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UNIVERSITA' DEGLI STUDI
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NAPOLI

SUBJECT OF THE RESEARCH: Test of Detergent Additives for Diesel Fuels.

NAME OF CONTRACTOR: Università di Napoli - Istituto di Meccanica Applicata alle Macchine - Napoli, Italy.

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# I N D E X



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ABSTRACT

The purpose of this research work is to develop an experimental test method to ashertain on a laboratory Petter AV-1 test engine the efficacy of detergent additives for diesel fuels.

The experimental test method developed consists of a standard test of 36 hours duration, executed on the test engine fed with a diesel fuel having controlled characteristics meeting with Federal Specification VV-F-800, to whom has been added the detergent additive to be investigated. The analysis of test results, intended as evaluation of the deposits formed on some established engine members, will furnish, by comparison with the results of a similar test conducted with the same fuel without additive, the necessary indications to evaluate the detergency of the tested additive.

As economical and time saving reasons suggested the shortest test duration, the test conditions had to be chosen the most severe sustainable by the test engine, in order to produce in the short test time such an amount of deposits, which may emphasize the eventual detergent action of the tested additive.

Therefore the first stage of the research has bean devoted to individuate test conditions as above by experimentally analyzing with suitable instruments the parameters which influence the test severity.

Part of instruments employed for this scope has been purposely studied and constructed during the research work; another part has been conveniently adapted.

The second stage of the research, conducted at the same time of the first one, has been devoted to the design and the construction of suitable means for quantitative evaluation of the deposits on

the selected engine members.

Finally a third stage of the research has included a set of engine tests, all having 36 hours duration, conducted in that particular test conditions, chosen on the basis of the results of the first stage of the research, as giving to the test the requested severity.

The analysis of the results of the set of tests, made using the means studied in the second stage of the research, brought to the formulation of the standard test conditions, i.e. of the method, which was the purpose of the research.

## THE TEST PLANT

The test plant for the research program is formed by a Petter AV1 laboratory engine coupled to a generator.

The technical data of the Petter engine are:
Vertical engine, four stroke cycle, compression ignition, water cooled, cold starting;

| | |
|---|---|
| Number of Cylinders .................. | 1 |
| Bore .................................. | 85 mm (3,15 in.) |
| Stroke ................................ | 110 mm (4,33 in.) |
| Cubic Capacity ....................... | 553 c.c. (33,73 cu.in) |
| Compression Ratio .................... | 16,5:1 |
| Rated Power and Speed ............. | 3 b.h.p.-1000 r.p.m. |
| | 4 b.h.p.-1200 r.p.m. |
| | 5 b.h.p.-1500 r.p.m. |
| | 6 b.h.p.-1800 r.p.m. |
| Fuel Injection Timing ............ | 24° Before T.D.C. |
| Inlet Valve opens ................ | 4,5° Before T.D.C. |
| Inlet Valve closes ............... | 35,5° After B.D.C. |

Exhaust Valve opens ................. 35,5° Before B.D.C.
Exhaust Valve closes ................ 4,5° After T.D.C.
Fuel Pump ........................... Bryce Type AIAA70/5SI52H
Nozzle .............................. Bryce Type HLS26 C 175P3

Only one modification has been made on the engine: suppression of the governor and application on the injection pump of a micrometric system for fuel flow rate regulation.

As electric brake has been used a separately excited dynamo.

The test stand is composed by:

a) A cooling system formed by an external motor-driven pump and a surface cooler. A slide valve and a calibrated flange allow to settle and control the flow rate of the cooling liquid. The temperatures of the cooling liquid inlet and outlet are mesured by two mercury thermometers.
b) A lubricating oil cooling system, external to the engine, composed by a motor driven pump and a surface cooler. Lubricating oil temperature in the crankcase is measured by a mercury thermometer.
c) A control board with excitation and load rheostats of the dynamo, with instruments for the control of the voltage, of the load current and of the excitation current, of the lubricating oil pressure, and with a tachymeter to control the angular speed of the engine.
d) A device to determine specific fuel consumption.

In fig. 1 is reported a scheme of the test plant.

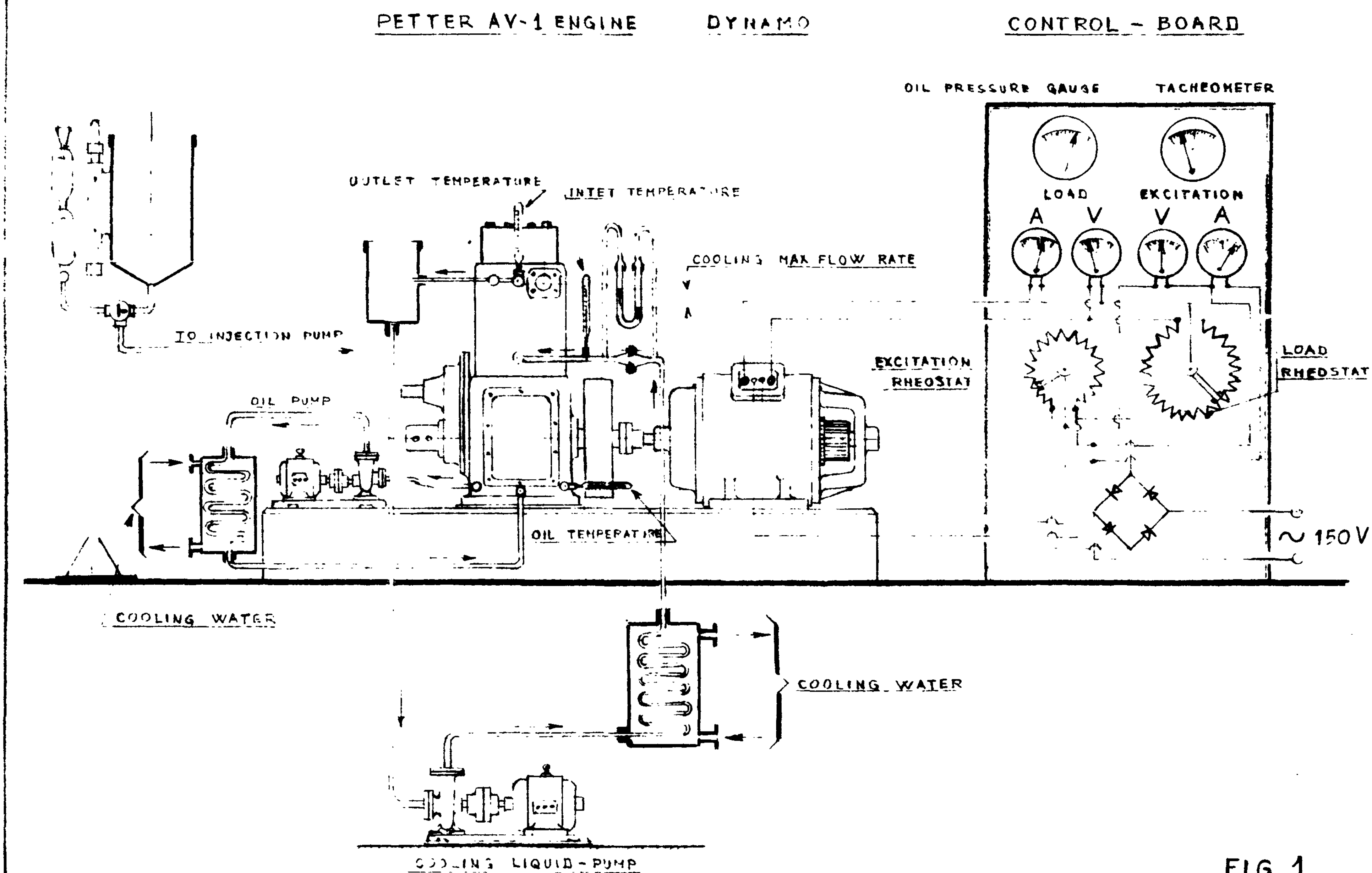

PETTER AV-1 ENGINE
DYNAMO
CONTROL - BOARD
OIL PRESSURE GAUGE
TACHEOMETER
LOAD
EXCITATION
A
V
V
A
OUTLET TEMPERATURE
INLET TEMPERATURE
COOLING MAX FLOW RATE
TO INJECTION PUMP
OIL PUMP
EXCITATION RHEOSTAT
LOAD RHEOSTAT
OIL TEMPERATURE
~ 150V
COOLING WATER
COOLING WATER
COOLING LIQUID-PUMP

FIG. 1

INSTRUMENTATION

The instruments used in the research program are of two kinds:

a) Instruments designed or adapted to investigate on the causes which produce formation of parti cularly severe deposits.
b) Instruments designed or adapted to analyze the deposits on injector nozzle and on the piston crown.

Instruments a)

The parameters which, more or less independently the ones from the others, influence the phenomenon of deposits formation in diesel engines are the following:

1°) The construction peculiarities of the engine, chiefly the cooling system, the lubricating system and the injection system.
2°) The working conditions.
3°) The physical and chemical properties of the lubricating oil.
4°) The physical and chemical properties of the gasoil.

In a test plant such as that one we have adopted,using a fixed type of lubricating oil and a fixed type of gasoil, only one parameter may very: the running conditions of the engine.

The experimental research has been therefore devoted to the individuation of the most severe test conditions, as far as the phenomenon of the deposit formation is concerned, and to correlate the same phenomenon with eventual abnormal working conditions of the injection system.

Therefore the instruments employed have had the purpose of investigating the parameters variations, which influence the injection process and particularly: a) the pattern of the injection pressure upstream of the injector; b) the pattern of the injector needle displacement; c) the average temperature of the end of the injector nozzle.

To investigate the pattern of the injection pressure up stream of the injector in different test conditions, has been studied and realized an indicator, having a sensing element such as to may be applied to the pipe connecting the injection pump to the injector without modifying the geometry of the same pipe. The indicator consists of a sensing element and a measure circuit, whose output may be connected to any laboratory oscilloscope.

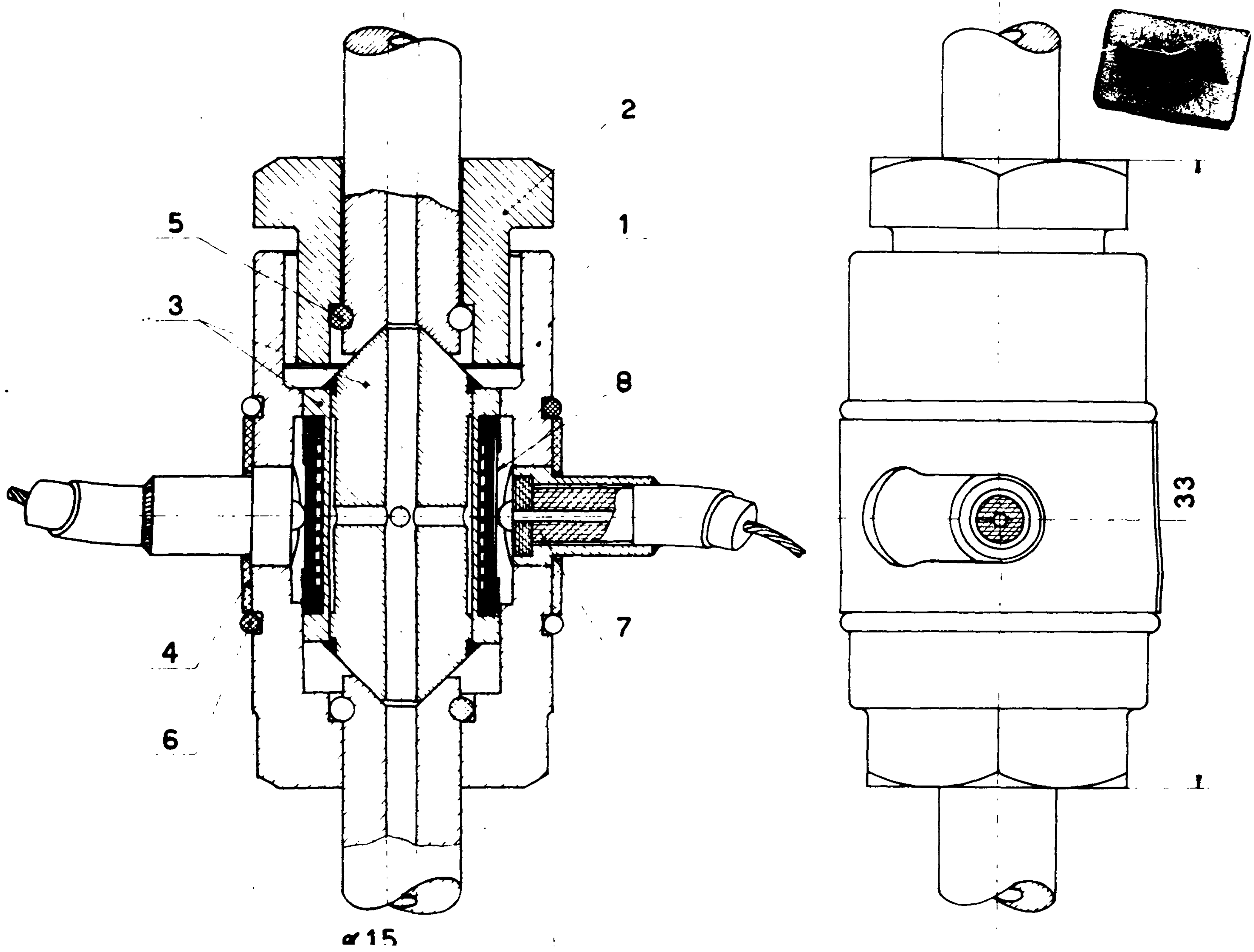
The sensing element has been designed and constructed following the general drawing of fig. 2.

