Fa for different values of speed.

No.	Angle	360R.P.M.		350 R.P.M		340 R.P.M.		330 R.P.M.	
		Fn	Fa	Fn	Fa	Fn	Fa	Fn	Fa(in l
1.	0	0	440	00	415	0	393	0	360
2.	60	419	135.8	394	128	374	121	350.5	113.9
3.	120	326.5	-194	308	-277	292	-262	-274	-246
4.	180	0	-440	0	-415	0	-393	0	-369
5.	240	-326.5	-294	-308	-277	-292	-262	-274	-246
6.	300	-419	135.8	-394.5	128	-374	121	-350.5	113.9
7.	360	0	440	0	415	0	393	0	369
8.	420	419	135.8	394.5	128	374	121	350.5	113.9
9.	480	326.5	-294	308	-277	292	-262	274	-246
10.	540	0	-440	0	-415	0	-393	0	-369
11.	600	-326.5	-294	-308	-277	-292	- 262	-274	-246
12.	660	-419	13558	-394.5	128	-374	121	-350.5	113.9
13.	720	0	440	0	415	0	393	0	369

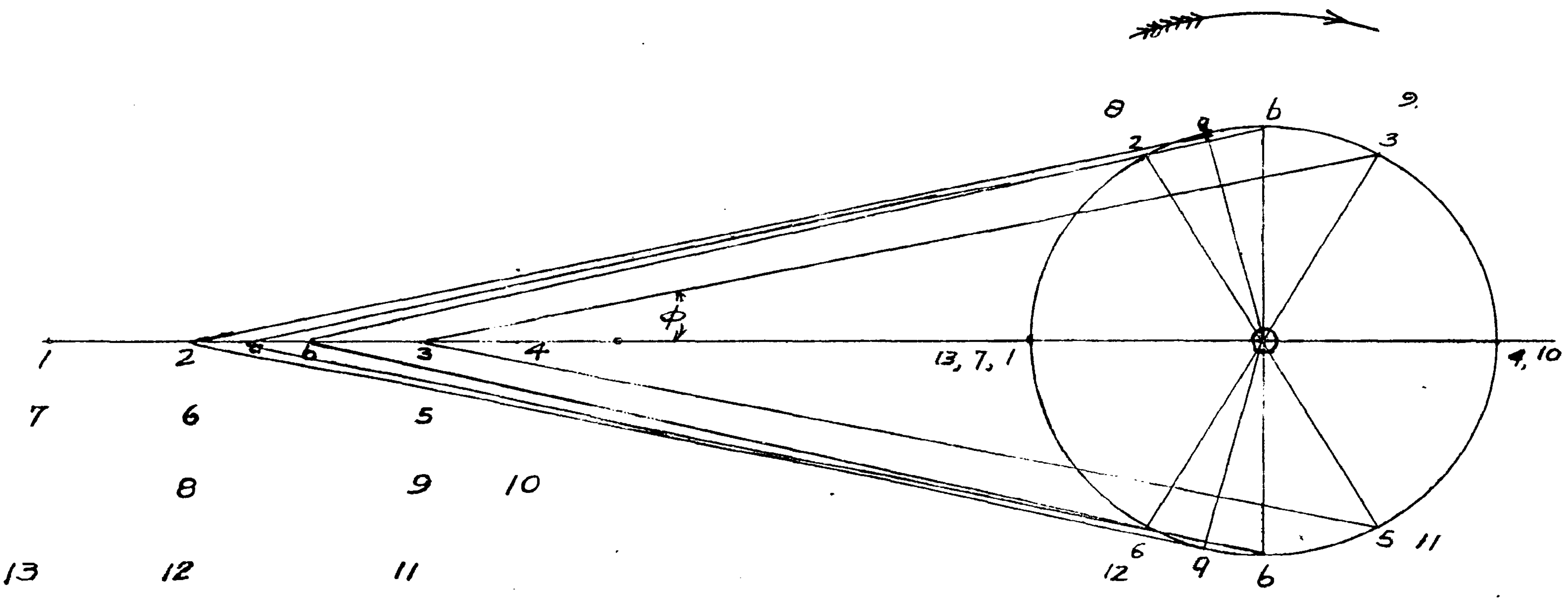


INDICATOR DIAGRAMS CORRESPONDING STN.-2



INDICATOR DIAGRAMS CORRESPONDING STN-3

DIAGRAM SHOWING DIFFERENT ANGLES 'φ'



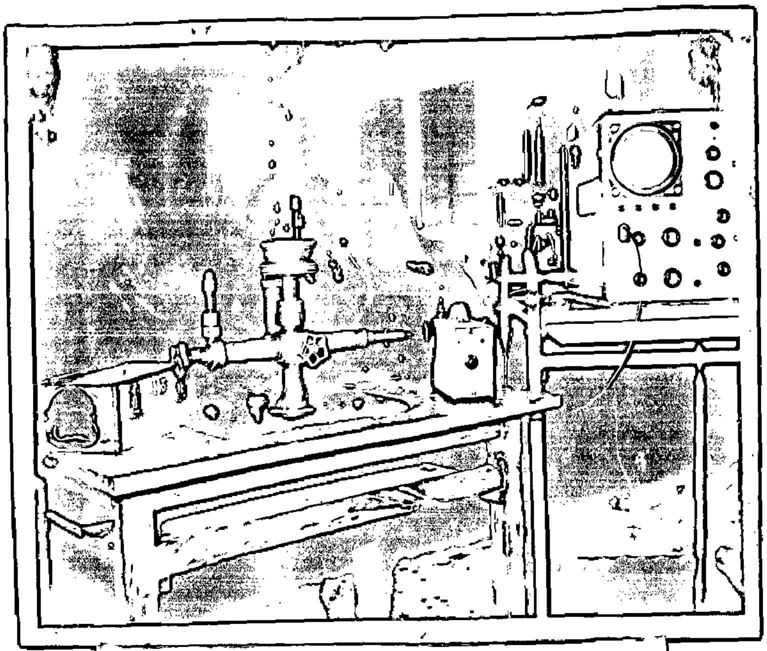
NO.	φ	NO.	φ	NO,	φ
1	0°	6	12°	11	12°
2	12°°	7	0°	12	12°
3	12°°	8	12°	13	0°
4	0°	9	12°°	θ	13.5°
5	12°	10	0°	6	14°

ANALYTICAL CORRELATION

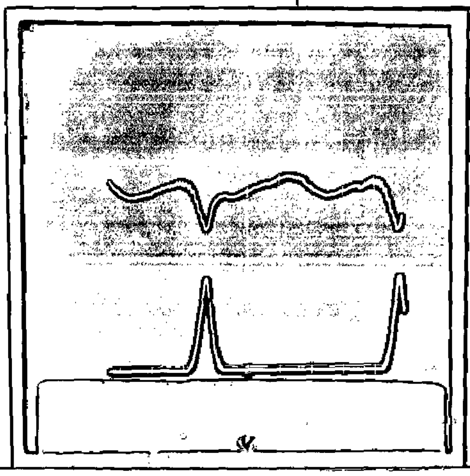
TABLES

[Note:- for Sample calculations see appendix 1. Serial 1/1 refers to fig. 1.4 photo 1.

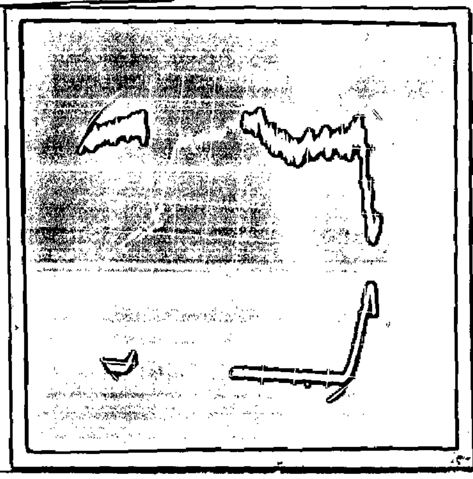
Each set of values from the following tables is superimposed on the corresponding enlarged photograph & shown as follows.



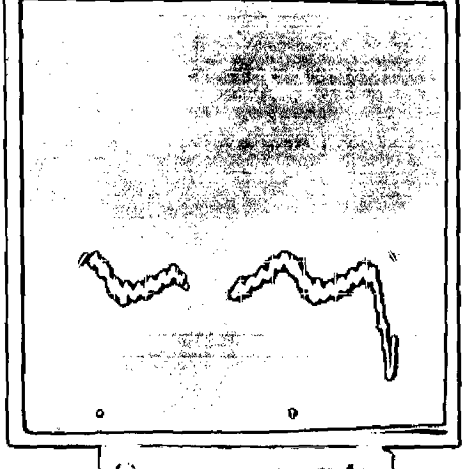
6. [illegible]



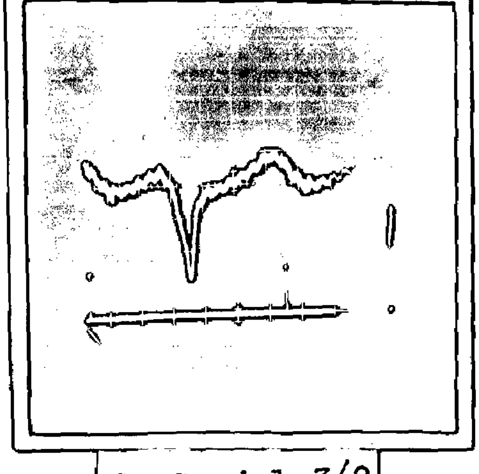
[illegible] 3/2 [illegible]



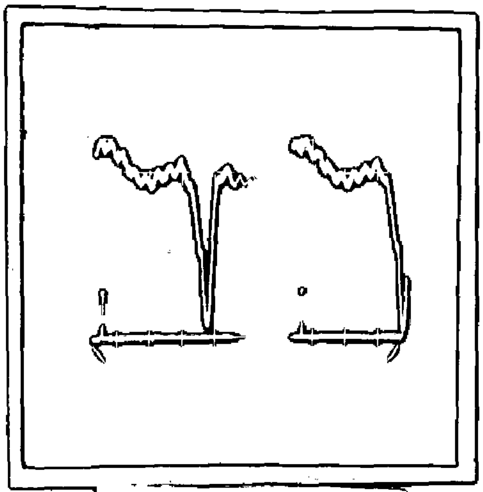
6. [illegible]



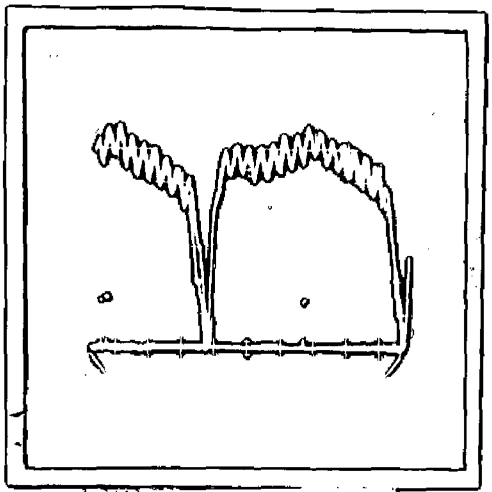
[illegible] 3/2

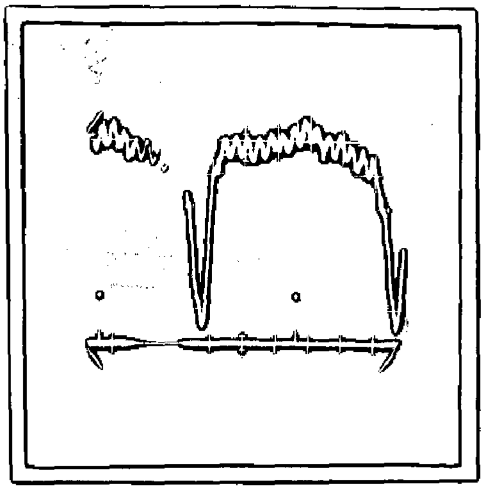


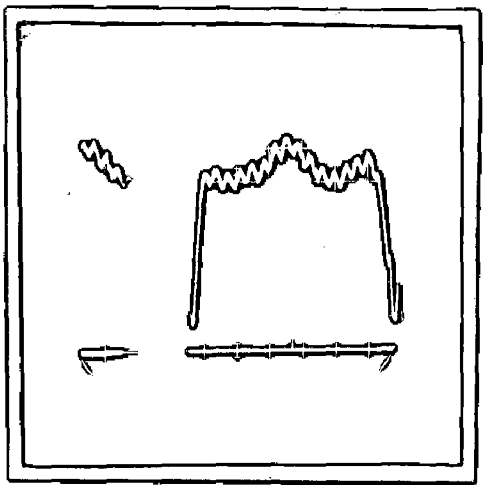
8. Serial 3/2



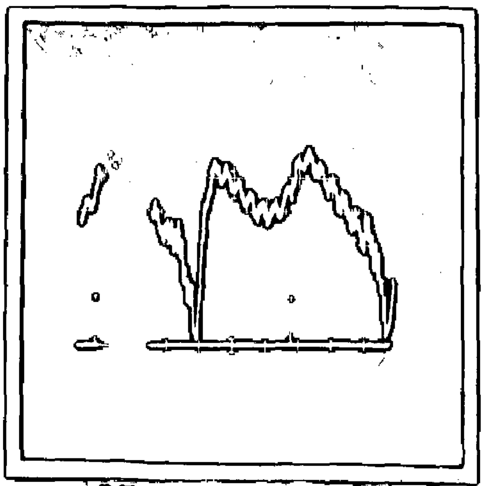
9. Serial 5/5



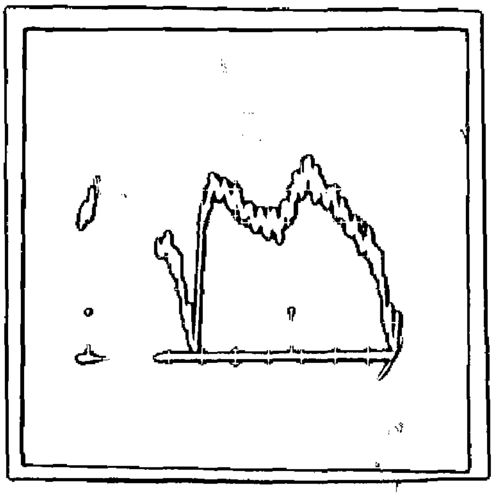




11. Serial 5/6



13. Serial 5/7



serial No. 1/1 — **Strain gage station-1** — speed = 340 R.P.M.

No.		P	F_{ip}		Cos	Q	F_a	F_r	F_n	M_x	f_{Mx}	f_{cd}	Net
1.	0	0	1267	0	1	1267	393	-874	0	0	0	-536	-536
2.	60°	0	388	12°	0,9781	-396	121	-275	374	1191	-2525	-168,75	-2693,75
3.	120°	0	-632,5	12°	0,9781	645	-262	383	292	932	-1975	235	-1740
4.	180°	0	-780	0	1	780	-393	383	0	0	0	237	237
5.	240°	0	-632,5	12°	0,9781	645	-262	383	-292	-932	1975	235	2210
6.	300°	809	388	12°	0,9781	450	121	571	-374	-1191	2525	350	2875
7.	362°	11,600	1267	0	1	10,333	393	10,726	0	0	0	6590	6590
8.	420°	829	388	12°	0,9781	450	121	571	374	1191	-2525	350	-2175
9.	480°	0	-632,5	12°	0,9781	645	-262	383	292	932	-1975	235	-1740
10.	540°	0	-780	0	1	780	-393	387	0	0	0	237	237
11.	600°	0	-632,5	-12°	0,9781	632,5	-262	383	-292	-932	1975	235	2210
12.	660°	0	388	12°	0,9781	-396	121	-275	-374	1191	2525	-168,75	2356,25
13.	720°	0	1267	0	1	-1267	393	-874	0	0	0	-536	-536

Serial No. 1/2 Strain gage station -1 Speed = 330 R.P.M.