The fuel pipe is cut in the selected section and shortened to obtain that the sensing element may be inserted without modifying the lenght and the shape of the pipe.

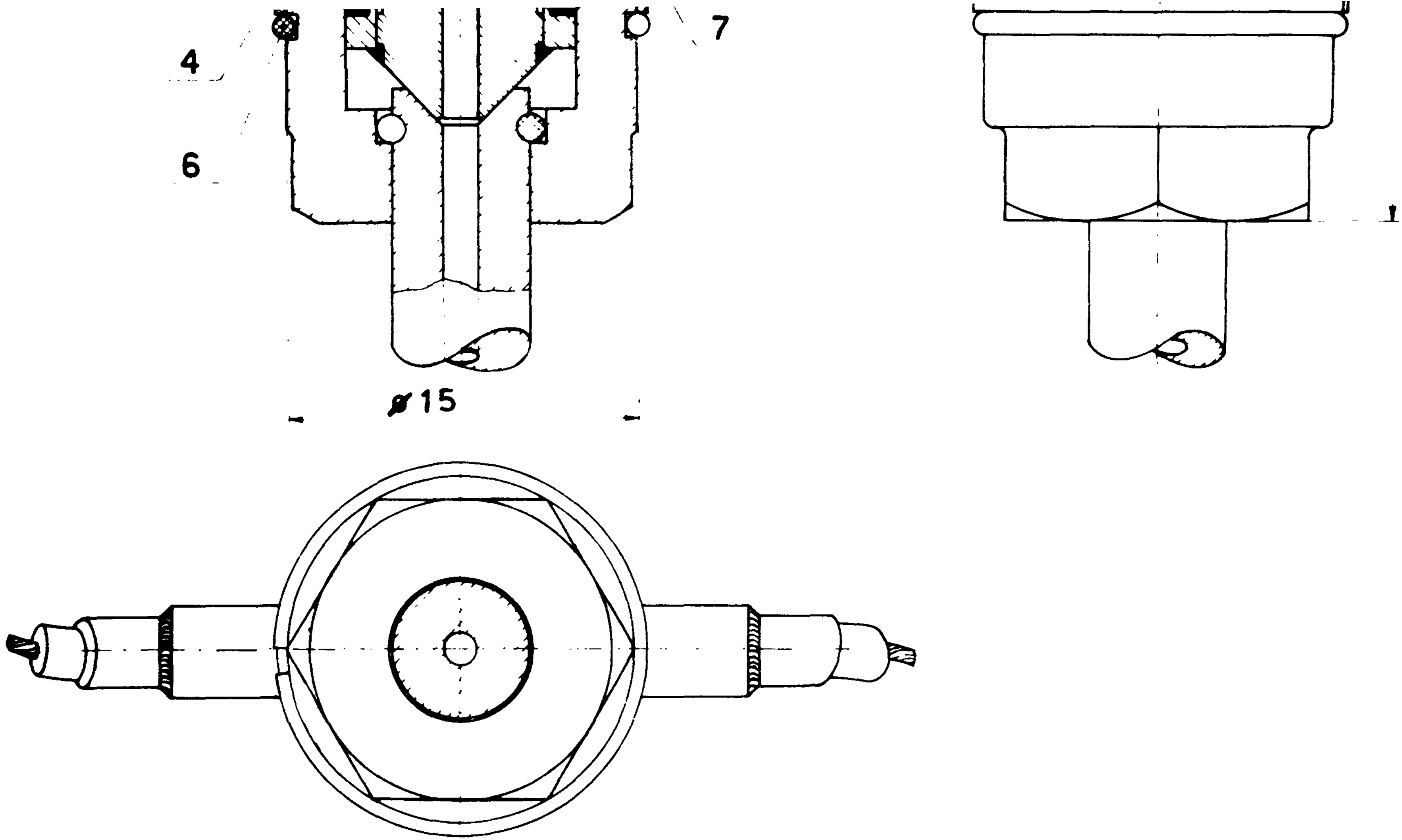
For this purpose the sensing element is only 19 mm long and the dimensions of its case are only 15 x 33 mm.

The sensing element is a steel cylinder, bored in axial direction to allow the fuel flow, with cone shaped ends. Two radial bores at right angle in the middle section of the cylinder allow the axial bore to communicate with a small hollow space, limited by the external face of the steel cylinder and by the internal face of an hollow cylinder, solded to the former at the ends.

The hollow cylinder has an external diameter of 7,8 mm



2
1
5
3
8
4
7
6
ø 15
33




1 - CASE
2 - BLOCKING CONNECTION
3 - SENSING ELEMENT
4 - SPRING CYLINDER FOR CABLE CONNECTION

5 - CLIP
6 - CLIP
7 - ELECTRICAL CABLE
8 - WINDING TERMINAL

FIG. 2

and a thickness of only 0,3 mm. This cylinder is strained by the fuel pressure and its strain is communicated to a 50 turns winding of cupro-nickel-wire, wound on its external face.

The cupro-nickel-wire is the same normally used in strain-gages construction with 0,03 mm diameter. The winding has an electrical resistance of about 800 Ω , variations of which, proportional to the cylinder strain and of course to the fuel pressure, produce, through a bridge circuit, an electrical signal proportional to the fuel pressure in the pipe. This signal, conveniently amplified, comes to a cathode-ray oscilloscope. The wire winding is double helicoidal (fig. 3) to minimize the inductance effects.

While performing the experimental work the pick-ups in our possession have been damaged. We have had therefore the necessity of constructing some others. Aiming to simplify the construction, the use of commercial strain-gauges has been attempted to avoid the wire winding. The results however have been absolutely satisfactory and allowed a sensible speeding in the whole construction. The Philips strain-gauges, type PR 9210, have been used.

The sensing element, at the assembling, is forced between the ends of the fuel pipe, to whom it is connected (see fig. 2) by means of a suitable blocking connection, locking together the conical ends of the element and of the pipe with sufficient pressure to assure sealing.

Fig.4 is a photograph of the sensing element inserted in the fuel pipe of a diesel engine.

On the dynamic characteristics of the sensing element, theoretical considerations allow to establish that the free

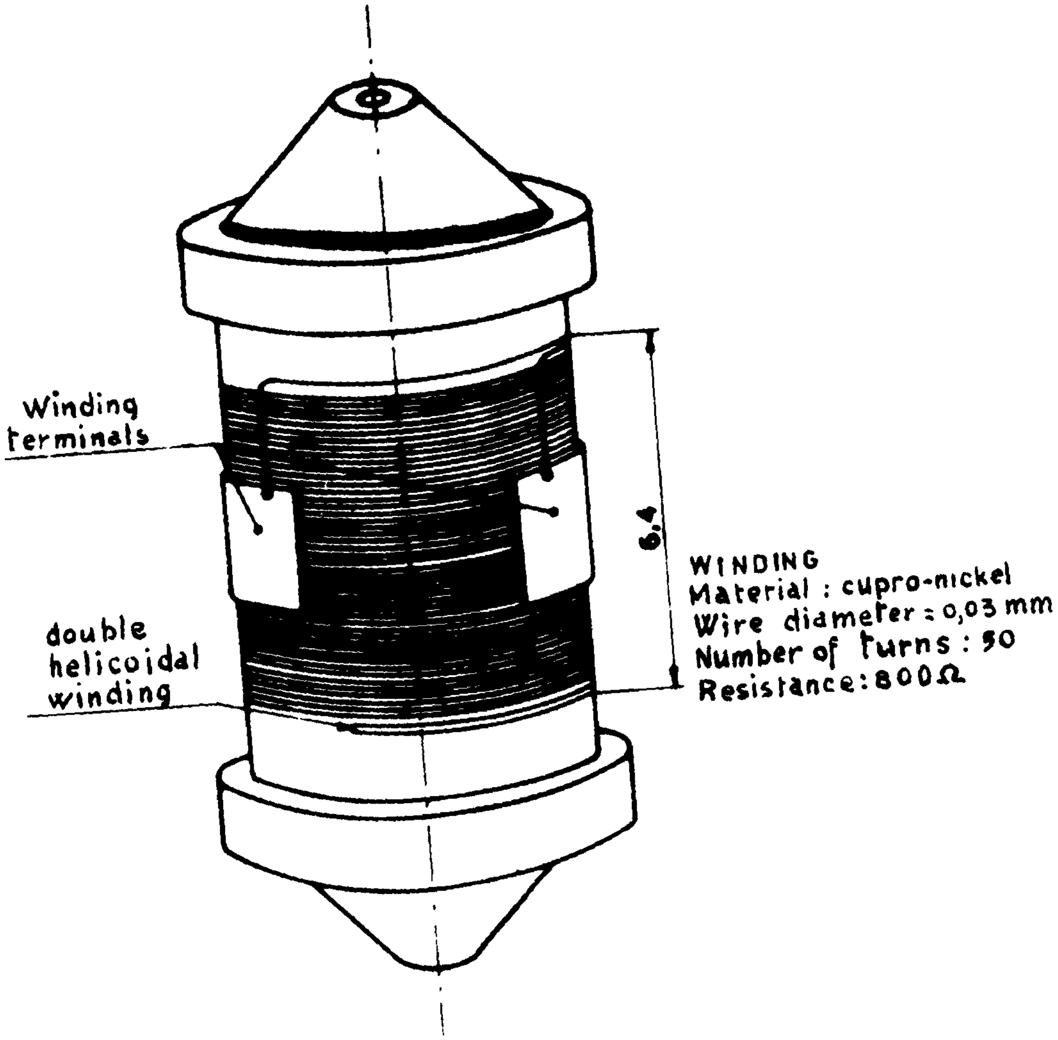
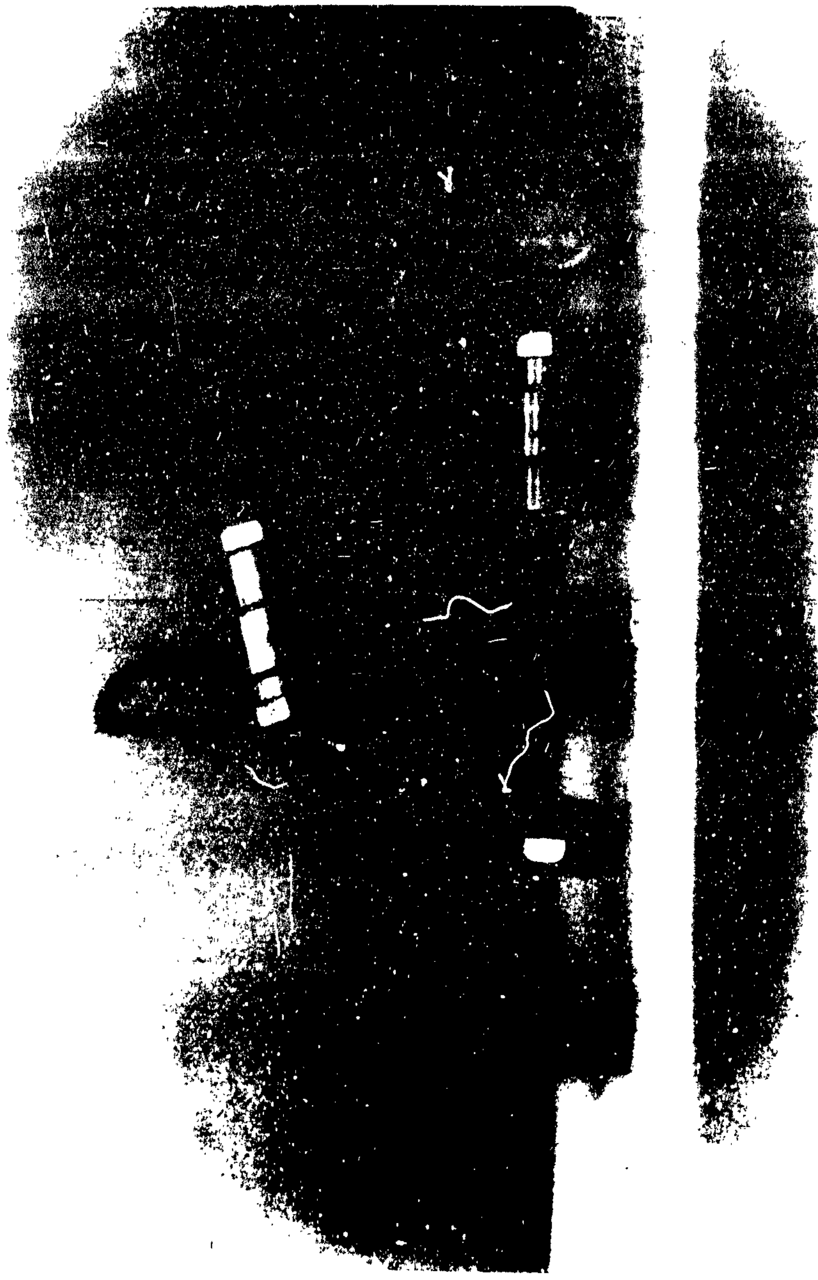

Winding
terminals
double
helicoidal
winding
6,4
WINDING
Material : cupro-nickel
Wire diameter = 0,03 mm
Number of turns : 50
Resistance: 800Ω

FIG. 3



vibration frequency of the element is certainly higher than 218.000 c. p. s. and therefore much higher than the frequency of the pressure oscillations in the injection system of an high-speed diesel engine.

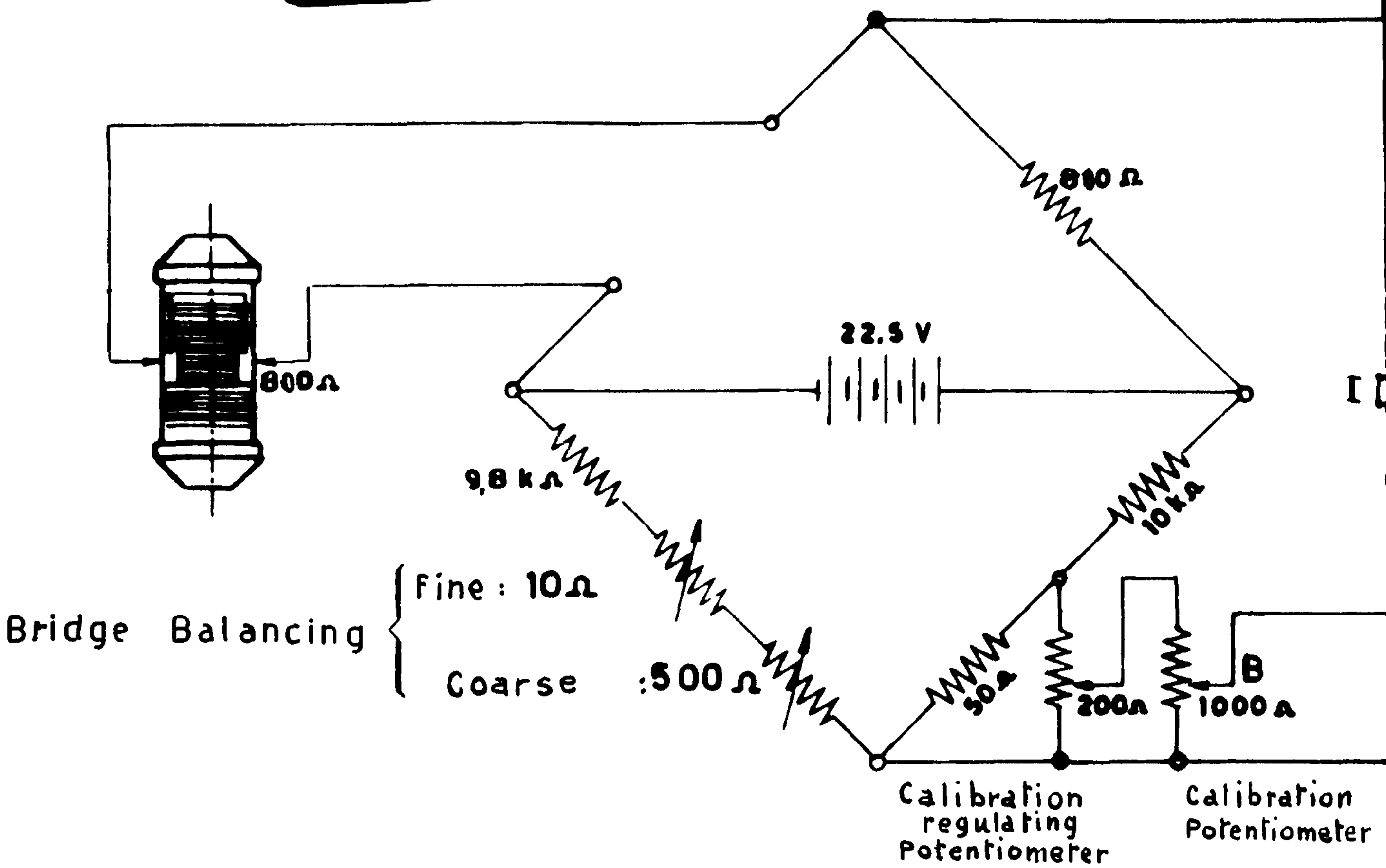
The measure circuit (see fig. 5) is a bridge circuit, one arm of which is the winding of the sensing element. No compensation for temperature effects has been provided, being very small the temperature variations of the fuel flowing in the element, and being very rapidly variable the injection pres sure, so as each injection cycle has a so short duration that in this little time, though the small thermal capacity of the element, temperature variations of no practical significance could be produced.

In the bridge arm opposite to the element there are two potentiometers for calibration. Calibration is obtained statical ly applying to the element constant pressures up to 250 $kg/cm^2$, by means of a direct weight manometer calibration apparatus.

With the output of the preamplifier connected to a cathode ray oscilloscope, by operating the calibration potentiometer, the output voltage of the bridge will be balanced by the voltage at the output of the calibration potentiometer.

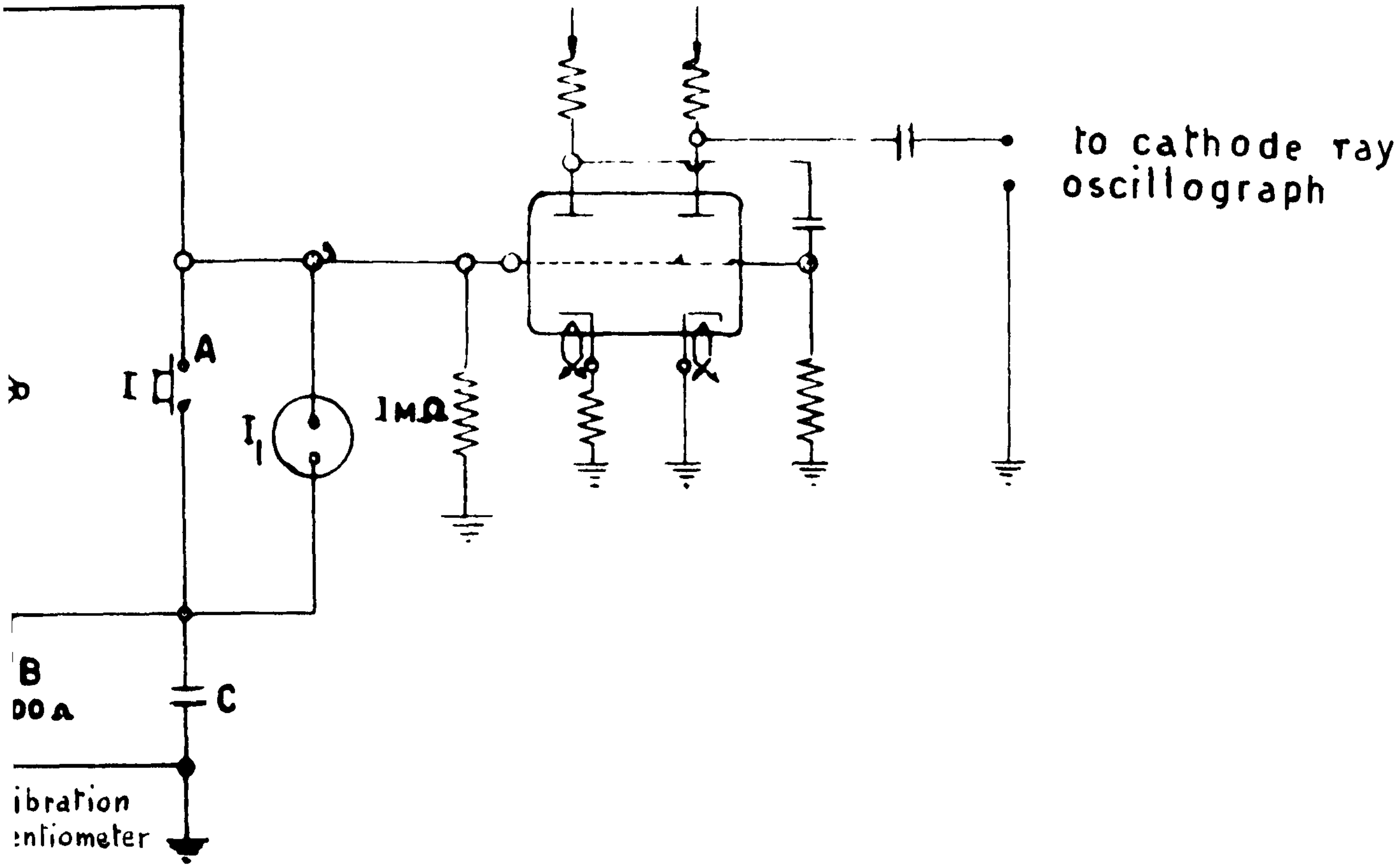
This balancing position of the potentiometer will be revealed by the circumstance that flicking the switch I gives no signal on the oscilloscope.

In fact the flicking of the switch I connects instanta neously the grid of the preamplifier - at a voltage proportional to the static pressure on the element - with the potentiometer output. If the potentiometer output B (see fig. 5) has a potential different from that of the point A (e. g. lower) a dischar ge through the condenser C will take place and on the screen of




SENSING ELEMENT

MEASURE CIRCUIT




PRE-AMPLIFIER

FIG.5

the oscilloscope will appear a pulse, the height of which will de pend from the voltage difference between points A and B. Disap pearing of such pulse will indicate the position of the potentiometer correspondiong to the balancing of the voltage at A and B. By repeating this procedure at different values of the pressure, it is possible to calibrate the potentiometer directly in $kg/cm^2$.

The linearity of the sensing element and of the measure circuit makes calibrations procedure easy, so as it will be sufficient, after the balancing of the bridge, to follow the described pro cedure only at the maximum pressure (250 $kg/cm^2$).

The calibration potentiometer will allow to generate, du ring the indicator operation, rectangular pulses of variable and adjustable height by flicking the switch I. By producing these pulses immediately before the injection cycle and in every case when fuel pressure is zero and the bridge is balanced, will be possible to have on the screen of the oscilloscope ordinates corresponding to injection pressure, which may be read directly on the calibration potentiometer graduation. It is possible the refore to determine, independently from the oscilloscope amplification, the value of the injection pressure at each point of the injection cycle by comparison with the height of the rectan gular pulses. By means of the plug $I_1$ , it is possible to con - nect in parallel to the switch I an istantaneous rotating switch, driven by the engine camshaft, which will produce on the screen the rectangular calibration pulse in a suitable position respect to the injection cycle.

The calibration regulating potentiometer can compensate the behaviour differences of different sensing elements as to obtain that the same graduation on the calibration potentiometer may be adapted to different elements. This procedure allows to employ different sensing elements only by opportunely presetting the calibration regulating potentiometer.

On the graph of fig. 6 are plotted bridge output voltages against different values of static pressure acting on the sensing element, obtained by means of a direct weight manometer calibrating apparatus.

The graph shows clearly the linearity of the realized indicator.

The sensitivity S, as results from the graph, is the ratio of the bridge output voltage to the static pressure acting on the element, and its deduced value is $26,6 \times 10^{-6}$ V $kg^{-1}$ $cm^2$.