No.		P	M_{ip}		Cos	Q	F_a	F_r	F_n	N_x	f_{mx}	f_{ed}	Net
1.	0	0	1190	0	1	1190	369	-831	0	0	0	-511	-511
2.	60°	0	365	12°	0.9781	-372	113.9	-258.1	350.5	1190	-2525	-158.5	-2683.5
3.	120°	0	-595	12°	0.9781	607	-246	361	274	875	-1855	221.5	-1633.5
4.	180°	0	-735	0	1	735	-369	366	0	0	0	224	224
5.	240°	0	-595	-12°	0.9781	607	-246	361	-274	-875	1855	221.5	221.5
6.	300°	829	365	-12°	0.9781	474	113.9	587.9	-350.5	-1190	2525	361	2886
7.	360°	12,200	1190	0	1	11,010	369	11,37	0	0	0	6980.	6980
8.	420°	2480	365	12°	0.9781	2155	113.9	2268.9	350.5	1190	-2525	1380.	-1135
9.	480°	0	-595	12°	0.9781	607 "	-246	361	274	875	-1855	221.5	-1633.5
10.	540°	0	-735	0	1	735	-369	366	0	0	0	224	224
11.	600°	0	-595	-12°	0.9781	607	-246	361	-274	-875	1855	221.5	2076.5
12.	660°	0	365	-12°	0.9781	-372	113.9	-258.1	-350.5	-1190	2525	-158.5	2366.5
13.	720°	0	1190	0	1	-1190	369	-831	0°	0	0	-511.	-511

Serial No. 1/3 Strain gage station -1 speed = 340 R.P.M.

No.		P	F_{ip}		Cos	Q	Fa	F_r	F_n	H_x	f_{Hx}	f_{cd}	Net
1.	0	0	1267	0	1	-1267	393	-874	0	0	0	-536	-536
2.	60°	0	388	12°	0.9781	-393	121	-275	374	1191	2525	-168.75	2356.25
3.	120°	0	-632.5	12°	0.9781	645	-262	383	292	932	1975	235	2210
4.	180°	0	-780.	0	1	780	-393	387	0	0	0	237	237
5.	240°	0	-632.5	12°	0.9781	645	-262	383	292	932	-1975	235	-1740
6.	300°	0	388	-12°	0.9781	-393	121	-275	-374	-1191	-2525	168.75	-2693.75
7.	360°	10,910	1267	0	1	9,653	393	10,046	0	0	0	6175	6175
8.	420°	1650	388	12°	0.9781	1289	121	1410	374	1191	2525	866.0	3391
9.	480°	0	-632.5	12°	0.9781	645	-262	383	292	932	1975	235	2210
10.	540°	0	-780	0	1	780	-393	387	0	0	0	237	237
11.	600°	0	-632.5	-12°	0.9781	645	-262	383	-292	-932	-1975	235	-1740
12.	660°	0	388	-12°	0.9781	-393	121	-275	-374	-1191	-2525	-168.75	-2693.75
13.	720°	0	1267	0	1	-1267	393	-874	0	0	0	-536	-536

Serial No. 2/2 Strain gage station 2 Speed 360 R.P.M.

No.		P	F_{Ip}		Cos	Q	F_a	F_F	F_n	M_x	f_{Mx}	f_{cd}	Tot
1.	0	0	1415	0	1	-1415	440	-975	0	0	0	-938	-667
2.	60°	0	436	12°	0.9781	-444	135.8	-308.2	419	1322	-3140	-210.5	-3350.5
3.	120°	0	-707	12°	0.9781	722	-294	428	326.5	1030	-2450	293	-2057
4.	180°	0	-875	0	1	875	-440	435	0	0	0	297.5	2975
5.	240°	621	-707	12°	0.9781	135.2	-294	1058	-326.5	-1030	2450	724	3174
6.	300°	1049	435	-12°	0.9781	627	135.8	762.8	-419	-1322	3140	521	3661
7.	360°	12,400	1415	0	1	10,935	440	11,425	0	0	0	7810	7810
8.	420°	2230	435	12°	0.9781	2600	135.8	2735.8	419	1322	-3140	1865	-1275
9.	480°	1655	-707	12°	0.9781	2410	-294	2116	326.5	1030	-2450	1446	-1004
10.	540°	830	-875	0	1	1705	-440	1265	0	0	0	865	865
11.	600°	830	-707	-12°	0.9781	1568	-294	1274	-326.5	-1030	2450	871	3321
12.	660°	830	436	-12°	0.9781	403	135.8	538.8	-419	-1322	3140	368	3508
13.	720°	0	1415	0	1	-1415	440	-1075	0	0	0	-938	-657

Serial No. 2/3 Strain gage Station 2 Speed= 360 R.P.M.

No.		P	F_{ip}		Cos	Q	F_a	F_r	F_n	M_x	$f_M x$	f_{cd}	Tot
1.	0	0	1336	0	1	-1336	415	-921	0	0	0	-630	-630
2.	60°	0	410	12°	0.9781	-418	128	-290	394.5	1248	-2975	-198	-3173
3.	120°	0	-667.5	12°	0.9781	681	-277	404	308	975	-2320	276	-2044
4.	180°	0	-925	0	1	840	-415	425	0	0	0	290	290
5.	240°	1030	-667.5	-12°	0.9781	1730	-277	1453	-308	-975	2320	995	3115
6.	300°	1450	410	-12°	0.9781	1060	128	1188	-394.5	-1248	2975	814	3789
7.	362°	12,800	1336	0	1	11,464	415	11,879	0	0	0	8140	8140
8.	420°	3720	410	12°	0.9781	3380	128	3508	394.5	1248	-2975	2400	-575
9.	480°	2276	6676	12°	0.9781	3000	-277	2723	308	976	-2320	1865	-455
10.	540°	1210	-925	0	1	2065	-415	1650	0	0	0	1128	1128
11.	600°	1210	-667.5	-12°	0.9781	1945	-277	1668	-308	-975	2320	1140	3460
12.	660°	1240	410	-12°	0.9781	448	128	976	-394.5	-1248	2975	667.5	3642.5
13.	720°	0	1336	0	1	-1336	416	-921	0	0	0	-630	-630

Serial No. 2/4 Strain gage station 2 Speed = 360 RPM

No.		P	F_{lp}		Cos	Q	F_a	F_r	F_n	M_x	f_{Mx}	f_{cd}	Net
1.	0	0	1416	0	1	-1416	440	-976	0	0	0	-667	-667
2.	60°	0	435	12°	0.9781	-444	135.8	-308.2	419	1322	0	-210.5	-210.5
3.	120°	0	-707	12°	0.9781	722	-294	428	-376.5	1030	0	292	292
4.	180°	0	-876	0	1	876	-440	435	0	0	0	286.5	286.5
5.	240°	621	-707	12°	0.9781	1420	-294	1126	-323.5	-1030	0	770	770
6.	300°	830	435	-12°	0.9781	403	135.8	538.8	-419	-1322	0	368	368
7.	360°	12,000	1416	0	1	10,585	440	11,025	419	0	0	7525	7525
8.	420°	2480	435	12°	0.9781	2080	135.8	2216.8	376.5	1322	0	1510	1510
9.	480°	1450	-707	12°	0.9781	2200	-294	1906	419	1030	0	1300	1300
10.	540°	1240	-876	0	1	2115	-440	1675	0	0	0	1142	1142
11.	600°	1240	-707	-12°	0.9781	2200	-294	1906	-323.5	-1030	0	1300	1300
12.	660°	1240	435	-12°	0.9781	822.5	135.8	958.3	-419	-1322	0	671	671
13.	720°	0°	1416	0	1	-1416	440	-976	0	0	0	-667	-667

Serial No. 2/5 Strain gage station 2 Speed = 350 R.P.M.

No		P	F_{1p}		Cos	Q	F_a	F_p	F_n	M_x	f_{Mx}	f_{ed}	Tot
1.	0	0	1336	0	1	-1336	415	-921	0	0	0	-630	-630
2.	60°	0	410	12°	0.9781	-418	128	-290	394.5	1248	00	-193	-193
3.	120°	0	-667.5	12°	0.9781	681	-277	404	308	975	0	276	276
4.	180°	0	-825	0	1	844	-415	419	0	0	0	286	286
5.	240°	415	-667.5	-12°	0.9781	1100	-277	823	-308	-975	0	562	562
6.	300°	621	410	-12°	0.9781	216	128	343	-394.5	-1248	0	234	234
7.	360°	11,800	1336	0	1	10,464	415	10,875	0	0	0	7450	7450
8.	420°	2580	410	12°	0.9781	2216	128	2343	394.5	1248	0	1600	1600
9.	480°	1655	667.5	12°	0.9781	2370	-277	2093	308	975	0	1430	1430
10.	540°	415	-825	0	1	1240	-415	825	0	0	0	564	630
11.	600°	415	-667.5	-12°	0.9781	1100	-277	823	-308	-975	0	562.5	562.5
12.	660°	415	410	-12°	0.9781	5.1	123	133.1	-394.5	1248	0	91.0	91.0
13.	720°	0	1336	0	1	-1336	416	-921	0	0	0	-630	-630

Serial No. 3/6 — Strain gage station 2 — speed =360

No		P	F_{1p}		Cos	?	F_a	F_p	F_n	M_r	f_{Nr}	f_{cd}	Net
1.	0	0	1415	0	1	-1415	440	-975	0	0	0	-632.5	-632.5
2.	60°	0	436	12°	0.9781	-444	153.8	-302.2	419	1322	0	-210.5	-210.5
3.	120°	0	-707	12°	0.9781	722	-284	438	323.5	1030	0	233	233
4.	180°	0	-875	0	1	875	440	430	0	0	0	284	284
5.	240°	415	-707	-12°	0.9781	1142	284	848	323.5	-1030	0	530	530
6.	300°	830	436	-12°	0.9781	403	135.8	433.8	-419	-1322	0	300	300
7.	360°	11,350	1415	0	1	9,935	440	10,375	0	0	0	7100	7100
8.	420°	3310	436	12°	0.9781	2930	135.8	3065.8	419	1322	0	2100	2100
9.	480°	1655	-707	12°	0.9781	2410	-284	2116	323.5	1030	0	1448	1448
10.	540°	415	-875	0	1	1290	440	850	0	0	0	531	531
11.	600°	415	-707	12°	0.9781	1142	-284	848	323.5	1030	0	530	530
12.	660°	450	436	12°	0.9781	-20.4	135.8	115.4	-419	-1322	0	790	790
13.	720°	0	1415	0	1	-1415	440	-284	0	0	0	-632.5	-632.5

.. No. 2/7 Strain gage station 2 Speed = 350 R.P.M.

No.		P	P_{sp}		Cos	Q	F_a	F_F	F_n	M_T	f_{Mx}	f_{cd}	Tot
1.	0	0	1336	0	1	-1336	415	-921	0	0	0	-630	-630
2.	60°	0	410	12°	0.9781	-418	[illegible]	-280	384.5	1248	0	-193	-193
3.	120°	0	-667.5	12°	0.9781	681	-277	404	308	975	0	273	273
4.	180°	0	-925	0	1	844	-415	419	0	0	0	236	236
5.	240°	207.5	-667.5	-12°	0.9781	894	-277	617	-308	-975	0	422.5	422.5
6.	300°	415	410	-12°	0.9781	5.1	128	133.1	-384.5	-1248	0	91.0	91.0
7.	360°	11,150	1336	0	1	9,814	[illegible]	10,329	0	0	0	7000	7000
8.	420°	2395	410	12°	0.9781	2510	128	2568	384.5	1248	0	1822	1822
9.	480°	1240	667.5	12°	0.9781	1945	-277	1668	308	975	0	1140	1140
10.	540°	415	-925	0	1	1240	-415	825	0	0	0	564	564
11.	600°	415	-667.5	-12°	0.9781	1102	-277	825	-308	-975	0	564	564
12.	660°	415	410	-12°	0.9781	5.1	128	133.1	-384.5	1248	0	91.0	91.0
13.	720°	0	1336	0	1	-1336	415	-921	0	0	0	-630	-630

Serial No. 2/8 Strain gage station 2 Speed =360

No.		P	F_{10}		Cos	Q	F_a	F_r	F_n	M_x	f_{Mx}	f_{cd}	Fct
1.	0	0	1415	0	1	-1415	440	-975	0	0	0	-666	-666
2.	60°	0	435	12°	0.9781	-444	135.8	-308.2	419	1322	3140	-210	2930
3.	120°	0	-707	12°	0.9781	722	294	4[illegible]3	3[illegible]6	[illegible]	2450	293	2743
4.	180°	0	-575	0	1	875	-440	435	0	0	0	297	297
5.	240°	414	-707	-12°	0.9781	1142	-294	848	323.5	-1030	-2450	580	-1870
6.	300°	414	435	-12°	0.9781	21.4	135.8	114.4	419	-1322	[illegible]	[illegible]	-3061.8
7.	360°	11,600	1415	0	1	10,185	440	10,625	0	0	0	7270	7270
8.	420°	2075	435	12°	0.9781	1670	135.8	1805.8	419	1322	3140	1232	4372
9.	480°	1450	-707	12°	0.9781	2200	-294	1906	323.5	1030	2450	1300	3760
10.	540°	414	875	0	1	1312	-440	872	0	0	0	596	596
11.	600°	414	-707	-12°	0.9781	1142	-294	848	-323.5	-1030	-2450	580	-1870
12.	660°	414	435	-12°	0.9781	-21.4	135.5	157.2	419	-1322	-3140	107.4	-3032.6
13.	720°	0	1415	0	1	1415	440	-875	0	0	0	-666	-666

Serial No. 3/ Strain gage station B Speed =350 R.P.M.

No.		P	F_{ip}		Cos	ψ	F_a	F_r	F_n	M_x	f_{tx}	f_{cd}	Net
1.	0	0	1336	0	1	-1336	416	-921	0	0	0	-479	-479
2.	60°	0	410	12°	0.9781	-419	128	-291	384.5	865	-2820	161.5	2471.5
3.	120°	0	-657.5	12°	0.9781	672.6	-270	406.6	303	675	-1810	731	-1627
4.	180°	0	-825	0	1	825	-415	410	0	0	0	283	283
5.	240°	414	-657.5	-12°	0.9781	1106	-277	829	-303	-675	1810	672.5	2382.5
6.	300°	621	410	-12°	0.9781	216.6	128	343.6	-384.5	-865	2820	737	3557
7.	360°	12,000	1336	0	1	10,664	416	11,079	0	0	0	7650	7650
8.	420°	1861	410	12°	0.9781	1487	128	1615	384.5	865	-2820	1115	-1705
9.	480°	932	-657.5	12°	0.9781	1630	-277	1353	303	675	-1810	936	-874
10.	540°	621	-825	0	1	1446	-415	1031	0	0	0	724	724
11.	600°	621	-657.5	-12°	0.9781	1315	-277	1038	-303	-675	1810	716	2557
12.	660°	621	410	-12°	0.9781	215.5	128	343.5	-384.5	-865	2820	737	3557
13.	720°	0	1336	0	1	-1336	416	-921	0	0	0	-479	-479

Serial No. 3/2 Strain gage station 3 speed =350 R.P.M.