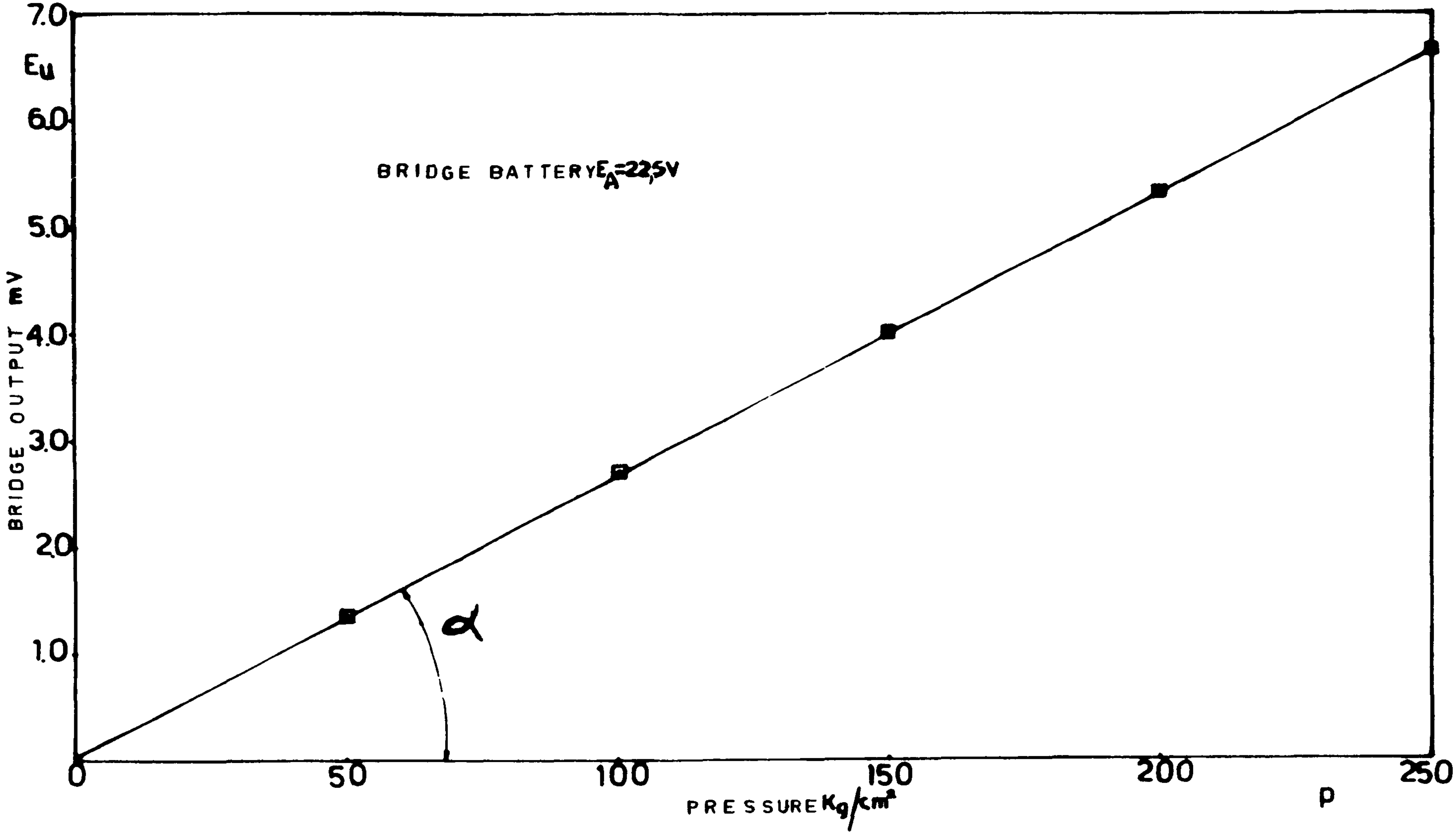
This comparatively small figure of the sensitivity, as in similar indicators, requests to employ a preamplifier, which has been realized with a double-triode.

As indicator of the injector needle displacement has been adapted to the injector of the AV1 Petter engine an electromagnetic indicator of the Sunbury type. The signal generated by this element is proportional to the velocity of the needle and therefore it needs to be integrated before to be applied to the oscilloscope.

Also the crankshaft angle indicator is of the Sunbury type, and it is driven by the camshaft of the AV1 Petter engine.

The three indicators described (injection pressure indicator, displacement of injector needle indicator and crankshaft angle indicator) are connected to a single multichannel cathode ray oscilloscope.

To determine experimentally the influence of the injector nozzle temperature on the deposit formation in correspondence of the spray hole and of the needle seat of the injector nozzle, has



7.0
Eu
6.0
5.0
4.0
3.0
2.0
1.0
BRIDGE OUTPUT mV
BRIDGE BATTERY E_A=22,5V
α
0
50
100
150
200
250
p
PRESSURE Kg/cm²

been designed and constructed a small platinum-platinum iridium thermocouple whose sensing end, penetrating in the air cell of the engine, is located inside a hole drilled at the end of the injector nozzle. In fig. 7 is represented the engine section from which it is possible to recognize the termocouple position. In fig. 8 is represented the injector nozzle with the position of the termocouple sensing end.

<u>Instruments</u> b)

As the purpose of the research was to individuate a test method able to emphasize the efficacy of a detergent additive added to the gasoil, the analysis of the deposits had to be made on those engine members, which may be reached from the fuel or from the combustion products. Some of these members, as e. g. the cylinder head, have a geometry not suitable for qualitative or quantitative analysis of the deposits formed on them, so as the same analysis had to be limited to those members which, for their geometry and the consequences which the deposits on them may have on the engine working conditions, are particularly easy to be analyzed and representative of the phenomenon. The members which we selected on the basis of the above said considerations were the injector nozzle and the piston crown.

To evaluate the quantity of the deposits on the needle seat and along the spray hole of the injector-nozzle has been realized a microphotography apparatus which allows to observe and to photograph the above said parts of the injector-nozzle enough enlarged.

In the fig.9 are represented the injector-nozzle and the parts being observed and photographed with the described appara-

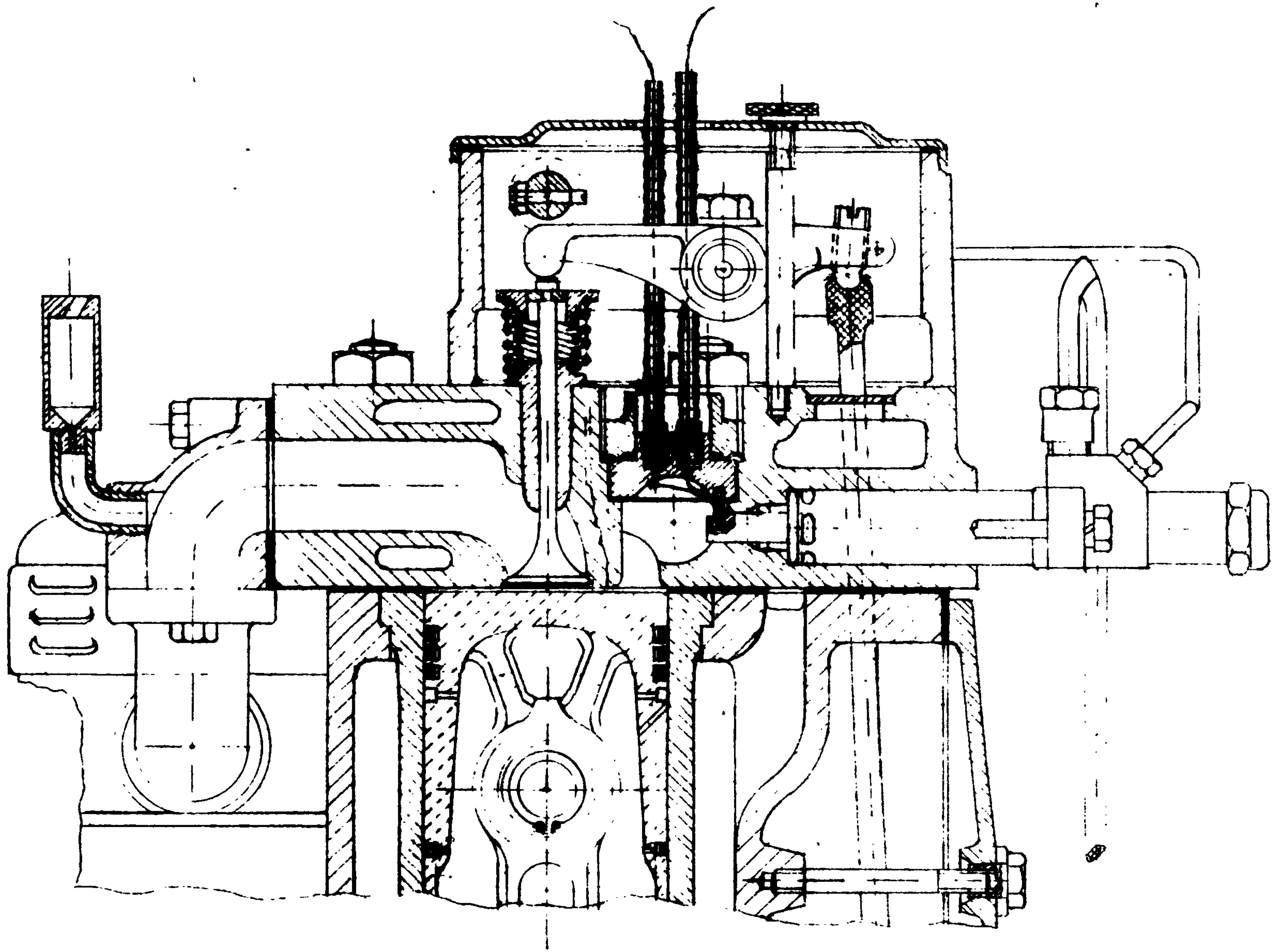


FIG. 7

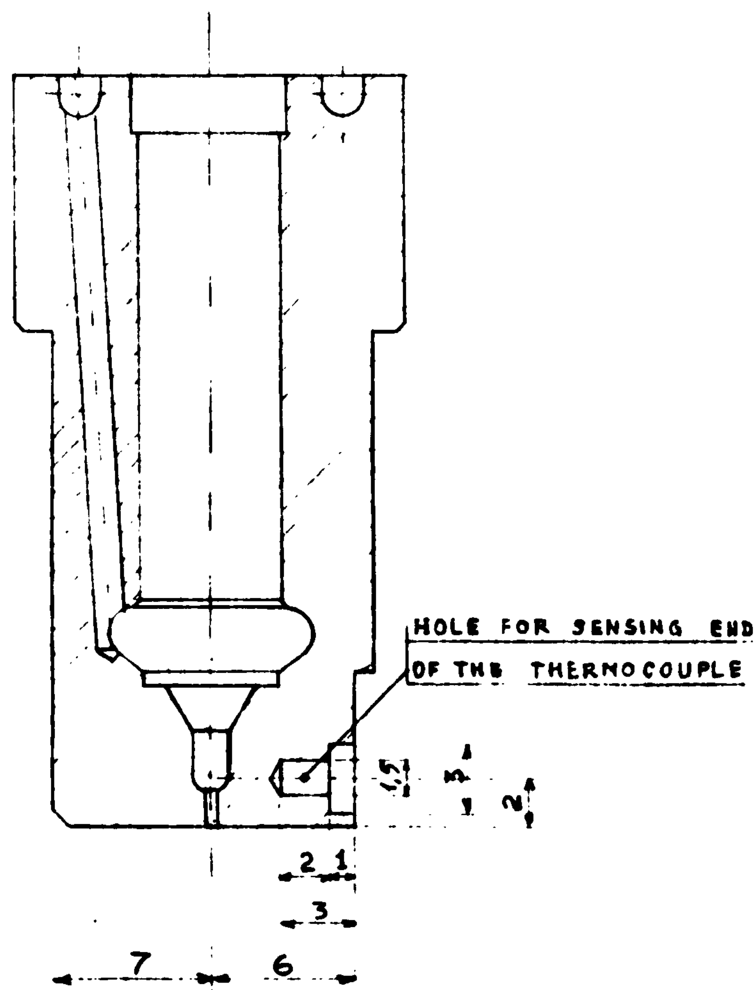
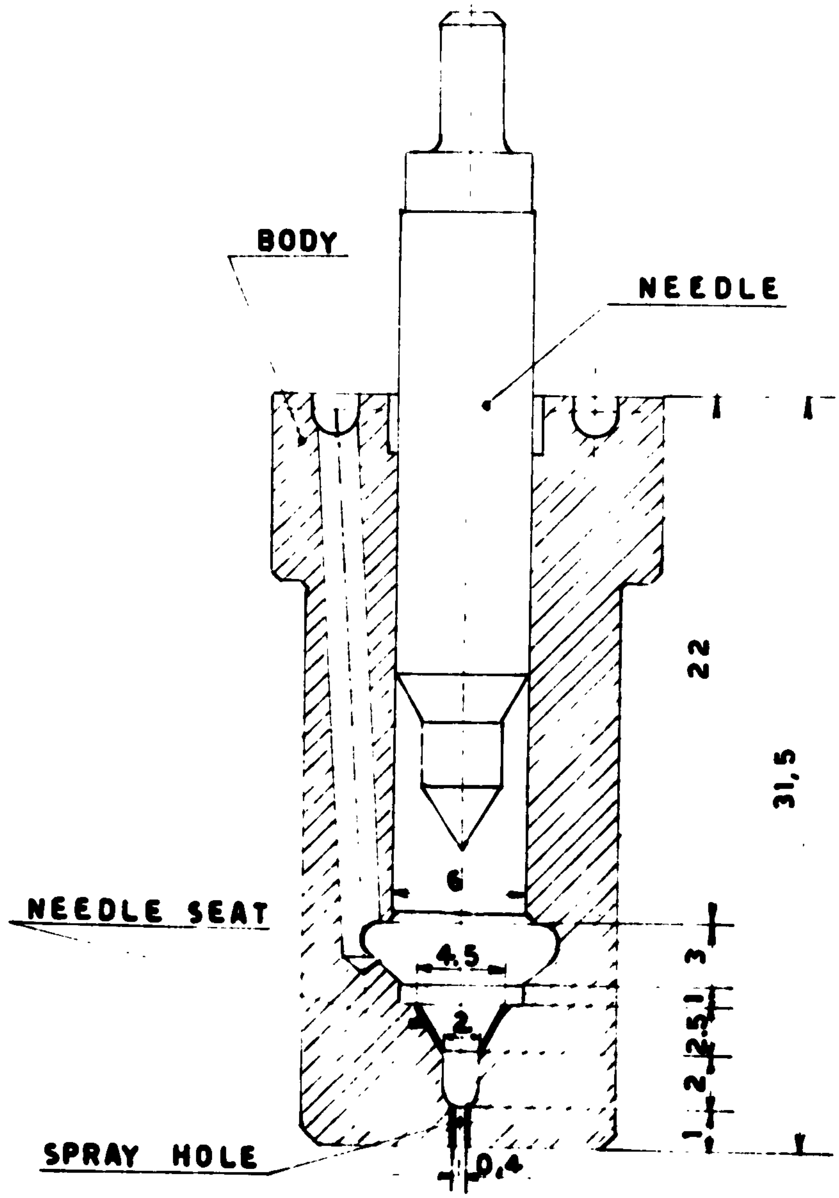