No		P	V_{2p}		Cos	Q	F_a	F_P	F_n	M_x	f_{mx}	f_{ed}	Net
1.	0	0	1336	0	1	-1336	416	921	0	0	0	-479	-479
2.	60°	0	410	12°	0.9781	-419	128	-291	394.5	865	-2320	-151.5	-2471.5
3.	120°	0	-667.5	12°	0.9781	682.5	-277	405.5	308	675	-1910	281	-1629
4.	180°	0	-825	0	1	825	-415	410	0	0	0	233	233
5.	240°	414	-667.5	-12°	0.9781	1105	-277	828	-308	-675	1910	572.5	2482.5
6.	300°	621	410	-12°	0.9781	215.5	128	343.5	-394.5	-865	2320	237	2557
7.	360°	11590	1336	0	1	10,254	415	10,669	0	0	0	7380	7380
8.	420°	2900	410	12°	0.9781	2540	128	2668	394.5	865	-2320	1840	-480
9.	480°	1840	-667.5	12°	0.9781	1954	-270	1668	308	675	-1910	1150	-660
10.	540°	519	825	0	1	1344	-415	929	0	0	0	641	641
11.	600°	414	-667.5	-12°	0.9781	1105	-277	828	-308	-675	1910	572	2482
12.	660°	310	410	-12°	0.9781	-102	128	26	-394.5	-865	2320	17.95	2337.95
13.	720°	0	1336	0	1	-1336	415	-921	0	0	0	-479	-479

S-rial No. 5/3 # 6/4 Strain gag station 2 Speed - 360 R.P.M.

No.		?	F_{gp}		Cos	(	F_a	F_r	F_n	F_R	[illegible]	f_{ed}	Net
1.	0	0	1336	0	1	-1336	415	-921	0	0	0	-470	-470
2.	60°	0	410	12°	0.9781	-410	123	-291	394.5	865	[illegible]	-151.5	-151.5
3.	120°	0	-337.5	12°	0.9781	672.5	-277	4050	303	675	0	231	231
4.	180°	0	-825	0	1	825	-415	410	0	0	0	233	233
5.	240°	414	-337.5	-12°	0.9781	1106	-277	828	-303	-675	0	572.6	572.6
6.	300°	621	410	-12°	0.9781	215.5	123	343.5	-394.5	-865	0	237	237
7.	360°	11,730	1336	0	1	10,454	415	10,869	0	0	0	7500	7500
8.	420°	2925	410	12°	0.9781	2535	123	2363	394.5	865	0	1940	1940
9.	480°	1740	-337.5	12°	0.9781	1846	-277	1663	303	675	0	1150	1150
10.	540°	414	-825	0	1	1239	-415	824	0	0	0	539	539
11.	600°	414	-337.5	12°	0.9781	1105	-277	828	-303	-675	0	572	572
12.	660°	414	410	-12°	0.9781	4.03	123	132.03	-394.5	-865	0	91.1	91.1
13.	720°	0	1336	0	1	-1336	415	-921	0	0	0	-470	-479

Serial No. 3/9 Strain gage station 2 speed = 360 R.P.M.

No.		P	M [illegible]		Cos	Q	F_a	F_r	F_n	M_x	f [illegible]	f_{cd}	Net
1.	0	0	1336	0	1	-1336	415	-921	0	0	0	-479	-479
2.	60°	0	410	12°	0.9781	-419	128	-291	394.5	865	0	-151.5	-151.5
3.	120°	0	-667.5	12°	0.9781	682.5	-277	405.5	308	675	0	231	231
4.	180°	0	-825	0	1	825	-415	410	0	0	0	283	283
5.	240°	414	-667.5	-12°	0.9781	1105	-277	828	-308	-675	0	572.5	572.5
6.	300°	621	410	-12°	0.9781	215.5	128	343.5	-394.5	-865	0	237	237
7.	360°	12,000	1336	0	1	10,664	415	11,079	0	0	0	7650	7650
8.	420°	2302	410	12°	0.9781	2325	128	2453	394.5	865	0	1692	1692
9.	480°	1666	-667.5	12°	0.9781	2375	-277	2098	308	675	0	1449	1449
10.	540°	414	-825	0	1	1239	-415	824	0	0	0	569	569
11.	600°	207	-667.5	-12°	0.9781	892	-277	615	-308	-675	0	425	425
12.	660°	207	410	-12°	0.9781	-207	128	-79	-394.5	-865	0	-41.0	-41.0
13.	720°	0	1336	0	1	-1336	415	-921	0	0	0	-479	-479

Serial No. 3/5 Strain gage station 3 speed = 350 R.P.M.

No.		P	F_{ip}		Cos	Q	F_a	F_r	F_n	H_x	f_{MX}	f_{cd}	Tot
1.	0	0	1336	0	1	-1336	415	-921	0	0	0	-479	-0,805
2.	60°	0	410	12°	0,9781	-419	123	-291	394,5	865	0	-151,5	-0,254
3.	120°	0	-667,5	12°	0,9781	682,5	-277	405,5	308	675	0	281	0,4776
4.	180°	0	-825	0	1	825	-415	410	0	0	0	[illegible]	[illegible]
5.	240°	310	-667,5	-12°	0,9781	1000	-277	723	-308	-675	0	499	0,840
6.	300°	723	410	-12°	0,9781	[illegible]	123	450	-394,5	-865	0	310,5	0,521
7.	360°	12,000	1336	0	1	10,664	415	11,079	0	0	0	7650	12,85
8.	420°	2480	410	12°	0,9781	2100	123	2223	394,5	865	0	1540	[illegible]
9.	480°	1035	-667,6	12°	0,9781	1736	-277	1463	308	675	0	1005	1,69
10.	540°	414	-825	0	1	1239	-415	824	0	0	0	569	0,955
11.	600°	414	-667,5	-12°	0,9781	1105	-277	828	-308	-675	0	572	0,962
12.	660°	414	440	-12°	0,9781	4,08	123	132,08	-394,5	-865	0	91,1	0,153
13.	720°	0	1336	0	1	-1336	415	-921	0	0	0	-479	-0,805

Serial No. 3/6 Strain gage station 3 Speed = 350 R.P.M.

No.		P	F_{ip}		Cos	Q	F_q	Fr	F_n	H_x	$\delta_M X$	Fed	Net
1.	0	0	1336	0	1	-1336	415	-921	0	0	0	-470	-470
2.	60°	0	410	12°	0.9781	-419	128	-291	384.5	366	0	-151.5	-151.5
3.	120°	0	-667.5	12°	0.9781	652.5	-277	405.5	303	675	0	381	381
4.	180°	0	-825	0	1	825	-415	410	0	0	0	238	238
5.	240°	307	-667.5	12°	0.9781	898	-277	616	-303	-675	0	425	425
6.	300°	414	410	12°	0.9781	409	128	132.03	-384.5	-366	0	91.1	91.1
7.	360°	11,720	1336	0	1	10,454	415	10,869	0	0	0	7500	7500
8.	420°	2195	410	12°	0.9781	2535	128	2363	384.5	835	0	1530	1530
9.	480°	1940	-667.5	12°	0.9781	1945	-277	1668	303	675	0	1150	1150
10.	540°	414	-825	0	1	1239	-415	824	0	0	0	560	560
11.	600°	414	-667.5	-12°	0.9781	1105	-277	828	-303	-675	0	578	578
12.	660°	414	410	-12°	0.9781	4.03	128	132.03	-384.5	-366	0	91.1	91.1
13.	720°	0	1336	0	1	-1336	415	-921	0	0	0	-410	-410

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Strain gage station = 3

INDICATOR DIAG. No. - 7 SPEED = 350 R.P.M.

No.	Angle	Gas(P) Force	N_{tp}	ø	cos ø	Q	F_a	F_r	F_n	M_x	f_{Mx}	f_{cd}	Net
1.	0	0	1336	0	0	-1336	415	-921	0	0	0	-479	-479
2.	60	0	410	12	0.9781	-419	128	-291	394.5	865	2320	-151.5	2168.5
3.	120	0	-667.5	12	0.9781	682.5	-277	365.5	308	675	1810	281	2091
4.	180	0	-825	0	1	825	-415	410	0	0	0	283	283
5.	240	207	-667.5	-12	0.9781	892	-277	615	-308	-675	-1810	425	-1385
6.	300	621	410	-12	0.9781	216.5	128	343.5	-394.5	-865	-2320	237	-2083
7.	360	12000	1336	0	1	10664	415	11079	000	0	0	7650	7650
8.	420	2480	410	12	0.9781	2150	128	2238	394.5	865	2320	1545	3865
9.	480	1845	-667.5	12	0.9781	2155	-277	1878	308	675	1810	1299	4109
10.	540	414	-825	0	1	1239	-415	824	0	0	0	570	570
11.	600	414	-667.5	-12	0.9781	1105	-277	828	-308	-675	-1810	572.5	-1237.5
12.	660	414	410	-12	0.9781	4.08	128	132.08	-394.5	-865	-2320	91.1	-2228.9
13.	720	0	1336	0	1	-1336	415	-921	0	0	0	-479	-479

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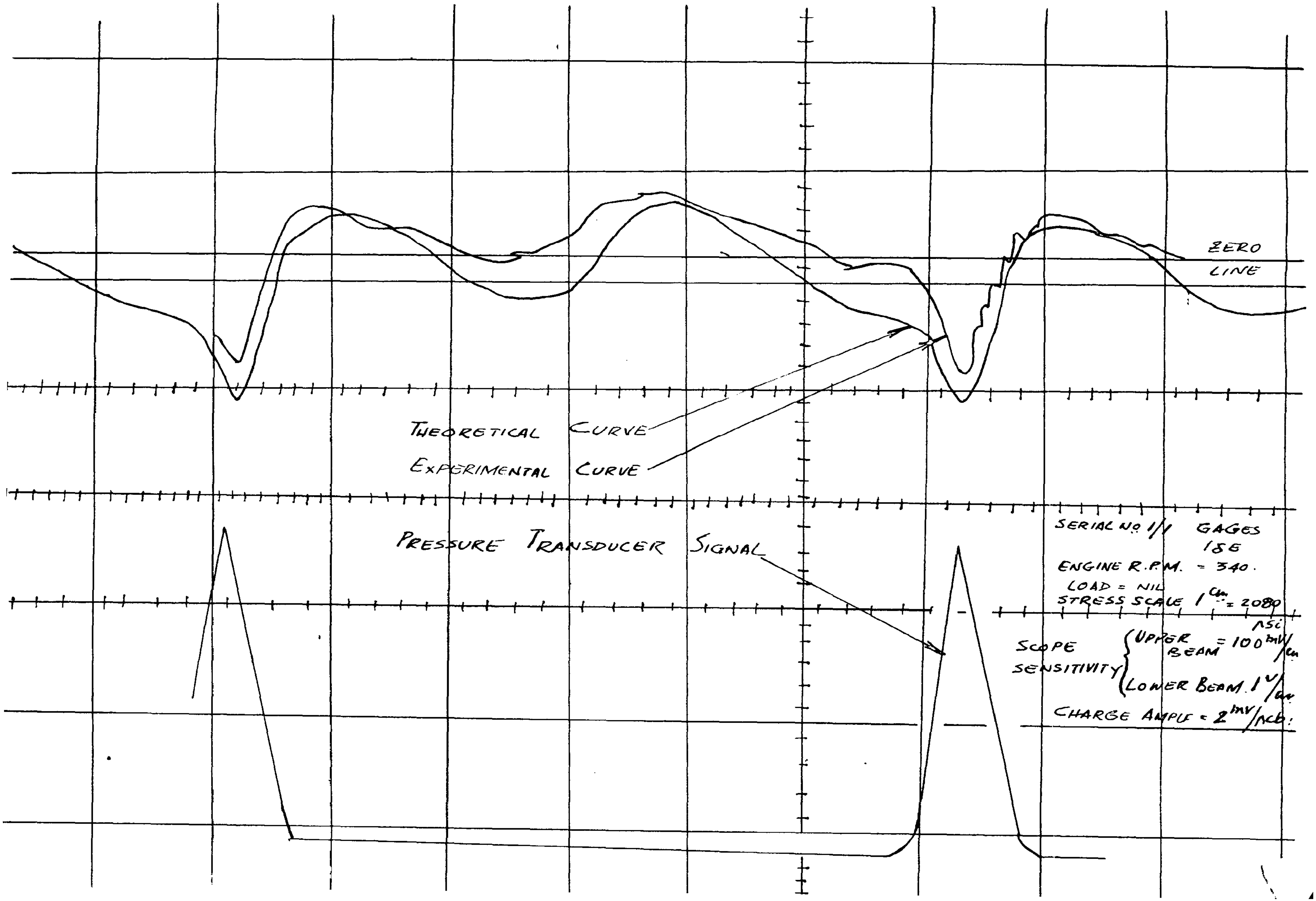
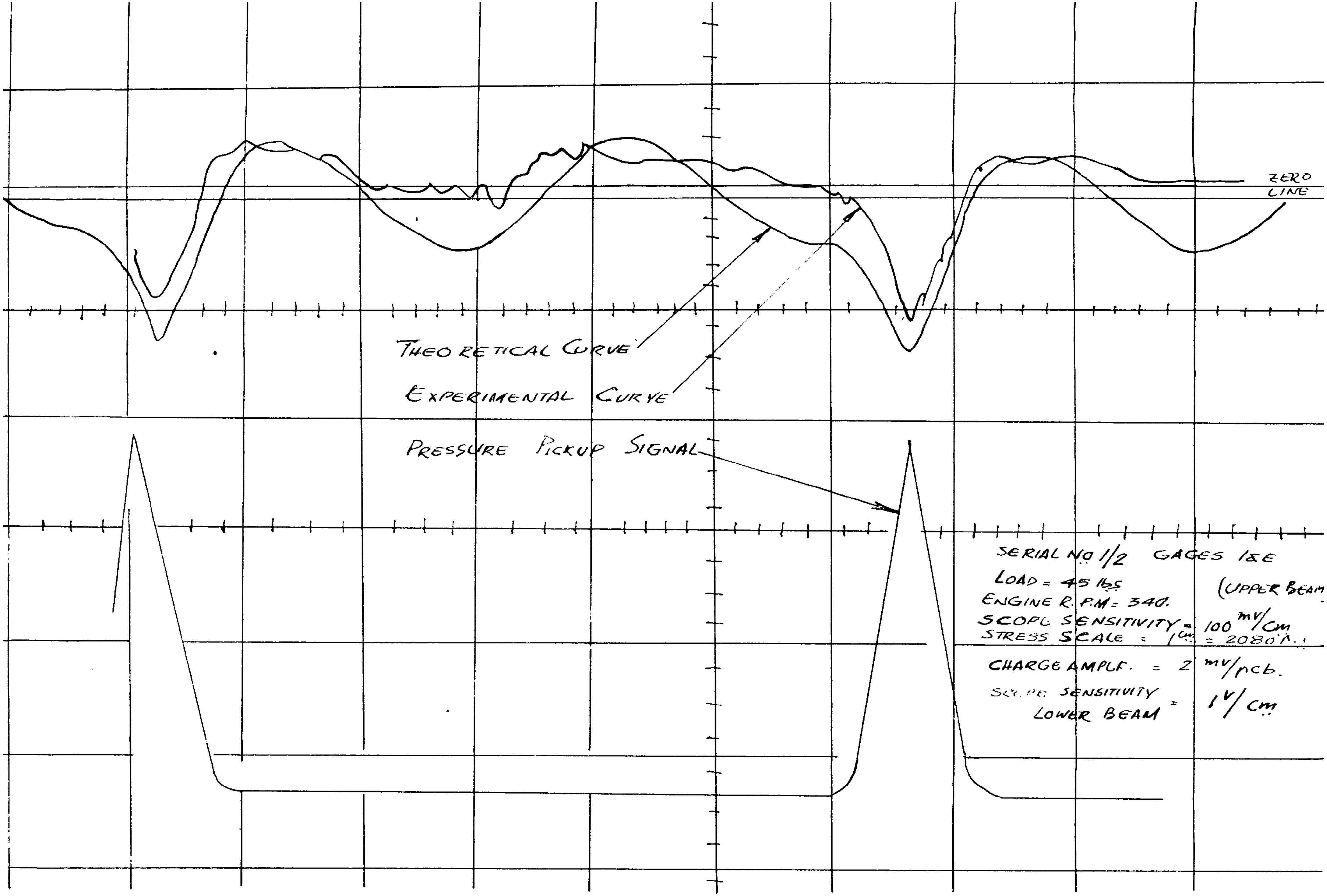
Strain Gage station = 3