FIG. 8




INJECTOR NOZZLE

FIG.9

tus. It is evident that the deposits on the above said parts are the most significant in respect of the efficiency of the injector-nozzle.

Fig. 10 represents the scheme of the arrangement of the microphotography apparatus intended to photograph the spray-hole. It is possible to focalize the different sections of the spray hole, whose length is about 1 mm and whose diameter is 0,4 mm. The quantity of the deposits may be so measured as variation of the spray-hole diameter at different sections after a convenient working period.

Fig. 11 represents the microphotography apparatus intended to photograph the needle seat. This goal has been obtained overcoming difficulties depending from the fact that the needle seat is located (see fig. 9) at the end of the needle guide, whose length is 26 mm and whose diameter is 6 mm. The most serious difficulty to be overcome was the lighting of the needle seat with a convenient light angle.

This difficulty has been overcome by means of a prism whose angular position may be regulated as to obtain maximum lighting of the part to be observed.

In the figs. 12, 13, 14,15 are the photographs of the hole and of the needle seat respectively of a new injector-nozzle and of an used one after a convenient working period.

The other of the elements to be analyzed after each engine test to evaluate the detergent aptitude of the fuel additive, is the piston crown.

In this piston zone in effect the deposits are due to a defective fuel combustion rather than to lubricating oil oxidation.

The detergent action of the fuel additive should be such

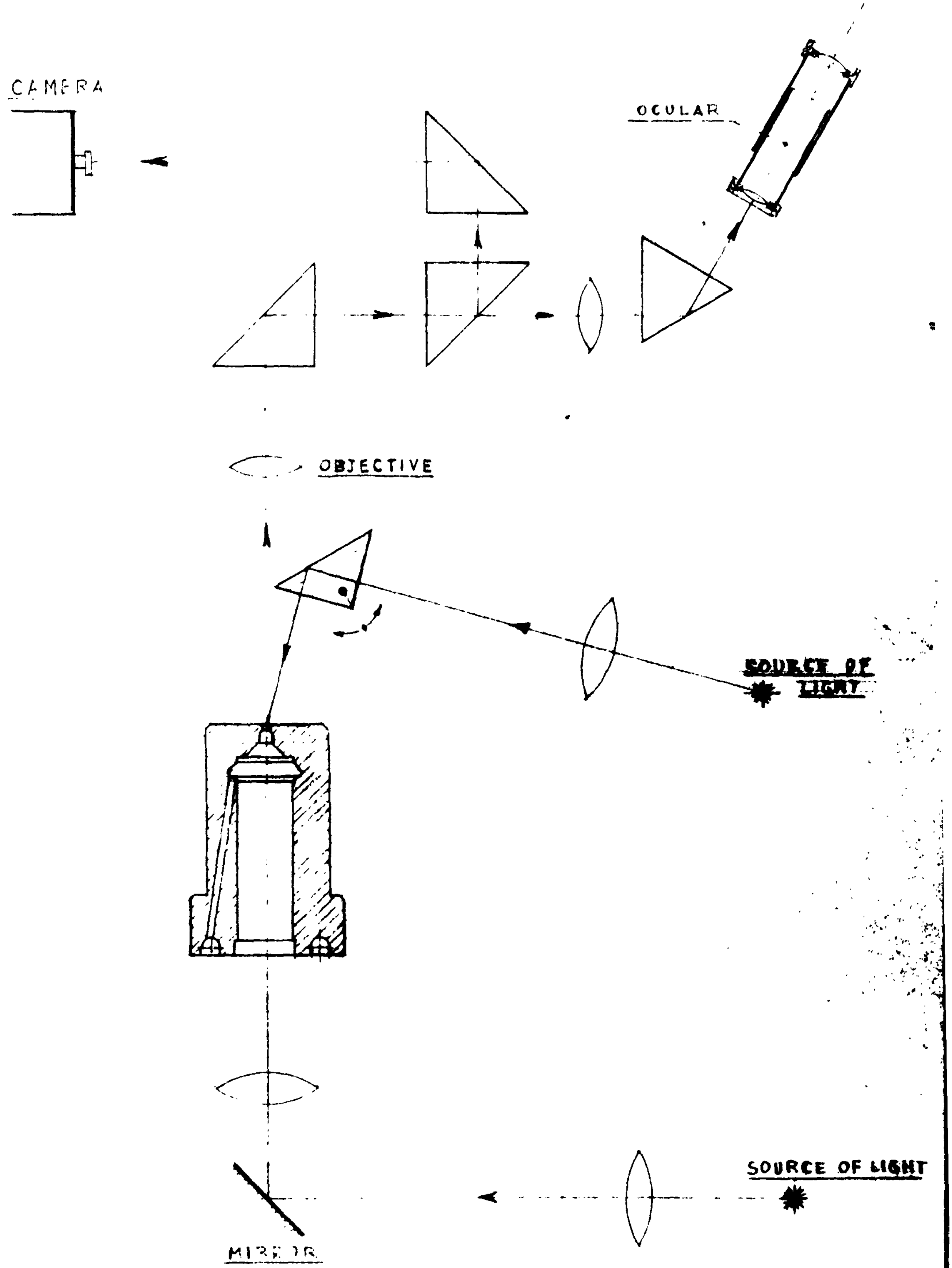
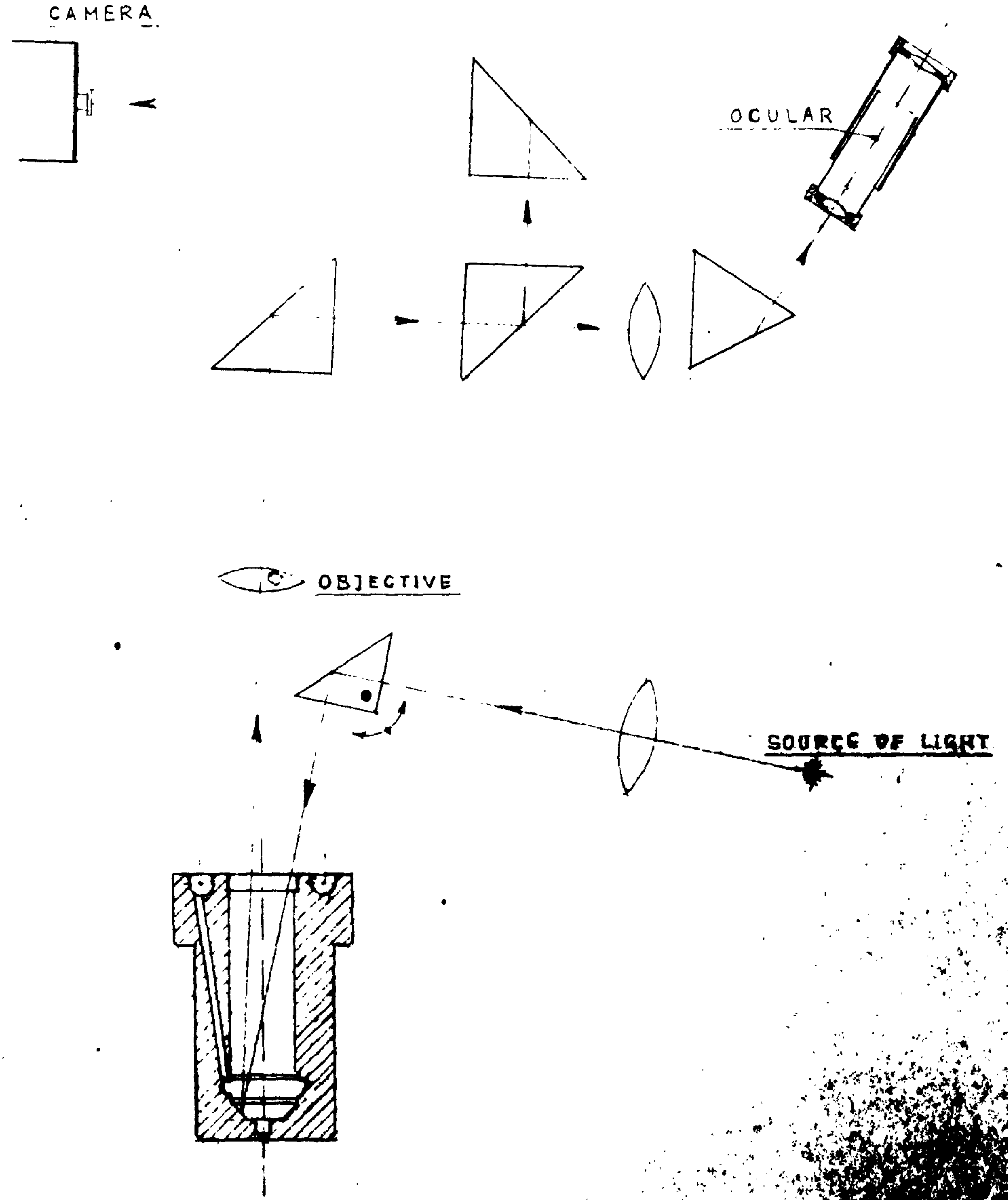