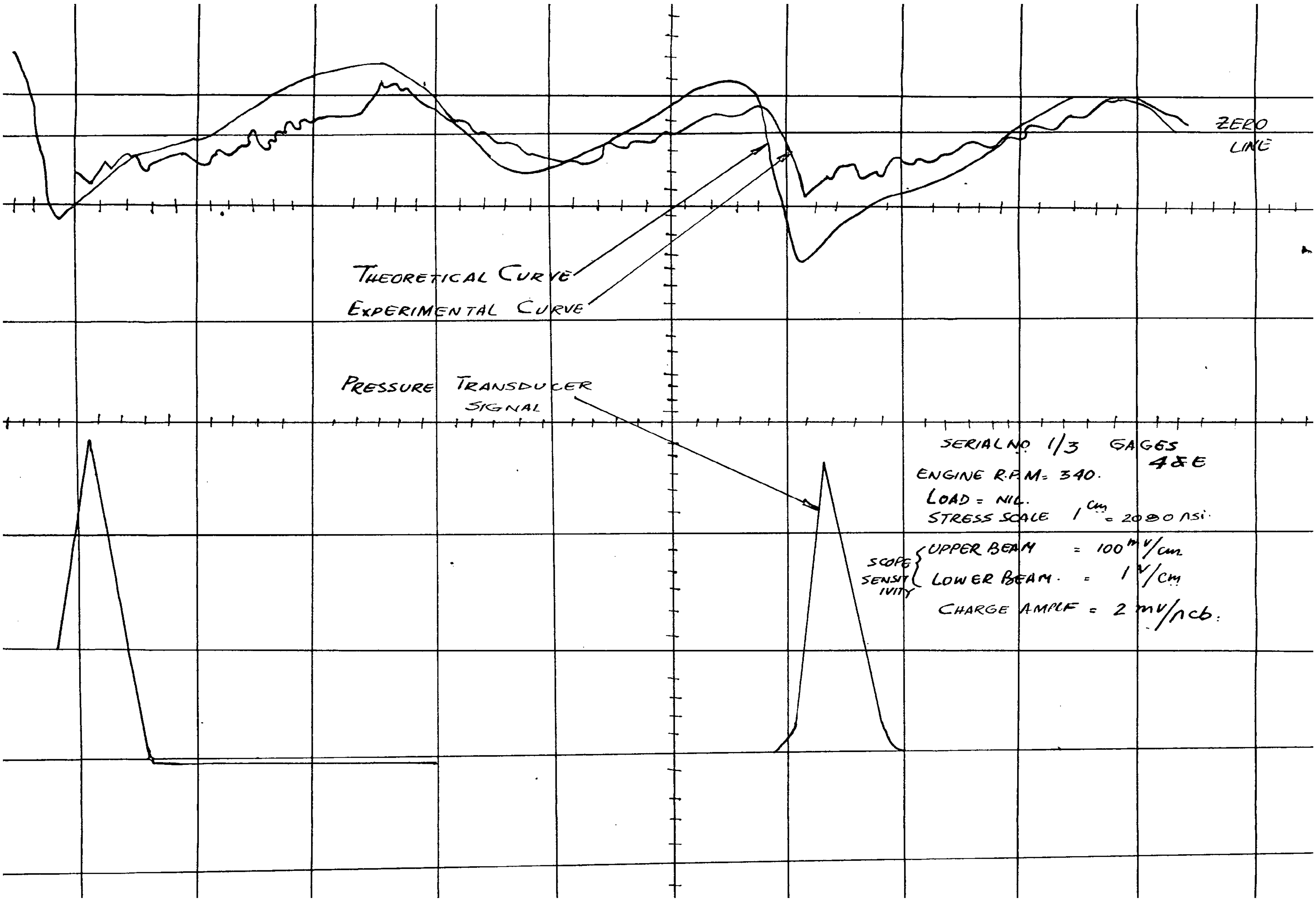
Indicator Diagram No = 8

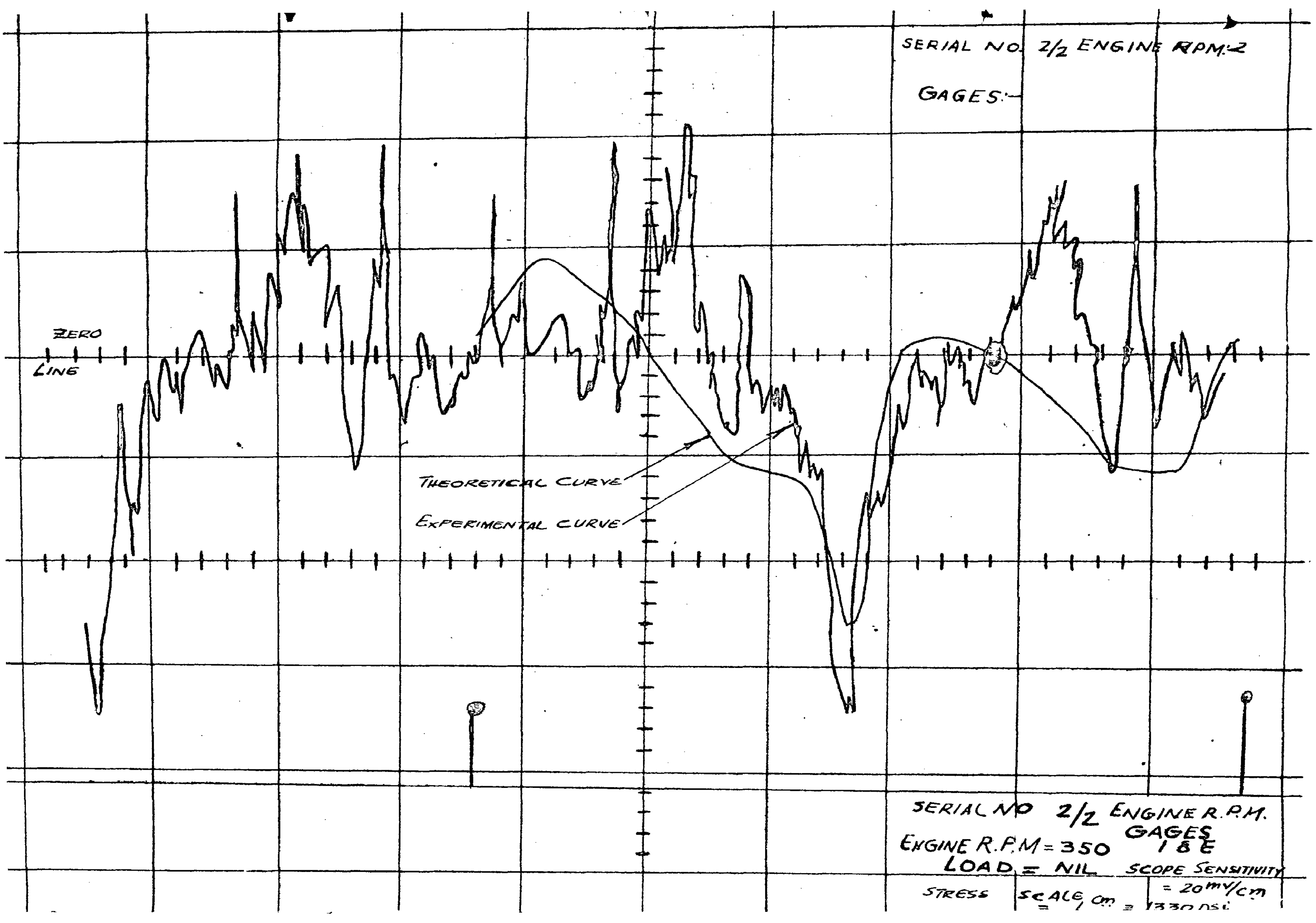
Speed = 350 R.P.M.

No.	θ	P	F_{ip}	∅	Cos ∅	Q	F_a	F_r	F_n	M_x	f_{Mx}	f_{cd}	Net
1.	0	0	1336	0	1	-1336	415	-921	0	0	0	-479	-479
2.	60	0	410	12	0.9781	-419	128	-291	394.5	865	2320	-151.5	2168.5
3.	120	0	-667.5	12	0.9781	682.5	-277	405.5	308	675	1810	281	2091
4.	180	0	-825	0	1	825	-415	410	0	0	0	283	283
5.	240	310	-667.5	-12	0.9781	1000	-277	723	-308	-675	-1810	500	-1310
6.	300	621	410	-12	0.9781	215.5	128	342.5	-394.5	-865	-2320	237	-2083
7.	360	11790	1336	0	1	10454	415	10869	0	0	0	7500	7500
8.	420	3100	410	12	0.9781	2745	128	2873	394.5	865	2320	1985	4305
9.	480	1240	-667.5	12	0.9781	1945	-277	1668	308	675	1810	1150	2960
10.	540	414	-825	0	1	1239	-415	824	0	0	0	570	570
11.	600	207	-667.5	-12	0.9781	892	-277	615	-308	-675	-1810	425	-1385
12.	660	207	410	-12	0.9781	-207	128	-79	-394.5	-865	-2320	-41.1	-2361.1
13.	720	0	1336	0	1	-1336	415	-921	0	0	0	-479	-479

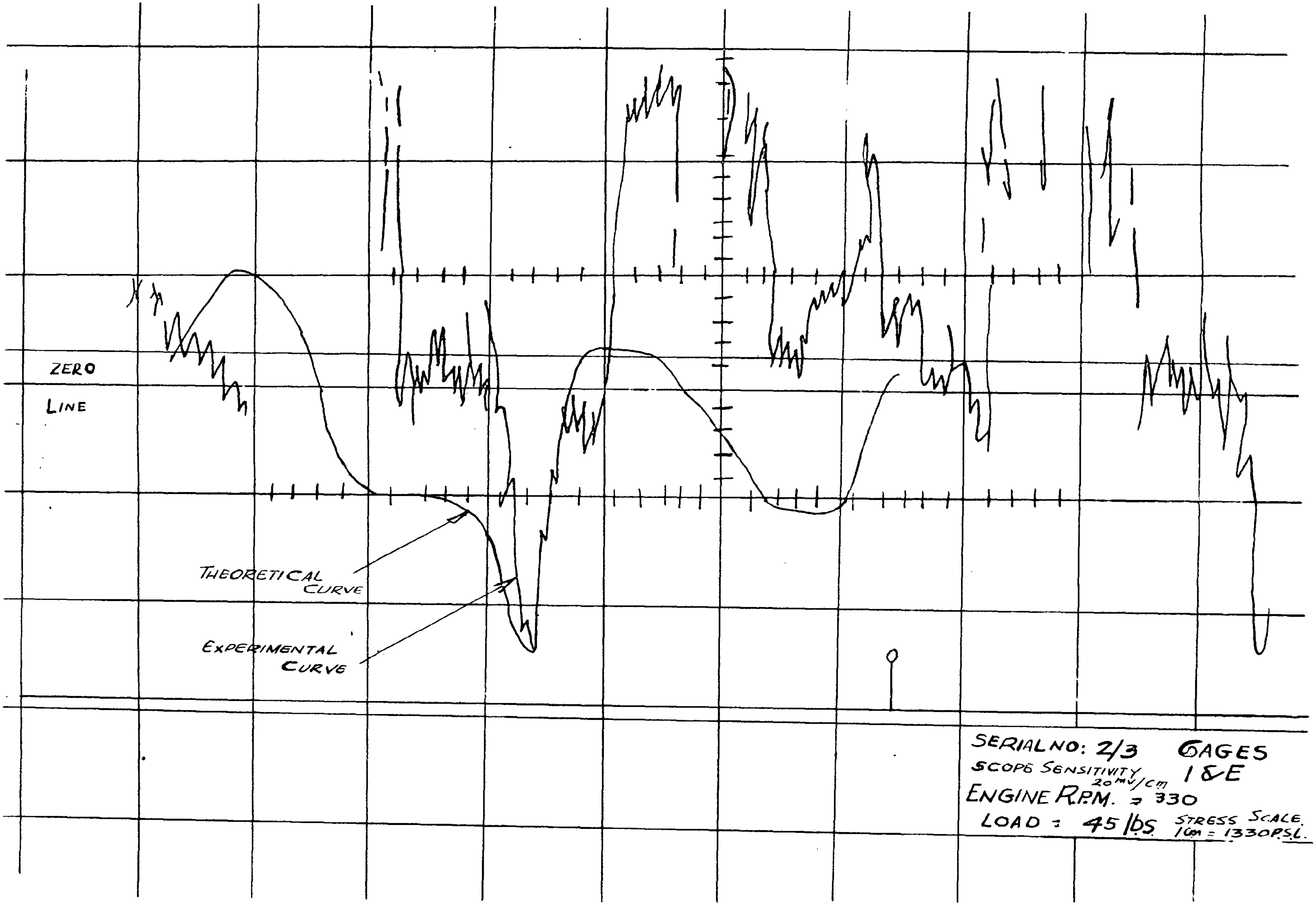

ZERO LINE
THEORETICAL CURVE
EXPERIMENTAL CURVE
PRESSURE TRANSDUCER SIGNAL
SERIAL No. 1/1 GAGES 1&5
ENGINE R.P.M. = 340.
LOAD = NIL
STRESS SCALE 1 cm = 2080 psi
SCOPE SENSITIVITY
UPPER BEAM = 100 mV/cm
LOWER BEAM. 1 V/cm
CHARGE AMPLF = 2 mV/pcb:

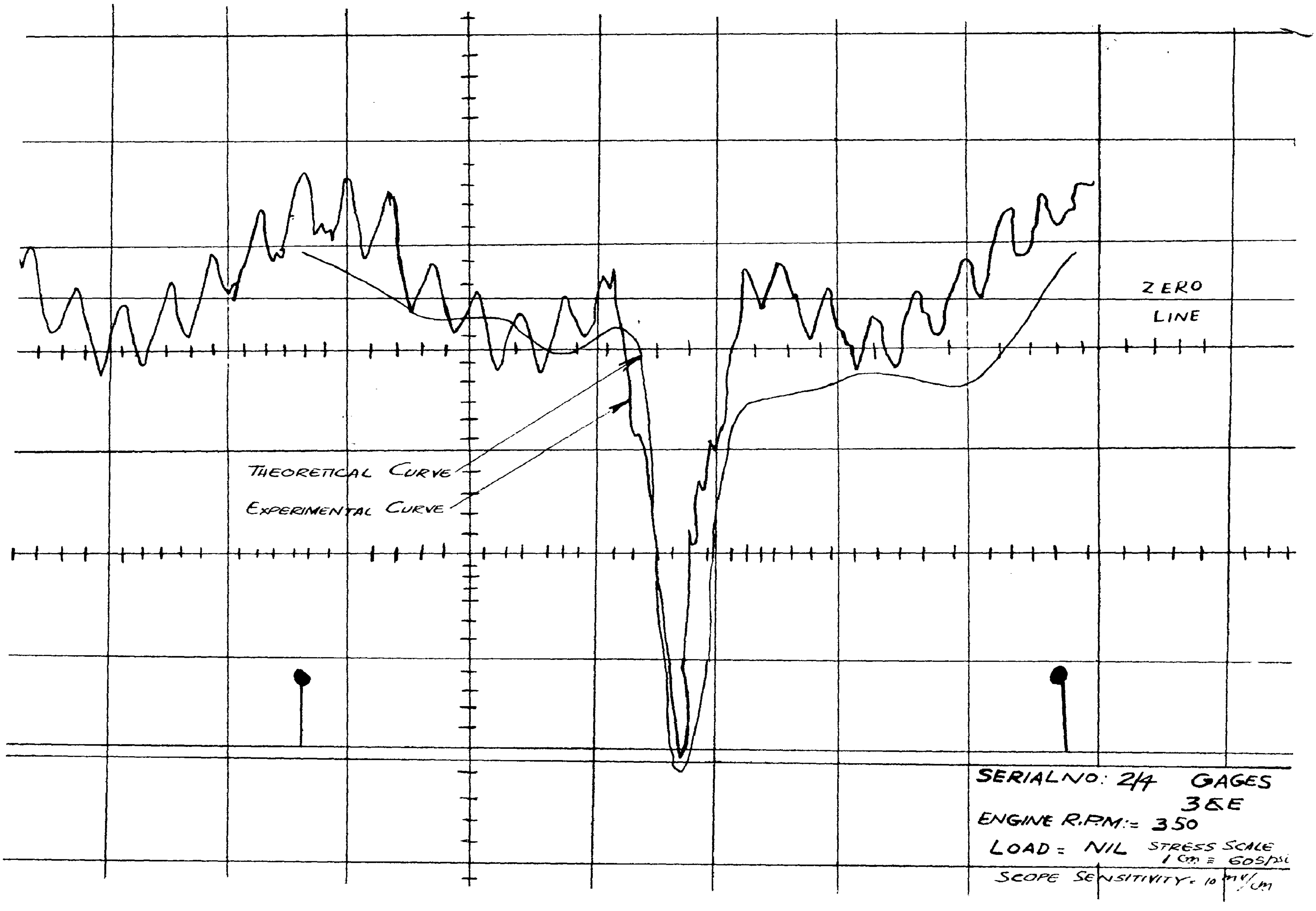

ZERO LINE
THEORETICAL CURVE
EXPERIMENTAL CURVE
PRESSURE PICKUP SIGNAL
SERIAL NO 1/2 GAGES 1&E
LOAD = 45 lbs
(UPPER BEAM
ENGINE R.P.M = 340.
SCOPE SENSITIVITY = 100 mV/Cm
CHARGE AMPLF. = 2 mV/pcb.
LOWER BEAM
1 V/Cm

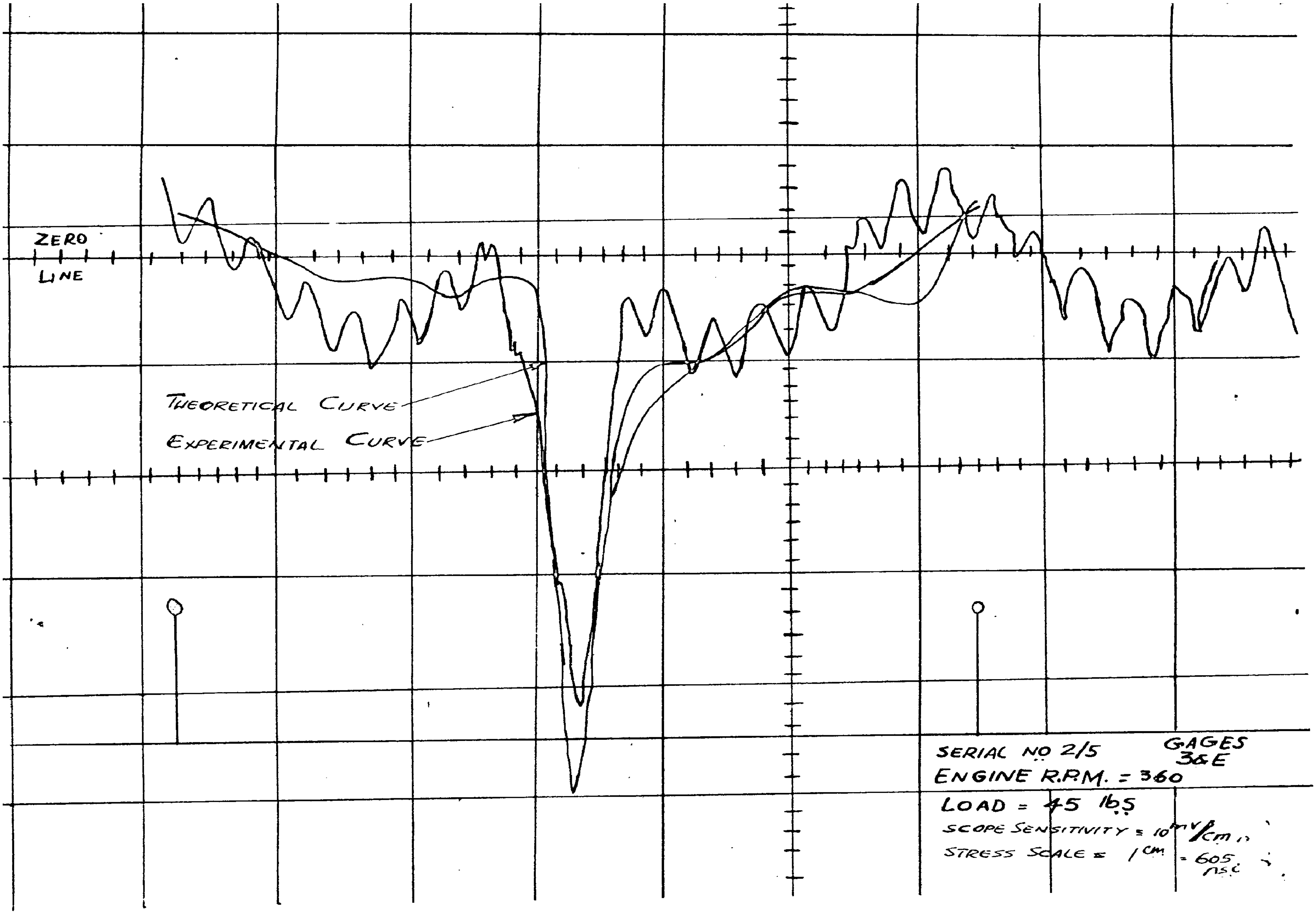

ZERO LINE
THEORETICAL CURVE
EXPERIMENTAL CURVE
PRESSURE TRANSDUCER SIGNAL
SERIAL NO 1/3 GAGES 4 & E
ENGINE R.P.M. = 340.
LOAD = NIL.
STRESS SCALE 1 cm = 2080 psi.
SCOPE SENSITIVITY { UPPER BEAM = 100 mV/cm
LOWER BEAM = 1 V/cm
CHARGE AMPLF = 2 mV/pcb.



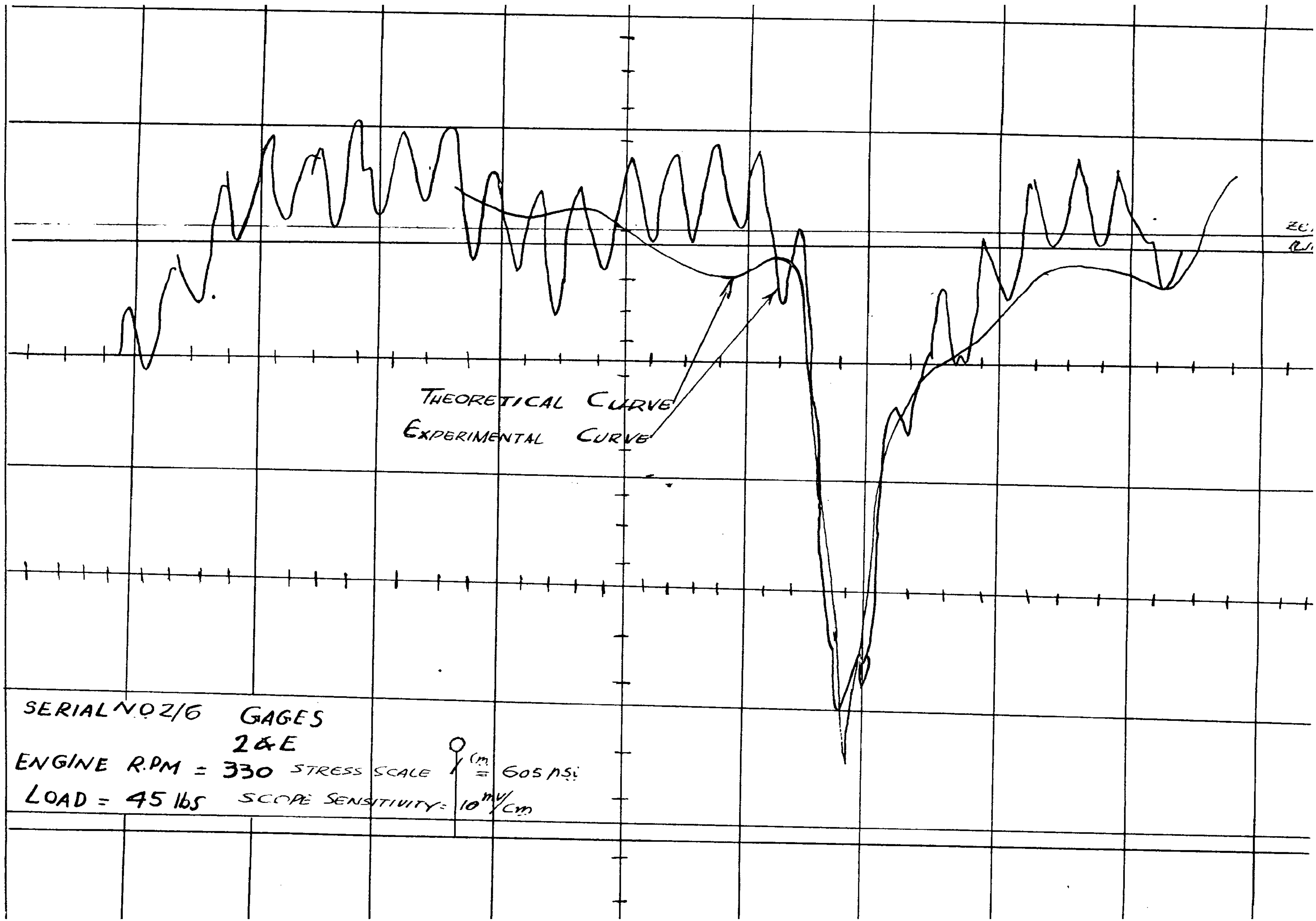
SERIAL NO. 2/2 ENGINE RPM:2
GAGES:-
ZERO LINE
THEORETICAL CURVE
EXPERIMENTAL CURVE
SERIAL NO 2/2 ENGINE R.P.M.
GAGES 1 & E
ENGINE R.P.M = 350
LOAD = NIL
SCOPE SENSITIVITY = 20 mV/cm
STRESS SCALE cm = 1 cm = 1330 psi

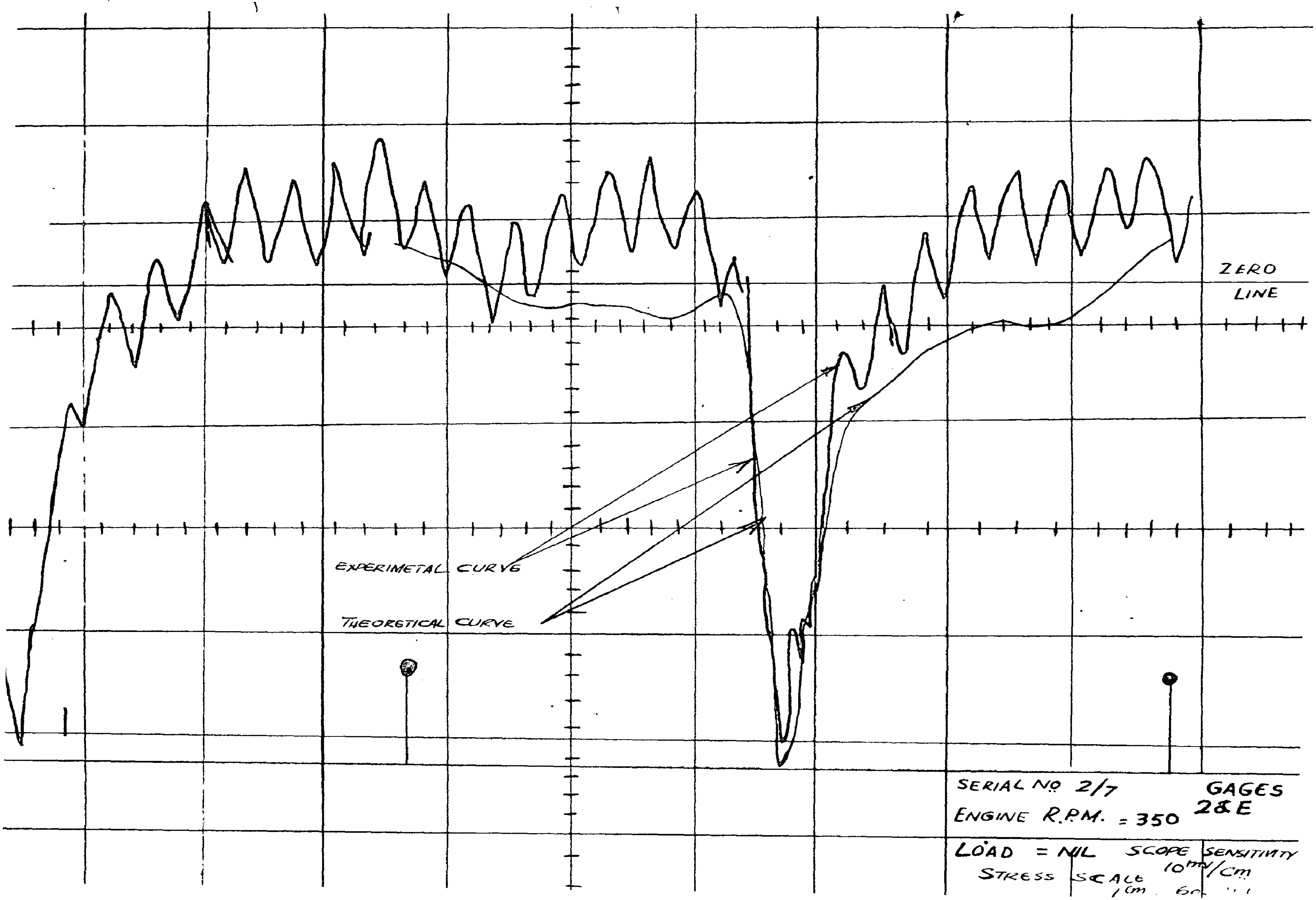

ZERO
LINE
THEORETICAL CURVE
EXPERIMENTAL CURVE
SERIAL NO: 2/3 GAGES 1 & E
SCOPE SENSITIVITY 20 mv/cm
ENGINE R.P.M. = 330
LOAD = 45 lbs
STRESS SCALE 1 cm = 1330 P.S.I.