CAMERA
OCULAR
OBJECTIVE
SOURCE OF LIGHT
SOURCE OF LIGHT
MIRROR

FIG. 10


CAMERA
OCULAR
OBJECTIVE
SOURCE OF LIGHT

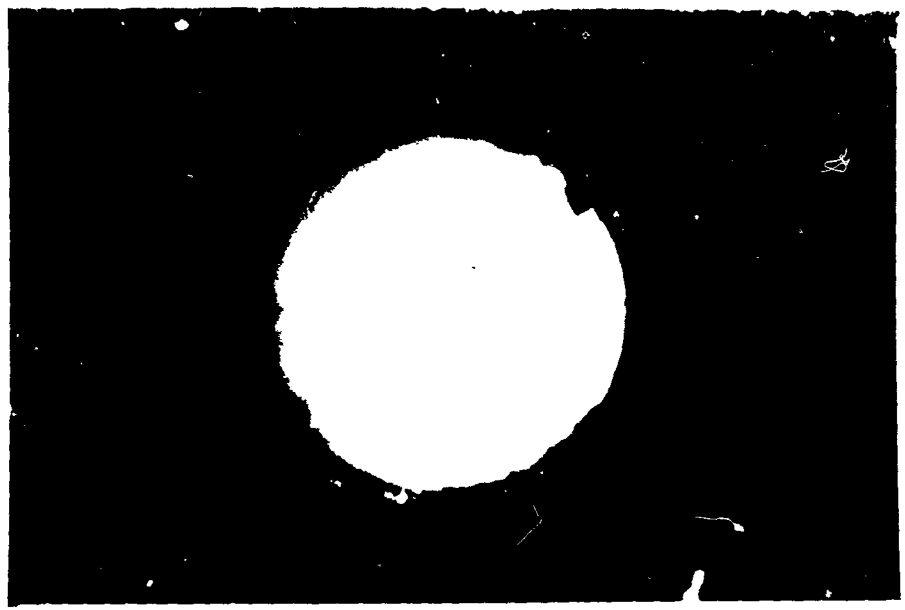


FIG. 12

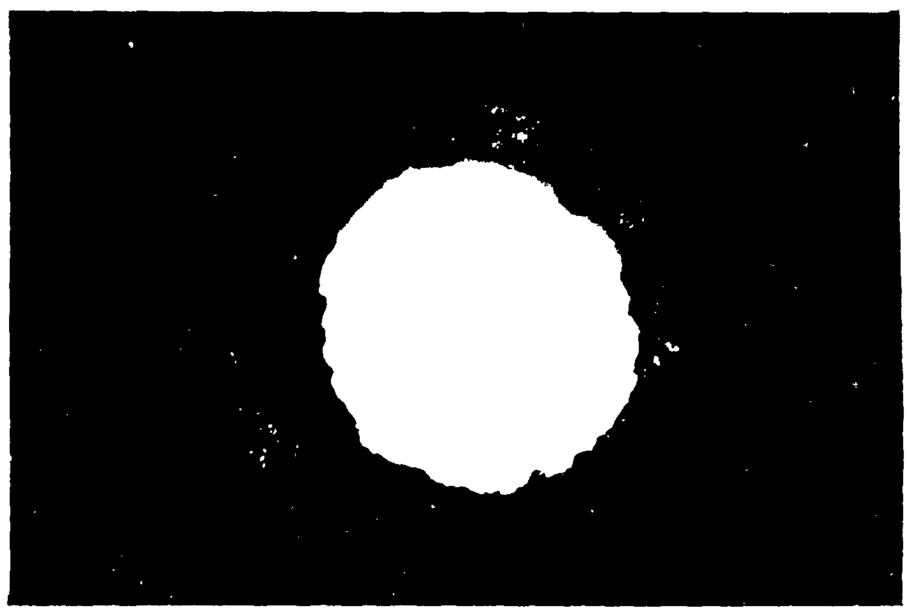


FIG. 11

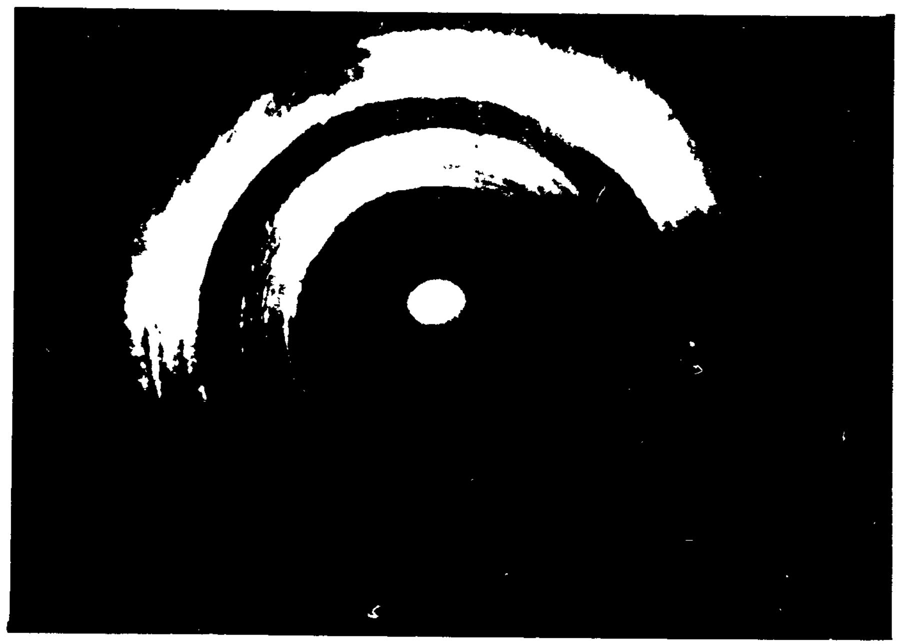


FIG. 14

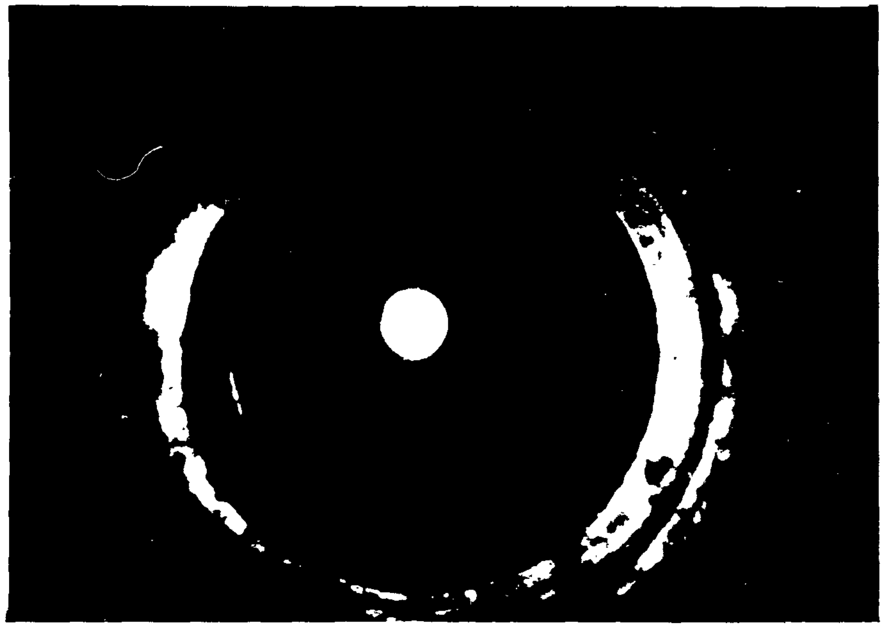


FIG. 15

to prevent or at least to limit the deposit formation in the above said piston zone, and to render incoherent the deposits already formed.

Two means have been studied and realized to analyse the above said deposits:

1) The former permits a quantitative analysis of such deposits.
2) The latter permits to obtain a permanent photographic record of the piston crown, which can be compared with the records of other tests.

For the evaluation of the deposits on the piston crown has been provided a transparent mask in plexiglass, divided in 25 parts, which can be adapted to the piston crown.

A merit equal 0 will be assigned to each part completely blackened by deposits, and a merit equal 1 to each part free from deposits.

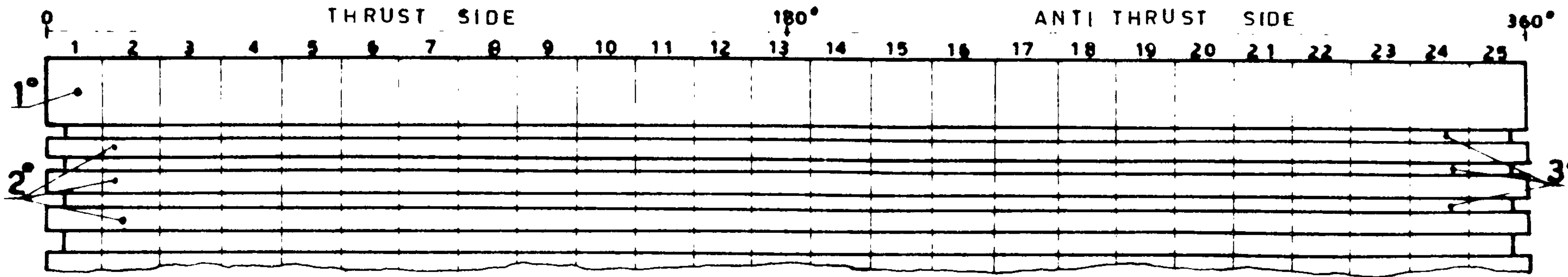
Intermediate merits are assigned to the parts only partially covered by deposits. Summing all the merits of each surface element gives a percent evaluation of the deposits on the piston crown.

The evaluation is performed by reporting on the table of fig. 16 the relative merits of each elementary part of the crown.

The evaluation procedure appears more clearly from the table. This evaluation, in spite of its subjective basis, has been tested satisfactorily repeatible and reproducible.

To obtain a photographic record of the piston crown and of the deposits has been realized a photographic system intended to obtain a developed surface of the piston crown.

The schematic drawing of this photographic system is in fig. 17.




| DEPOSITS | ZONE | | ELEMENTARY ZONE | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
| LACQUER DEPOSITS | 1° CROWN | | | | | | | | | | | | | | | | | | | | | | | | | | |
| LACQUER DEPOSITS | 2° PISTON LAND | I | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | II | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | III | | | | | | | | | | | | | | | | | | | | | | | | | |
| LACQUER DEPOSITS | 3° RING GROOVE | I | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | II | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | III | | | | | | | | | | | | | | | | | | | | | | | | | |

1° - Piston crown
2° - Piston lands (average)
3° - Ring grooves (average)

FIG.16

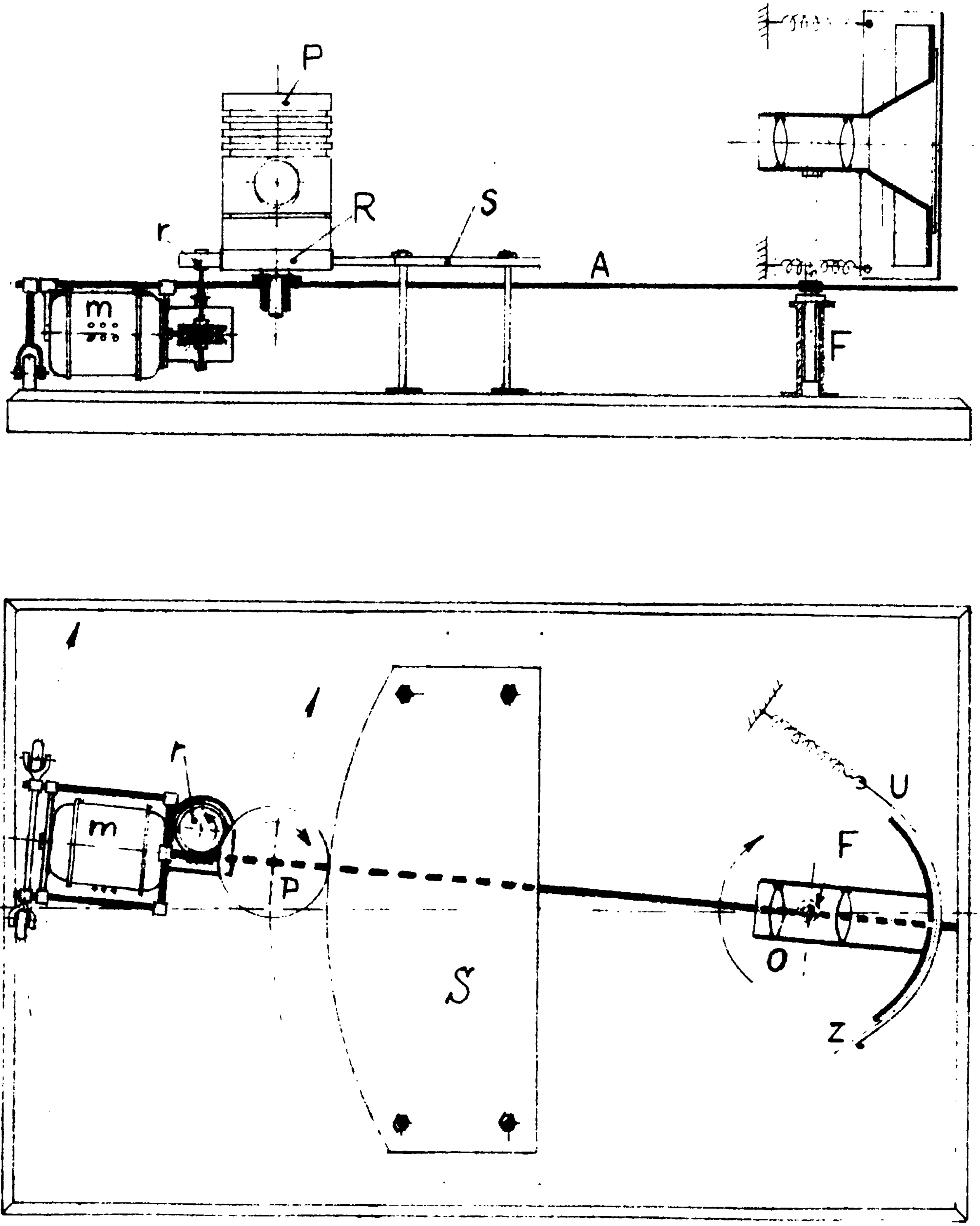



FIG 17

An electric motor, m, through a worm gear operates a friction wheel, r, in contact with another friction wheel, R, having the same diameter of the piston, P, to be photographed, and firmly connected to the piston. The wheel R is free on its axis and is supported by a long rod A, which can rotate around the point F.