ZERO LINE
THEORETICAL CURVE
EXPERIMENTAL CURVE
SERIAL NO: 2/4 GAGES 3&E
ENGINE R.P.M.:= 350
LOAD = NIL
STRESS SCALE 1 Cm = 605psi
SCOPE SENSITIVITY = 10 mV/Cm

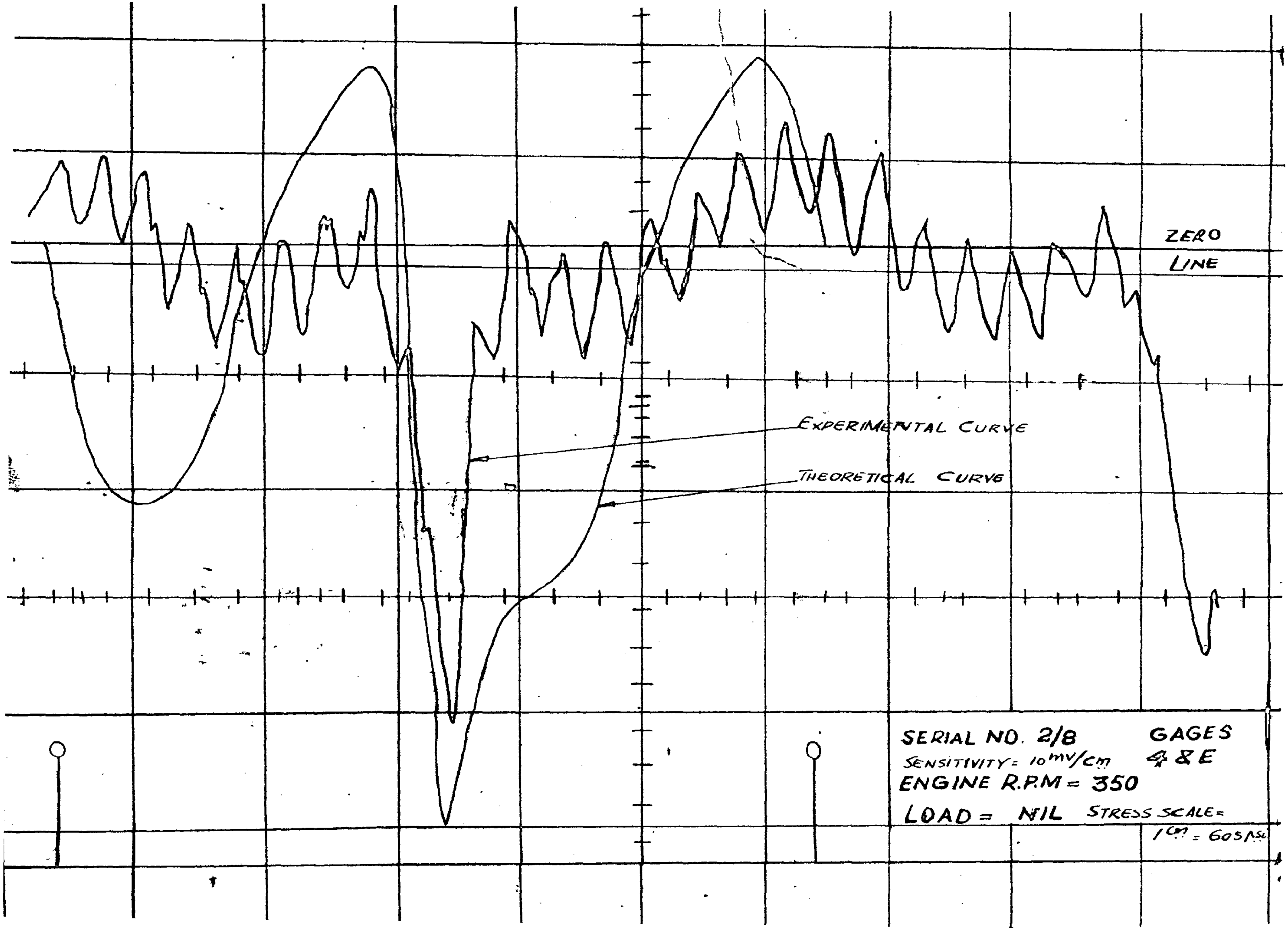


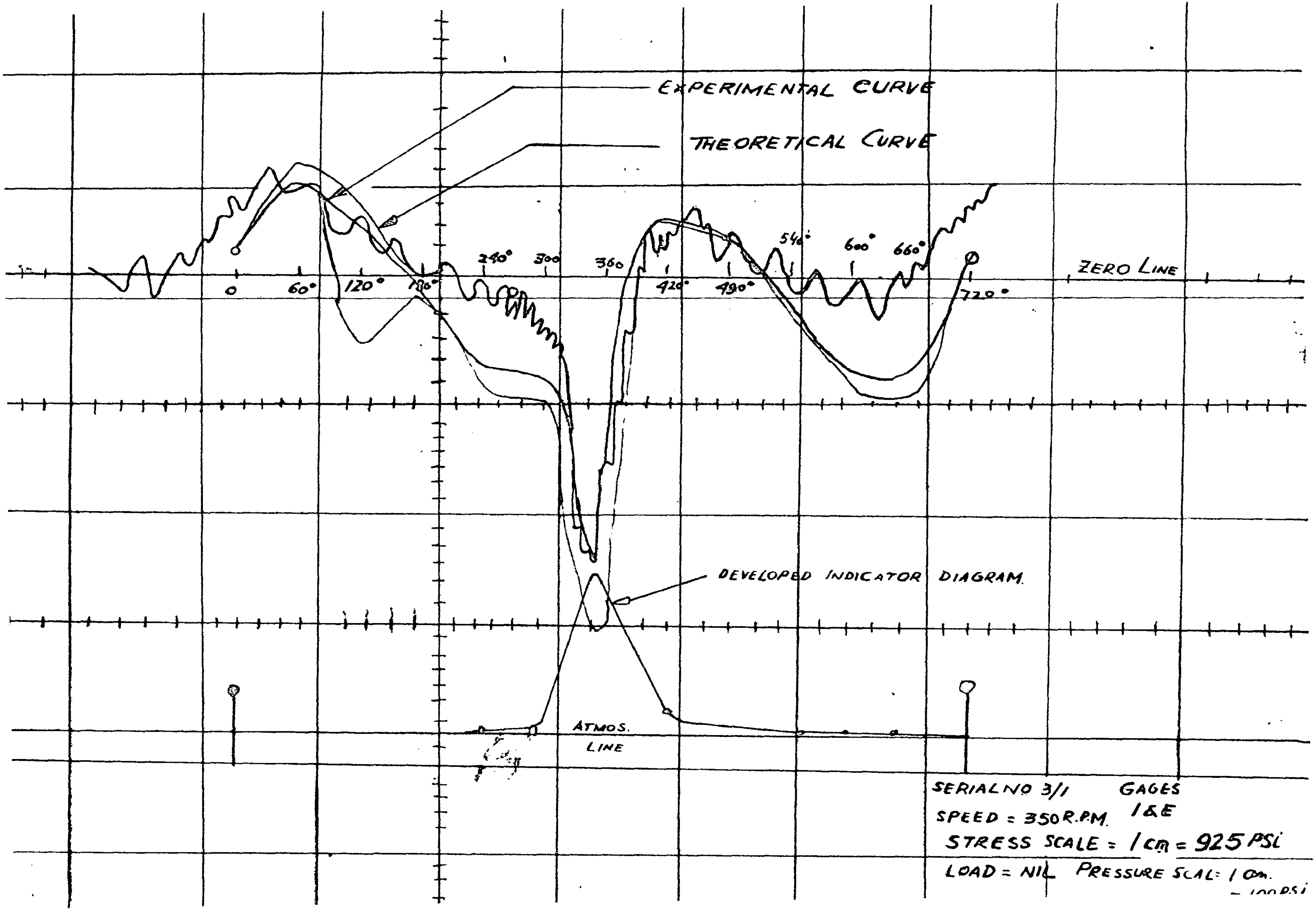
ZERO
LINE
THEORETICAL CURVE
EXPERIMENTAL CURVE
SERIAL NO 2/5
GAGES 3&E
ENGINE R.P.M. = 360
LOAD = 45 lbs
SCOPE SENSITIVITY = 10 mV/cm
STRESS SCALE = 1 cm = 605 psi


THEORETICAL CURVE
EXPERIMENTAL CURVE
SERIAL NO 2/6
GAGES 2&E
ENGINE R.P.M = 330
STRESS SCALE 1 cm = 605 psi
LOAD = 45 lbs
SCOPE SENSITIVITY: 10 mv/cm

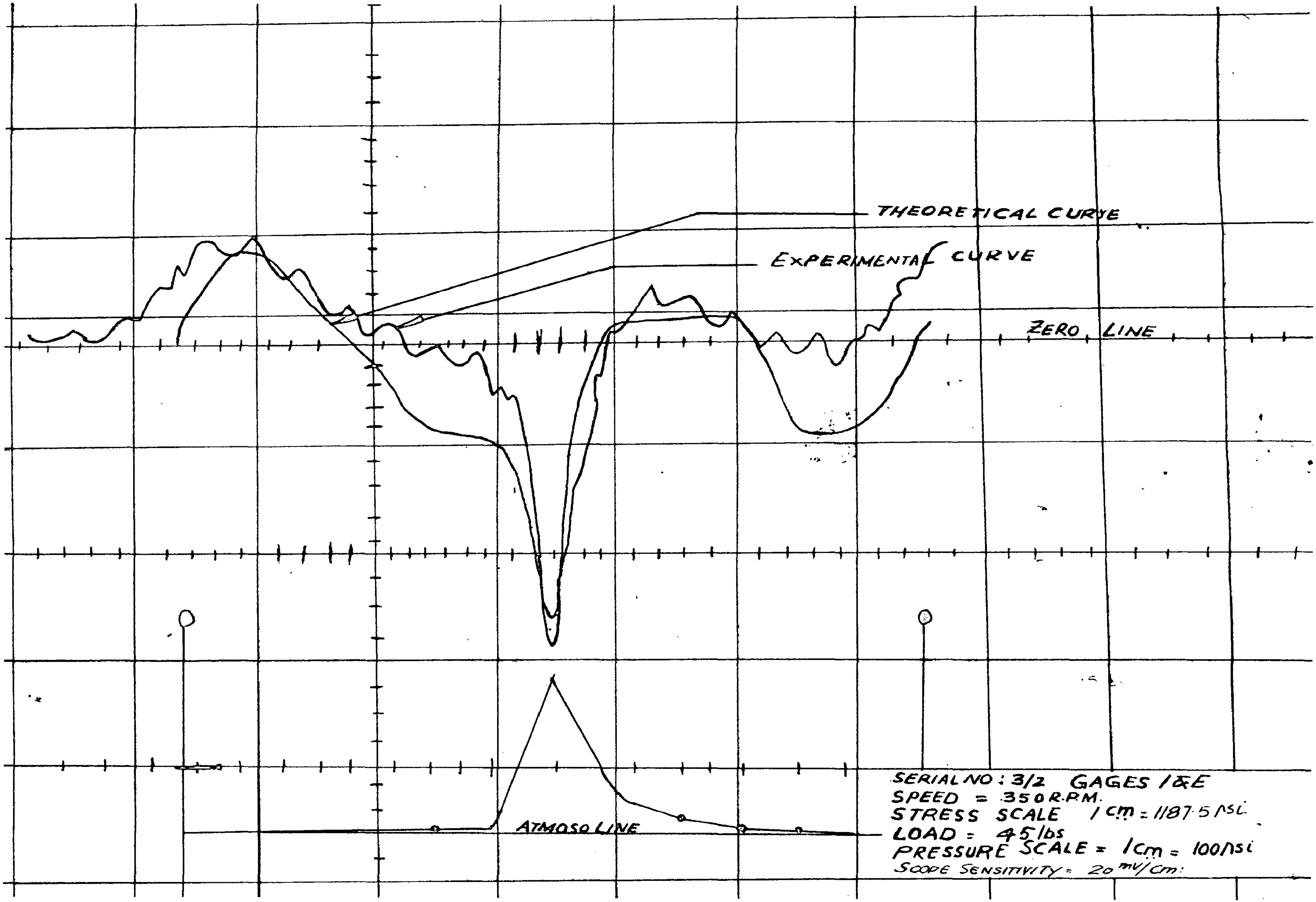


ZERO LINE
EXPERIMETAL CURVE
THEORETICAL CURVE
SERIAL No 2/7
GAGES 2&E
ENGINE R.P.M. = 350
LOAD = NIL
SCOPE SENSITIVITY 10mV/cm
STRESS SCALE

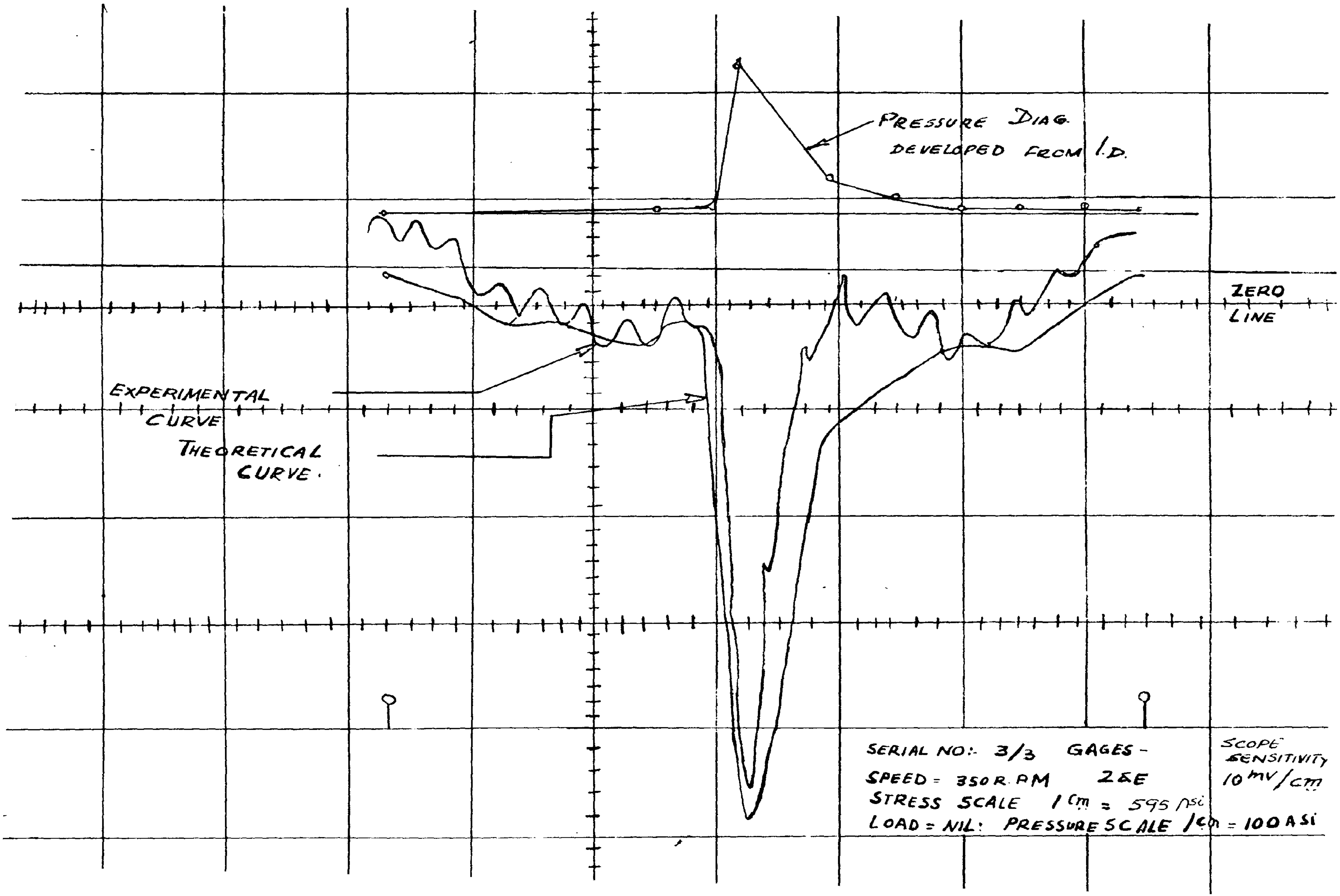

ZERO LINE
EXPERIMENTAL CURVE
THEORETICAL CURVE
SERIAL NO. 2/8
GAGES 4 & E
SENSITIVITY = 10 mV/cm
ENGINE R.P.M = 350
LOAD = NIL
STRESS SCALE = 1 cm = 605 psi



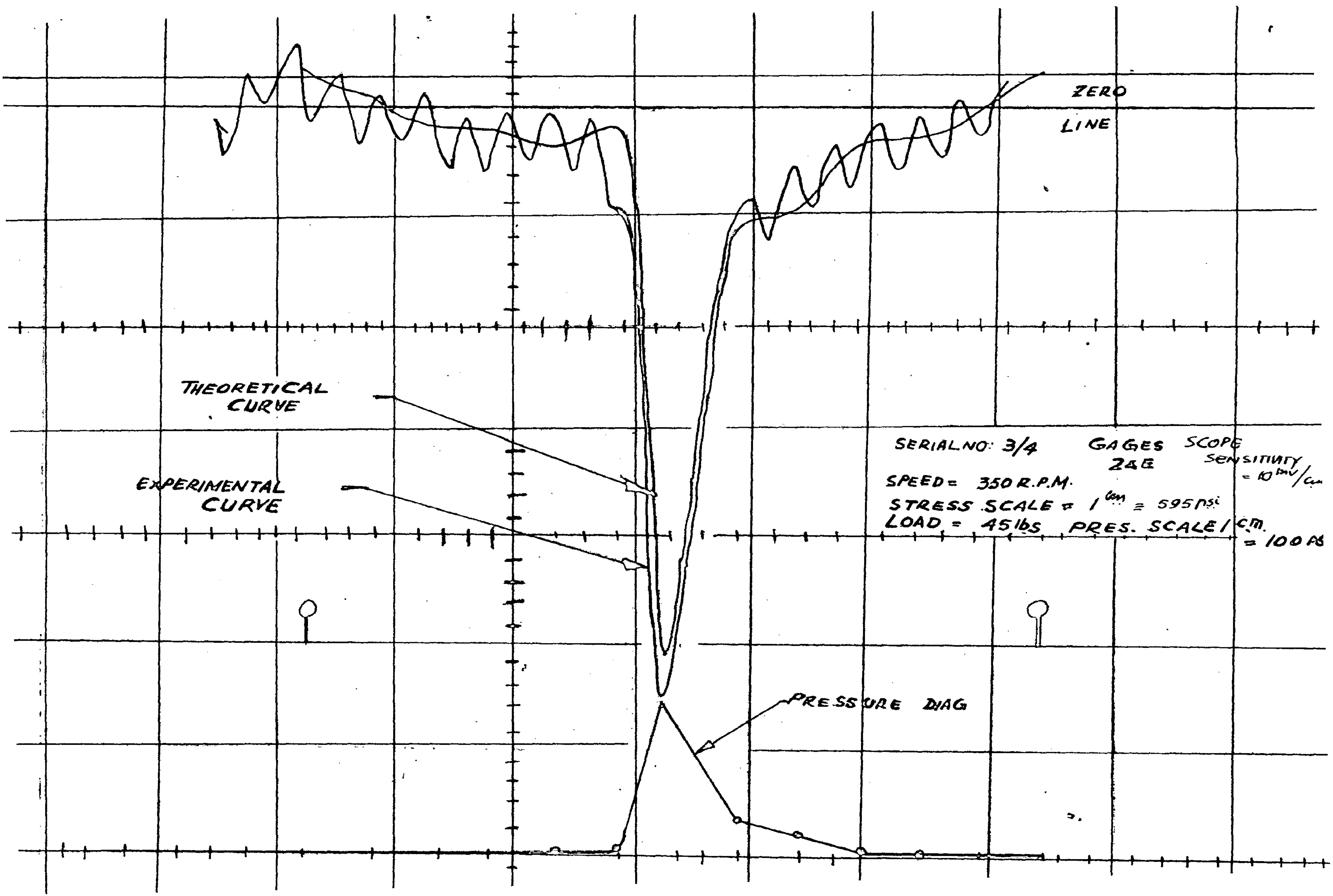
EXPERIMENTAL CURVE
THEORETICAL CURVE
0
60°
120°
180°
240°
300
360
420°
480°
540°
600°
660°
720°
ZERO LINE
DEVELOPED INDICATOR DIAGRAM
ATMOS. LINE
SERIAL NO 3/1
GAGES 1&E
SPEED = 350 R.P.M.
STRESS SCALE = 1 cm = 925 PSI
LOAD = NIL
PRESSURE SCAL: 1 cm. = 100 PSI



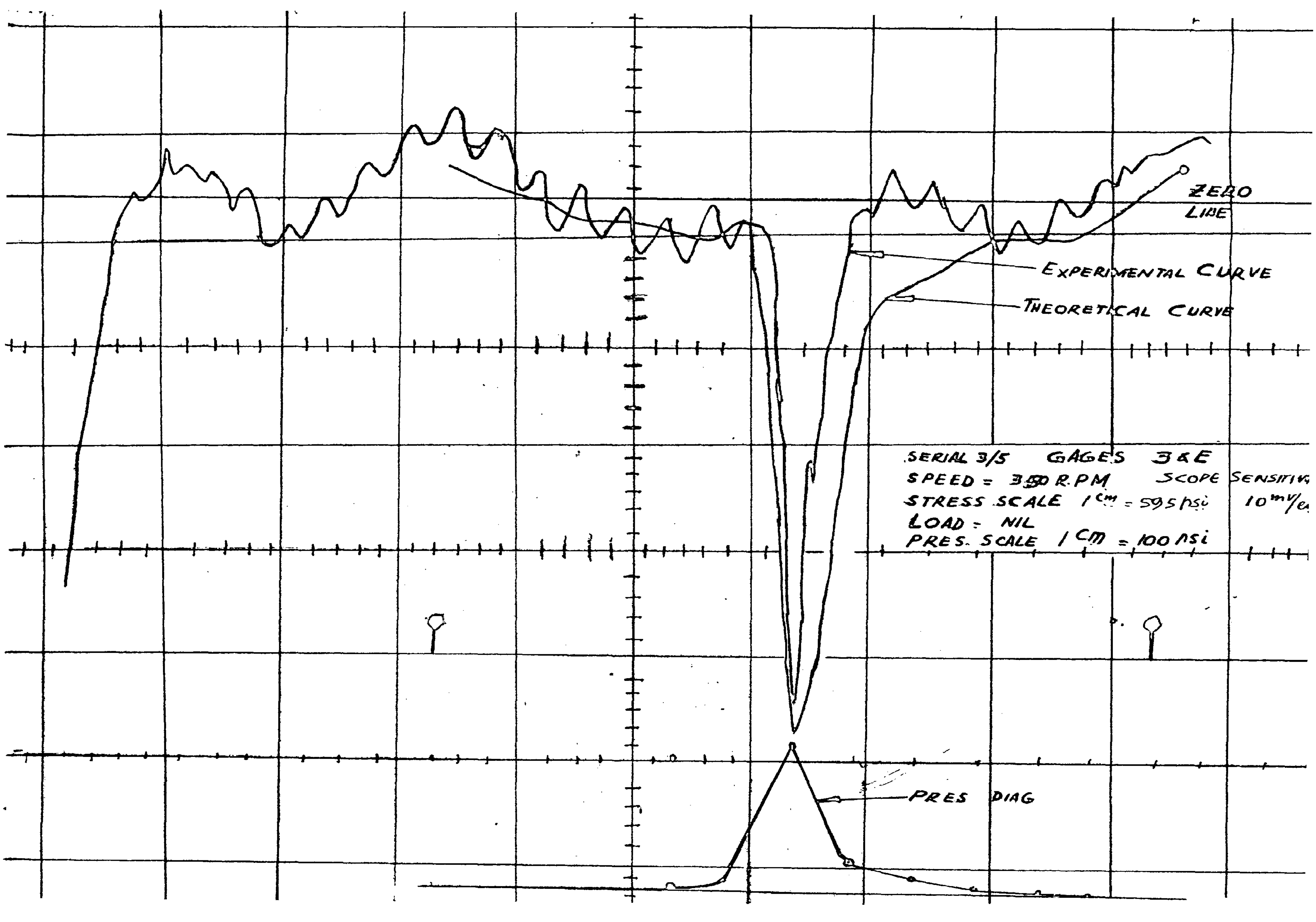
THEORETICAL CURVE
EXPERIMENTAL CURVE
ZERO LINE
ATMOSO LINE
SERIAL NO: 3/2 GAGES I&E
SPEED = 350 R.P.M.
STRESS SCALE 1 cm = 1187.5 psi
LOAD = 45 lbs
PRESSURE SCALE = 1 cm = 100 psi
SCOPE SENSITIVITY = 20 mV/cm

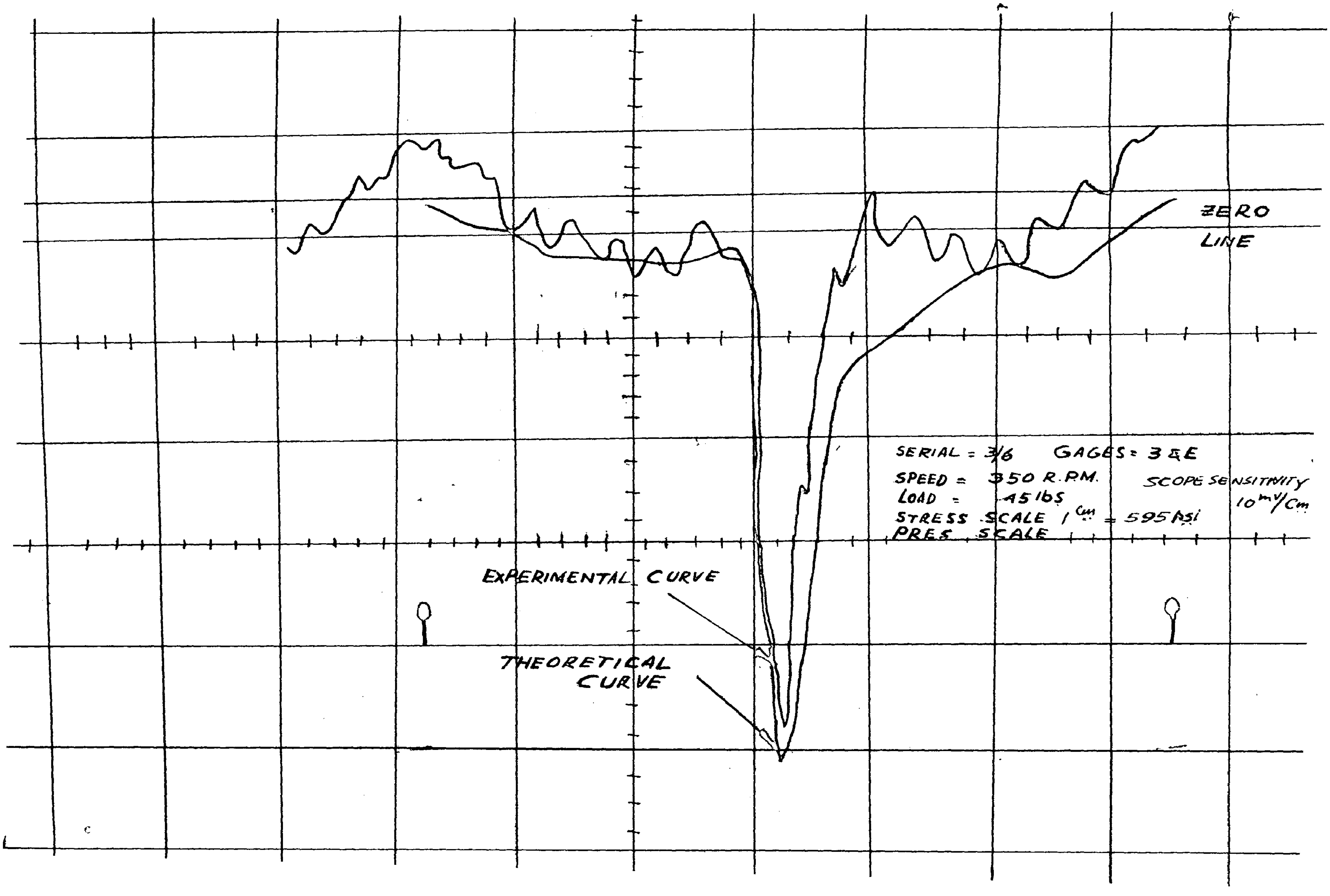


PRESSURE DIAG. DEVELOPED FROM I.D.
ZERO LINE
EXPERIMENTAL CURVE
THEORETICAL CURVE.
SERIAL NO:- 3/3 GAGES -
SPEED = 350 R.PM 2&E
STRESS SCALE 1 Cm = 595 psi
LOAD = NIL: PRESSURE SCALE 1 cm = 100 psi
SCOPE SENSITIVITY 10 mV/cm