The wheel R is in contact with a fixed circular profile, S, the center of which is in F. The rotation of the wheel r causes the rolling of the wheel R on the profile S. The axis of istantaneous motion of the piston movement are the generating lines of the lateral surface of the piston. An objective, O, placed at F, focuses on a fixed photographic film, U, each generating line of the piston, while it is the istantaneous axis of rotation. An opaque screen, Z, connected to the objective O, has a narrow opening in correspondence of the objective focus, through which only a limited zone, around the contact generating line, can be photographed.

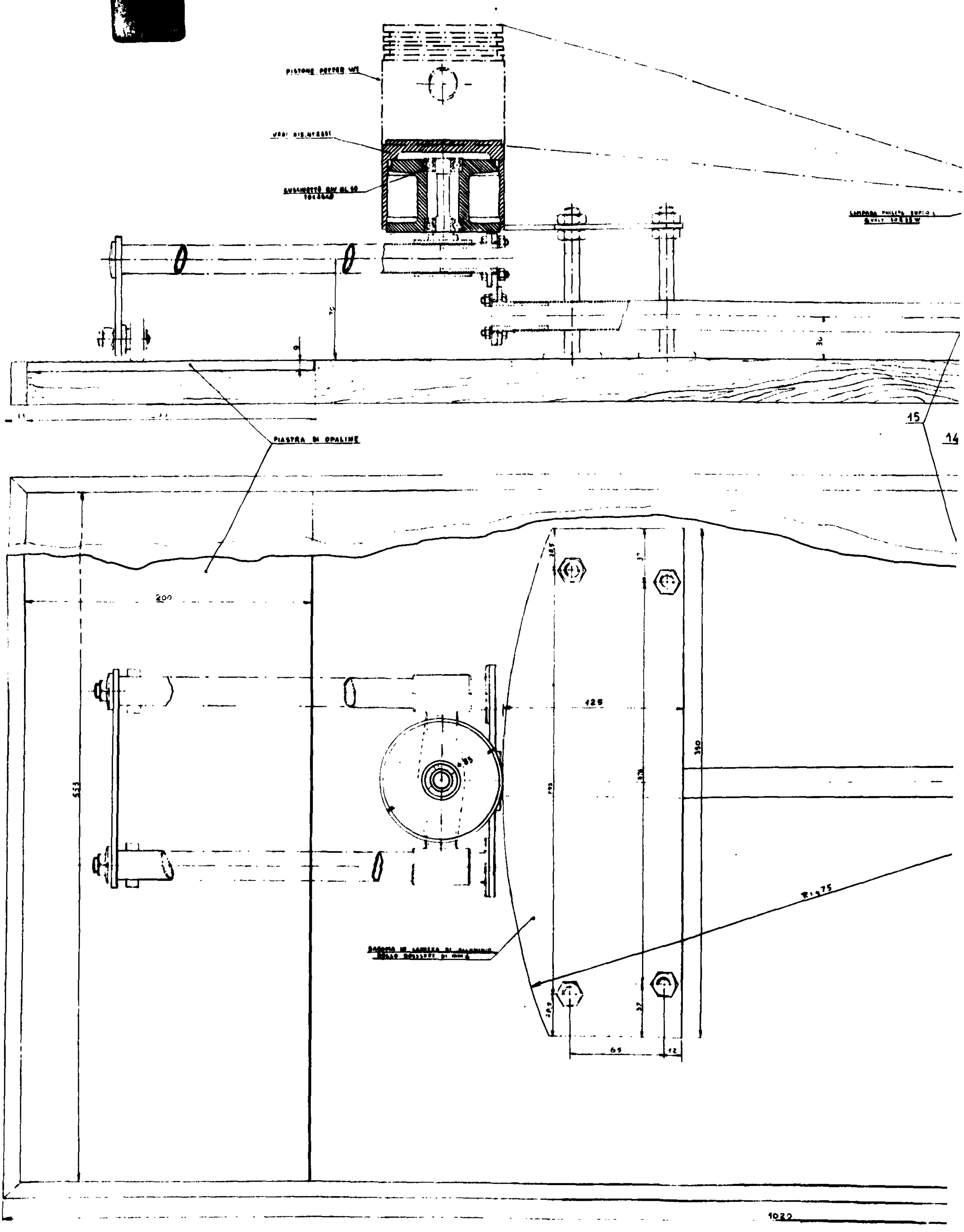
In this manner, while the piston P completes one revolution, rolling on the profile S, all the generating lines of the piston are consecutively photographed on the same film U. So can be obtained a photograph of the lateral surface of the piston crown, developed on a plane. An example of such photographies is reproduced in fig. 18.

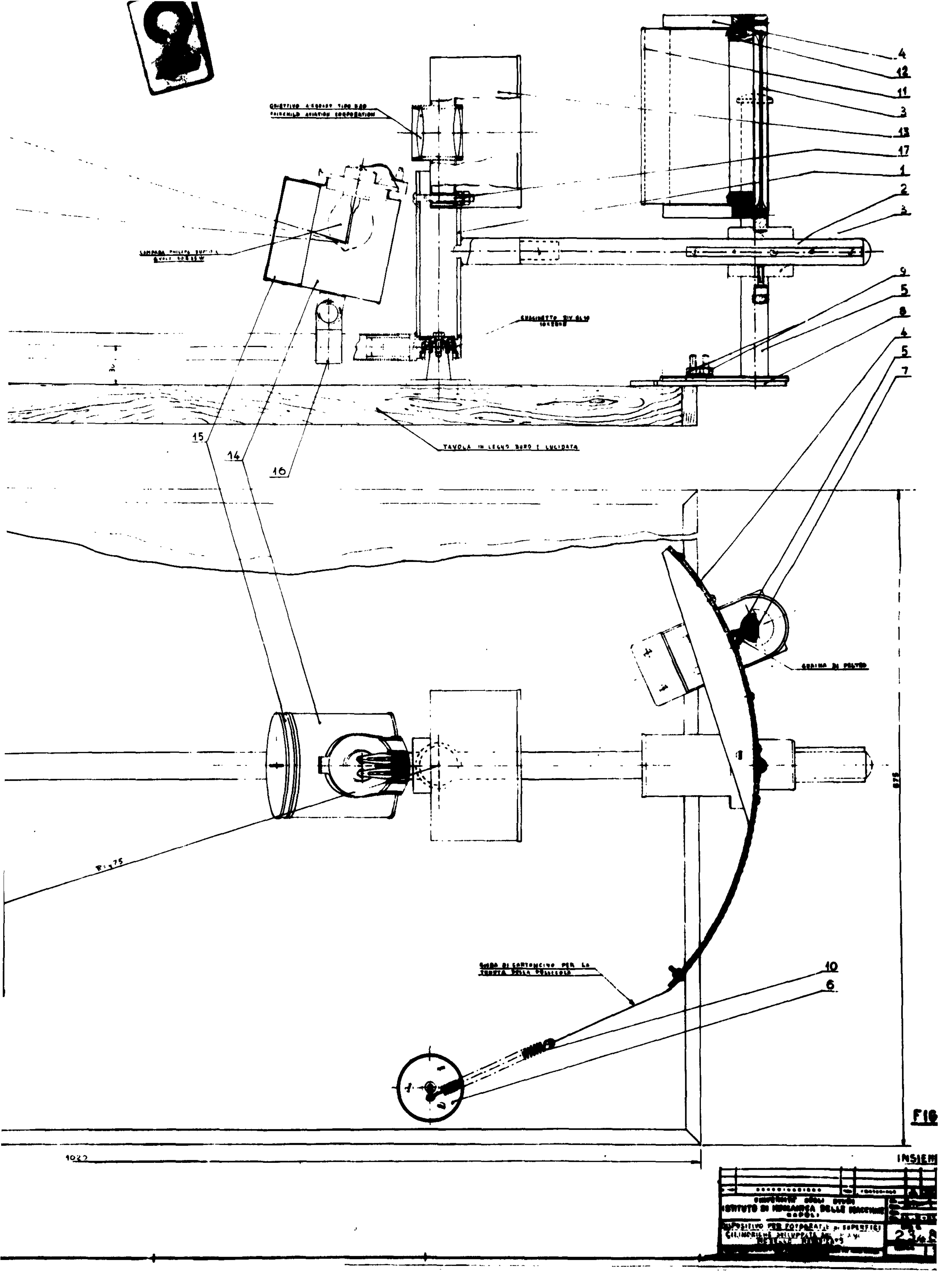
The general drawing of the above described photographic system is in fig. 19.

## THE PERFORMED TEST PROGRAM

The performed test program consists of two different test sets: the former has aimed to analyze the operation of the injection appa-

FIG. 18


PIASTRA DI OPALINE
15
14
200
553
125
390
30
65
12
37
1020


4
12
11
3
13
17
1
2
3
9
5
8
4
5
7
15
14
16
TAVOLA IN LEGNO DURO E LUCIDATA
10
6
1022
875
FIG
INSIEM

ratus at different loads,obtained by varying the mass flow rate supplied by the injection pump; the latter has had the purpose to individuate, between the running conditions, for which the first test set had revealed an imperfect injection, the most severe in regard to the deposits formation.

The former test set has been run as follows.

At each load, i. e. at each preset position of the control rod of the injection pump, three tests have been performed, each at different r. p. m.

The test conditions have been chosen to cover the complete field of normal running of the engine; the upper limit of such a field is given by the maximum mass flow rate of the injection pump, while the lower limit occurs at the minimum mass flow rate which allows a regular running of the engine at minimum r. p. m. (1000 r. p. m.).

At each test condition has been recorded an oscillogram: each one contains three diagrams; of the injector needle displacement, of the injection pressure ahead of the injector, and finally a reference signal with period corresponding to a rotation of two degrees of the crankshaft.

The oscillograms are numbered and the numeration is the same of that of the table I, in which corresponding test conditions are reported.

The columns of table I report in the order:

1) The number of the oscillogram;
2) The average angular velocity "n" of the engine;
3) The micrometer setting of the injection pump-control rod. Note that the lowest figures correspond to the highest mass flow rate of the injection pump.