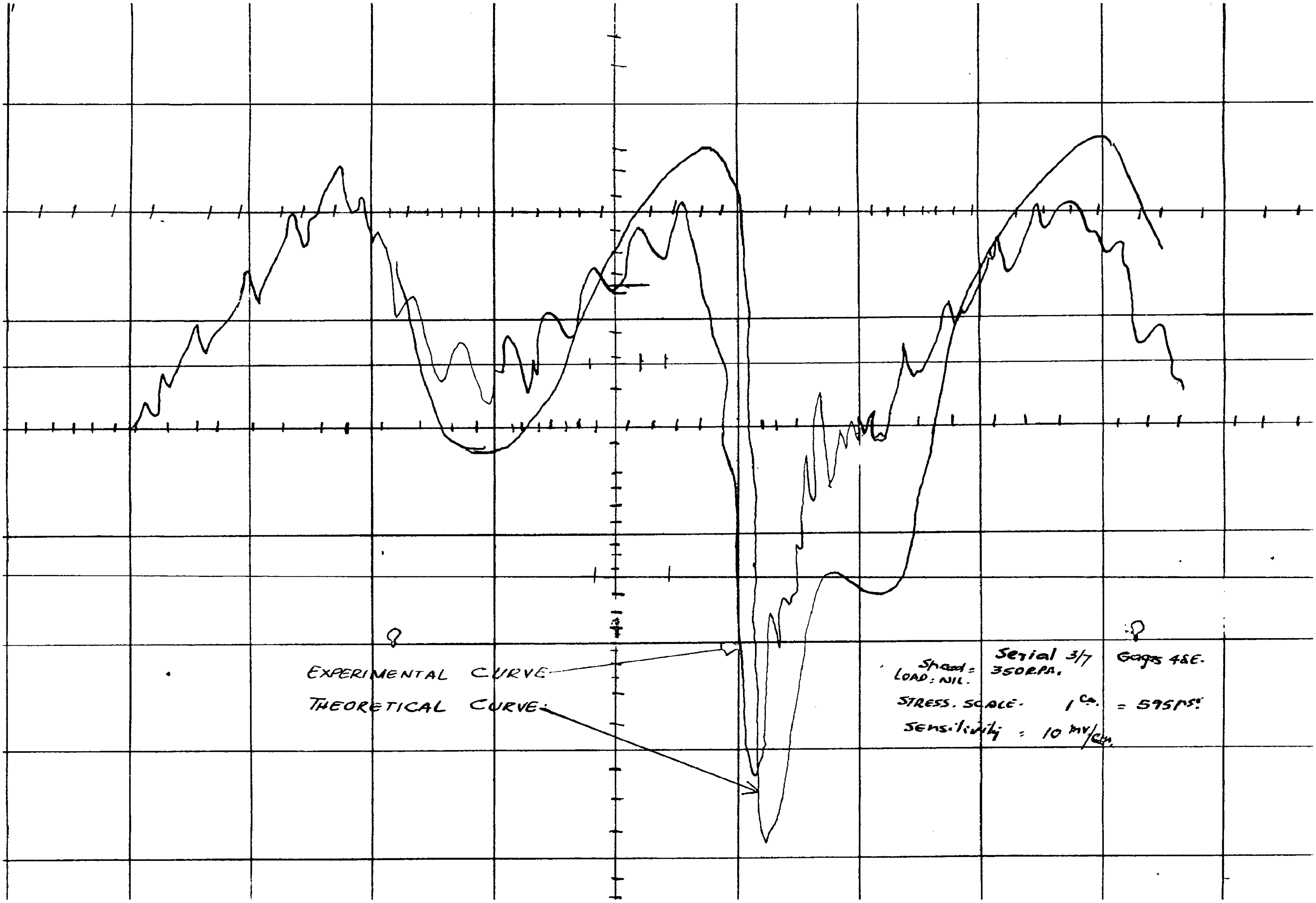


ZERO
LINE
THEORETICAL CURVE
EXPERIMENTAL CURVE
SERIAL NO: 3/4
GAGES 2&3
SCOPE SENSITIVITY = 10 mv/cm
SPEED = 350 R.P.M.
STRESS SCALE = 1 cm = 595 psi
LOAD = 45 lbs
PRES. SCALE / cm = 100 ps
PRESSURE DIAG

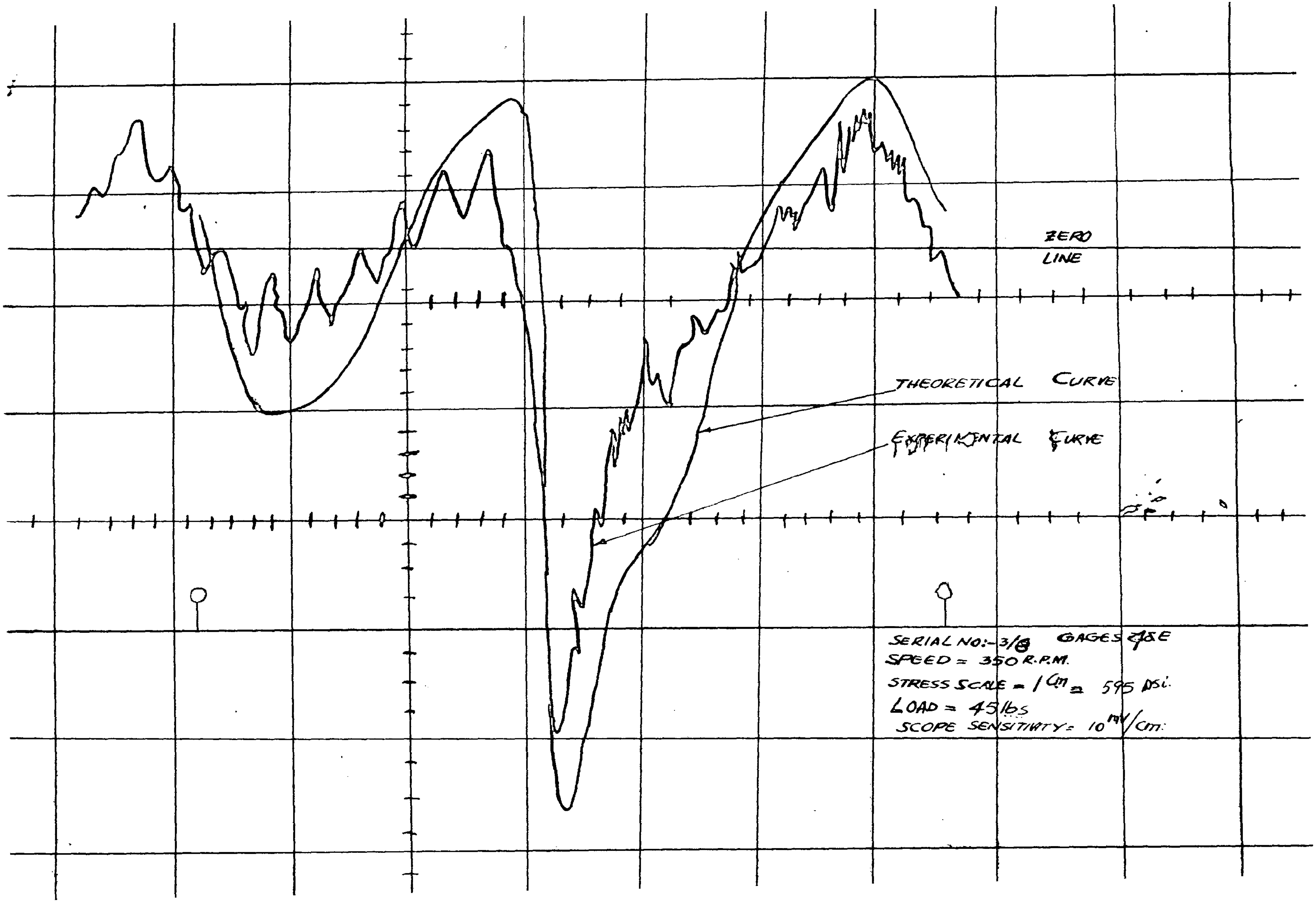

ZERO LINE
EXPERIMENTAL CURVE
THEORETICAL CURVE
SERIAL 3/5 GAGES 3 & E
SPEED = 350 R.P.M.
SCOPE SENSITIVITY 10 mV/cm
STRESS SCALE 1 cm = 595 psi
LOAD = NIL
PRES. SCALE 1 cm = 100 psi
PRES DIAG



ZERO LINE
SERIAL = 3/6 GAGES = 3 & E
SPEED = 350 R.P.M.
LOAD = 45 lbs
STRESS SCALE 1 cm = 595 psi
PRES. SCALE
SCOPE SENSITIVITY 10 mV/Cm
EXPERIMENTAL CURVE
THEORETICAL CURVE



EXPERIMENTAL CURVE
THEORETICAL CURVE
Serial 3/7
Gages 4&E.
Speed = 350 R.P.M.
LOAD: NIL.
STRESS. SCALE. 1 cm. = 595 psi
Sensitivity = 10 mv/cm.


ZERO
LINE
THEORETICAL CURVE
EXPERIMENTAL CURVE
SERIAL NO:-3/8 GAGES
SPEED = 350 R.P.M.
STRESS SCALE = 1 Cm = 595 psi.
LOAD = 45 lbs
SCOPE SENSITIVITY = 10 mV/Cm.

CONCLUSIONS & DISCUSSIONS

The traces that have been obtained from cathode ray oscilloscope when superimposed on the theoretical one give a fairly reasonable agreement between the two at peak pressures. With the explosion stroke the values are widely different. This may be due to certain torsion which acts on the rod. This may not be so significant at peak pressure, but may become significant at other lower pressures. Thus the component of stresses arising due to twist may affect the axial stress.

The explosion causes a sharp change in stress level almost acting like an impulse and falls down quicker than theoretical one. Thus rate of change of slope of the curves indicates that the response of the connecting rod in respect of stress is not so prononsed at lower pressures as it is at higher pressures. This fact may be due to the rod being stiff enough to be stressed by small pressures.

Temperature compensation method is also limited in accuracy by the sensitivity of the potentiometer used. However much care has been taken to note the zero level by stopping the engine immediately after photographting a perticular trace, but it is sure that this method is not very accurate .(Error in temperature compensation will only result in varying the zero level strain, but the whole pattern will remain unchanged. It is presumed that still better comparison could be actived by noting this point carefully)

From the combined photograph of strain & pressure pick up signal it can be noted that peak stress occurs at explosion point of the cycle . Now the arrangement for locating the dead centres can not be used simult aneously with these. This means that either the zero po sition or explosion position is indeterminate in a dual channel measurement where one channel is already blocked by the strain signal.

The indicator diagram does not accurately locate the peak explosion point. As such slight manipulations had to be done in superimposing the theoretical curve on the experimental one by bringing the two peaks under the same vertical line. This might have caused some inaccuracies.

The experimental set up that has been developed in this way needs further development. It may be posible to enclose the lead wires within a coil spring attached between the rod & the floating link. This will further lower the stress on the lead wires and it may be possible to run the engine continuously with out trouble (of lead wires) for longer hours.

Further work in stress analysis will comprise of determinations of principal stress and stresses in various directions on the rod.

APPENDIX I

SAMPLE CALCULATION :-

A sample calculation is shown below:-

Let us take 8th reading of strain gage stn. 2 1

Indicator diagram: no = 1.

From indicator diagram:

Pressure (p) = height of the diagram x spring no.

$$= \frac{29}{64} \times 200 = 90 \text{ psi.}$$

Gas force P = p x Area of the piston = 90 x 33.1 = 2980 pds

Equivalent piston inertia force (Fip)

$$= \frac{\text{Weight of piston + wt. of conn. rod concetrated at the piston pin}}{g} \times$$

Acceleration of piston

$$= \frac{36.75 + 15.05}{g} \omega^2 r \left(\cos\theta + \frac{\cos 2\theta}{n}\right)$$

$$= \frac{51.80}{32.2} \times \left(\frac{2\pi . 360}{60}\right)^2 \times 5/12 \left(\cos 420 + \frac{\cos 840}{4.21}\right)$$

$$= + 435 \text{ lbs}$$

Q = Component of gas pressure corrected for inertia effects of piston and connecting rod, acting axialy along the rod.

$$= \frac{P - F_{ip}}{\cos\phi} = \frac{2980 - 435}{\cos 12} = 2600 \text{ lbs}$$

ϕ being the obliquity angle of the connecting rod.

$$F_a = F_i \cos(\theta + \phi) = \frac{19.95}{g} \times \left(\frac{2\pi . 360}{60}\right)^2 \times 5/12 \left(420^\circ + 12^\circ\right)$$

$$= 135.8 \text{ lbs}$$

$$F_r = \text{net axial load} = F_a + Q = 2600 + 135.8$$

$$= 2735.8 \text{ lbs}$$

The body of the rod is treated as a column with pin ends subjected to an additional bending load due to the inertia of the oscillating rod. The stress due to column action,

$$f_{cd} = \frac{F_r}{A\left[1 - \frac{S_y}{4n\pi^2 E}\left(\frac{l}{K}\right)^2\right]}$$

where the symbols have their usual significance. (Refer Gloss

Now dia of rod at stn 2 = $1\frac{5}{8}''$ $\quad \therefore K^2 = d^2/16 = 0.165.$

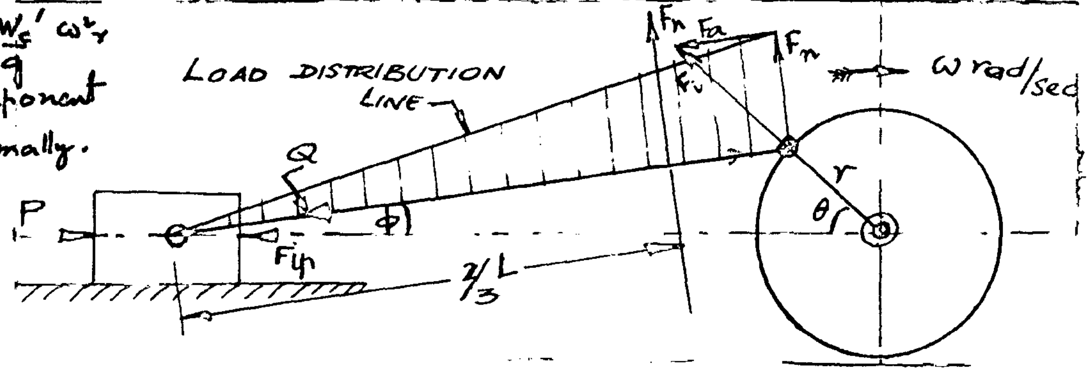
$\therefore$ Area = 2.07 □"

S_y assumed = 90,000 psi

hence $f_{cd} = \dfrac{F_r}{2.07\left[1 - \dfrac{90{,}000}{4\times 9.87\times 30\times 10^6} \times \dfrac{(25.25)^2}{0.165}\right]} = 0.684 F_r$

& hence in this case f_{cd} = 2735.8 × 0.684 = 1865 psi (A + sign indicates compressive stress)

Again the inertia force due to the rotating mass is given by $F_1 = \frac{W_s'}{g}\omega^2 r$ & F_n is the component acting normally.



Now this force results due to the rotation of the crank. The angular velocity is zero at the piston pin and maximum at crank pin such that this whole force may be assumed to be distributed as zero at the piston pin and maximum at crank pin (see fig above). This indicates that the C.G. of the triangular load distribution acts at a distance 2/3 L from the piston pin.

The bending moment at any section of the rod is

$$M_x = \frac{F_n \cdot x \cdot (L^2 - x^2)}{3L^2}$$ where x is the distance from the wrist pin.

& in this case

$$= \frac{F_n \cdot 12.625\,(25.25^2 - 12.625^2)}{3 \times 25.25^2}$$

$$= 3.16\,F_n = 3.16 \times 419 = 1322 \text{ lbs. inch.}$$

Now Z for the section $= I/y = \pi/32\, d^3 = \frac{3.14}{32} \times (1\tfrac{5}{8})^3$

$= 0.42$;

$\therefore 1/Z = 2.38$.

$\therefore f_{M_x} = M_x \cdot 1/Z = 2.38\, M_x = 2.38 \times 1322$

$= -3140$ psi (tensile)

$\therefore$ Net stress $= f_{M_x} + f_{cd}$

$= -3140 + 1865 = -1275$ psi (tensile)

/

R E F E R E N C E S

1. Hand book of Experimental Stress Analysis

   by M. Hetenyi.

   Pub. John Wiley & Sons.

2. Mechanics of Gasoline Engine

   by H.A. Huebotter

   Pub. Mc-Graw-Hill.

3. Dynamics of Machinery

   by A.R. Holowenko.

   Pub. Mc-Graw-Hill.

4. Design of Machine Members.

   by Vallance & Doughtie.

   Pub. Mc-Graw-Hill.

5. Strain Gage Primer .

   by Perry & Lissner.

   Pub.

6. Laboratory Manual of Applied Instrumentation.

   by Suresh Chandra & A.B.L. Agarwal.

   Pub. Deptt. Mech. Engg. University of Roorkee.

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