## TABLE I

| Oscillogram Nr. | r.p.m. | Micrometer setting | Cooling water temperature °C | | t | S | Injection advance | Injection Period | | $p_{max}/p_i$ | $p_s/p_i$ | Post-opening | $t_n$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_i$ | $T_u$ | sec | $mm^3$ | degrees | degrees | $sec \cdot 10^{-6}$ | | | | °C |
| 1 | 980 | 0,40 | 45,0 | 47,8 | 240,4 | 50,2 | 12,0 | 22,0 | 374 | 1,43 | 0,81 | yes | 660 |
| 2 | 1250 | 0,40 | 47,2 | 51,1 | 183,2 | 52,4 | 12,0 | 22,0 | 293 | 1,43 | 0,82 | yes | 700 |
| 3 | 1450 | 0,40 | 48,9 | 53,4 | 157,4 | 52,6 | 10,0 | 21,0 | 241 | 1,21 | 0,58 | yes | 800 |
| 19 | 1060 | 0,75 | 43,3 | 47,2 | 246,4 | 45,9 | 9,0 | 18,0 | 283 | 1,37 | 0,60 | --- | 900 |
| 20 | 1240 | 0,75 | 45,6 | 48,3 | 213,2 | 45,4 | 9,0 | 19,0 | 255 | 1,48 | 0,51 | --- | 930 |
| 21 | 1540 | 0,75 | 47,2 | 50,0 | 169,4 | 46,0 | 9,0 | 21,0 | 227 | 1,42 | 0,51 | --- | 940 |
| 16 | 1030 | 1,00 | 45,0 | 47,8 | 278,4 | 41,8 | 9,5 | 15,5 | 251 | 1,23 | 0,71 | --- | 830 |
| 17 | 1300 | 1,00 | 45,0 | 48,3 | 217,3 | 42,5 | 9,0 | 17,0 | 218 | 1,54 | 0,57 | --- | 940 |
| 18 | 1500 | 1,00 | 46,1 | 50,0 | 192,5 | 41,6 | 10,0 | 20,0 | 222 | 1,44 | 0,62 | --- | 950 |
| 13 | 1180 | 1,30 | 61,7 | 64,4 | 274,8 | 37,0 | 8,0 | 14,5 | 205 | 1,21 | 0,50 | --- | 930 |
| 14 | 1380 | 1,30 | 68,4 | 70,6 | 244,2 | 35,6 | 9,0 | 17,0 | 205 | 1,21 | 0,52 | --- | 950 |
| 15 | 1600 | 1,30 | 72,8 | 75,5 | 207,0 | 36,2 | 6,0 | 17,0 | 177 | 1,22 | 0,49 | --- | 950 |
| 10 | 960 | 1,50 | 42,2 | 44,4 | 416,0 | 30,0 | 12,0 | 13,0 | 226 | 1,19 | 0,60 | --- | 570 |
| 11 | 1250 | 1,50 | 43,3 | 46,7 | 328,2 | 29,2 | 12,0 | 16,0 | 213 | 1,44 | 0,61 | --- | 600 |
| 12 | 1500 | 1,50 | 46,1 | 48,9 | 235,7 | 33,9 | 10,0 | 18,0 | 200 | 1,36 | 0,66 | --- | 940 |
| 7 | 1000 | 1,75 | 43,3 | 45,6 | 441,0 | 27,2 | 9,0 | 10,0 | 167 | 1,08 | 0,45 | --- | 550 |
| 8 | 1200 | 1,75 | 44,4 | 47,2 | 355,6 | 28,1 | 10,0 | 12,0 | 167 | 1,14 | 0,57 | --- | 560 |
| 9 | 1450 | 1,75 | 45,6 | 48,3 | 306,3 | 27,0 | 11,0 | 13,0 | 150 | 1,34 | 0,78 | yes | 570 |
| 4 | 1000 | 1,95 | 40,0 | 42,2 | 518,4 | 23,1 | 5,5 | 6,5 | 108 | 1,10 | 0,69 | yes | 470 |
| 5 | 1250 | 1,95 | 42,2 | 44,4 | 355,0 | 27,0 | 11,5 | 13,0 | 173 | 1,20 | 0,76 | yes | 540 |
| 6 | 1450 | 1,95 | 43,3 | 46,7 | 342,5 | 24,2 | 10,0 | 14,5 | 167 | 1,28 | 0,72 | yes | 510 |

TABLE I

4) The temperature of cooling water at the inlet ($T_i$)and at the outlet ($T_u$) of the engine.
5) The time "t", in seconds, requested for the consumption of 100 $cm^3$ of fuel. This figure has been measured during each test.
6) The average volume of fuel injected in each cycle of the engine. This figure, S, has been obtained through:

$$S = \frac{12}{t \times n} 10^6 \ mm^3$$

where:

t = time for consumption of 100 $cm^3$ of fuel.

n = average r. p. m. of the engine.

7) The injection advance, obtained from the oscillograms.
8) The injestion period, obtained from the oscillograms.
9) The Pmax/pi ratio between the maximum pressure of the injection cycle and the pressure at wich the needle opens.
10) The ps/pi ratio between the maximum pressure after the end of the injection and the injection pressure.
11) The occurrence of post-openings of the needle.
12) The temperature $t_n$ at the end of the injector nozzle, recorded during each test, through the platinum-platinum iridium thermocouple.

The latter test set, which has been established by means of the results of the former set has comprehended the following heigt tests:

1) Four tests performed in the same conditions of those

tests marked with numbers 1, 3, 4, 6 in the table I. These have been performed cooling the engine with forced circulation of water with the aim to obtain the highest refrigeration of the cylinder walls. Each of these tests has had a complete duration of 36 hours, and has been performed in six periods each of six hours. At the beginning of each test the engine has been completely overhauled and a new piston and a new injector - nozzle have been mounted.

At the end of each six hours period the piston and the injector-nozzle have been removed from the engine and photographed with the described apparatus; the deposits on the piston crown, the piston lands and the ring grooves have been analyzed with the described method. In this way we have obtained a record of deposits formation process during each test.

2) Four tests performed in the same manner described in the point 1), but using kerosene as cooling liquid, with the aim to obtain the highest temperatures of the cylinder walls. The comparison of tests, carried out in the same test conditions but using different cooling liquid, has indicated the influence of the piston wall temperatures on the deposits formation process.

All the above said tests have been performed with the same type of diesel fuel and with the same type of lubricating oil, whose characteristics are reported in Appendix 1 e 2. The analysis of the results of the complete test program has indicate the test conditions which are the most severe with respect to the deposit

PROPERTIES OF THE DIESEL FUEL USED FOR THE ENGINE TESTS

| P R O P E R T Y | Ref. ASTM | ANALYSIS RESULTS |
|---|---|---|
| 1-Flash point, °F ........................ | D 93 | 147 |
| 2-Cloud point, °F ........................ | D 97 | 25 |
| 3-Pour point, °F ........................ | D 97 | 15 |
| 4-Kinematic viscosity .................... | D 445 | 2,8 |
| 5-Water and sediment, percent by volum ... | D 96 | less than 0,05 |
| 6-Sulphur, percent ........................ | D 129 | 1,0 |
| 7-Carbon residue on 10 percent residuum, per-cent | D 189 | 0,20 |
| 8-Ash, percent ........................ | D 482 | 0,01 |
| 9-Corrosion, copper strip, 3hour at 122 °F. | D 130 | 1 |
| 10-Ignition quality, cetane number ....... | D 613 | 45 |
| 11-Distillation : ........................ | D 158 | |
| 50 percent point, °F ........... | | 509 |
| 90 percent point, °F ........... | | 637 |
| End point, °F .................. | | 687 |
| 12-Gravity A P I ........................ | D 287 | 0,835 |

N O T E : The properties of the diesel fuel meet with the Federal Specification VV - F - 800.

PROPERTIES OF THE LUBRICATING OIL USED FOR THE ENGINE TESTS

| PROPERTY | Ref. ASTM | ANALYSIS RESULTS |
|---|---|---|
| 1-Flash point, °F ...................... | D 93 | 390 |
| 2-Viscosity, Kinematic ................. | D 445 | |
| at 100 °F ................ | | 131 |
| at 210 °F ................ | | 13,8 |
| 3-Viscosity Index ...................... | D 567 | 108 |
| 4-Carbon residue, percent .............. | D 189 | 1,39 |
| 5-Neutralization value ................. | D 974 | 0,17 |
| 6-Sulfated residue, percent ............ | D 874 | 0,90 |
| 7-Specific Gravity ..................... | D1298 | 0,890 |

**NOTE : The lubricating oil is a Supplement 1 oil.**

formation phenomenon.

THE TEST RESULTS

The examination of the oscillograms, obtained from the former test set, emphasizes that in particular test conditions there is in the injection system a residual pressure. Indeed in these test conditions the pressure waves, that take place at the end of injection, extend below the pressure line that precedes the injection diagram.

Not yet has been set up a system to measure this residual pressure . In default of a precise figure, the values of the pres sure have been measured from the tangent to the inferior pressure peak, present in the diagram. With this the values of the ratio $p_{max}/p_i$ reported in column 9 of table I, exceed the real ones, as well as the values, reported in column 10,of the ratio $p_s/p_i$ are smaller.

From the observation of the recorded oscillograms one can deduce also that the pattern of pressure versus time, after the injector needle has closed the nozzle, depends on the position of the injection-pump control rod. In particular the following considerations wan be made:

A) (see oscillograms nr.1,2,3,of fig.20) when the pump delivers the highest flow-rates, the highest frequencies are in the pressure oscillations. This oscillation seems to promote forced vibrations of the needle.

These vibrations increase with time until the nozzle reopens. Consequently the amplitude of the pressure oscilla tions suddenly abates, owing to the fuel flow through the

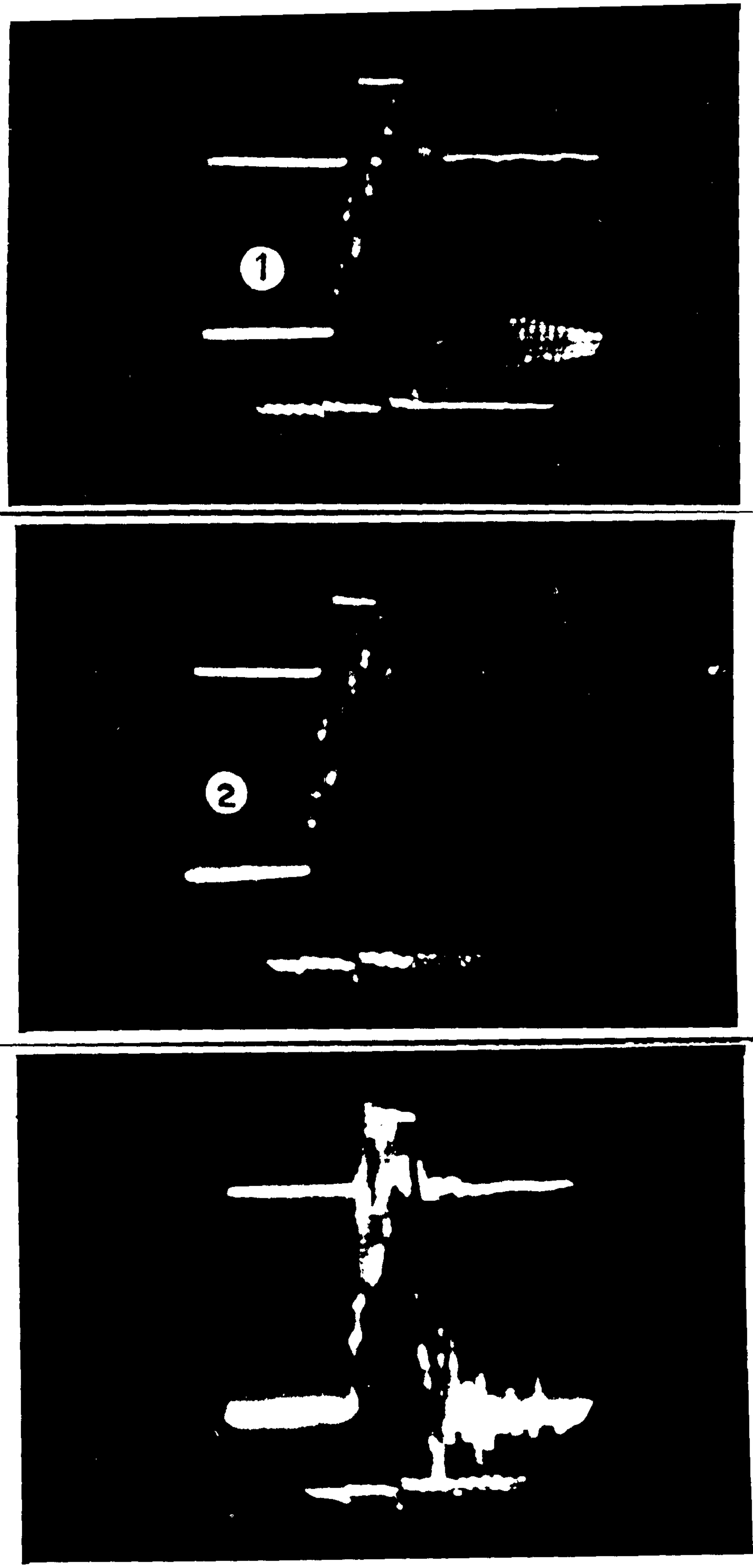



FIG. 20

reopened nozzle.

The needle comes finally at rest, and the remaining pressure oscillations arenotable to excite again the needle vibrations. The above phenomenon is more sensible particularly when the engine runs at low r. p. m.

B) (See oscillograms nr.4,5,6 of fig.21) when the pump delivers the lowest flow-rates, the frequency of pressure waves, after the nozzle shutting, is smaller. The needle does undergo vibrations, however these are damped and go out before the second cycle of the pressure oscillation starts.

This oscillation is not able to excitate again any vibration of the needle. The phenomenon is more sensible when the engine runs at high r. p. m..

At any rate the amplitude of the pressure oscillations increases with residual pressure.

The residual pressure within the injection system is important for what concernes deposit formation.

This pressure, if of sufficient value, can cause by itself the fuel to flow through the seat of the needle.

Furthermore the increase of the residual pressure increases, as said, the amplitude of the pressure fluctuations, after the nozzle shutting.

The consequent possible reopening of the nozzle gives rise to conditions of imperfect after-injection, i. e. to fuel dropping.

It is interesting to emphasize that the nozzle reopening happens with values of the pressure which are always smaller than the normal pressure of injection. It seems logical, for what

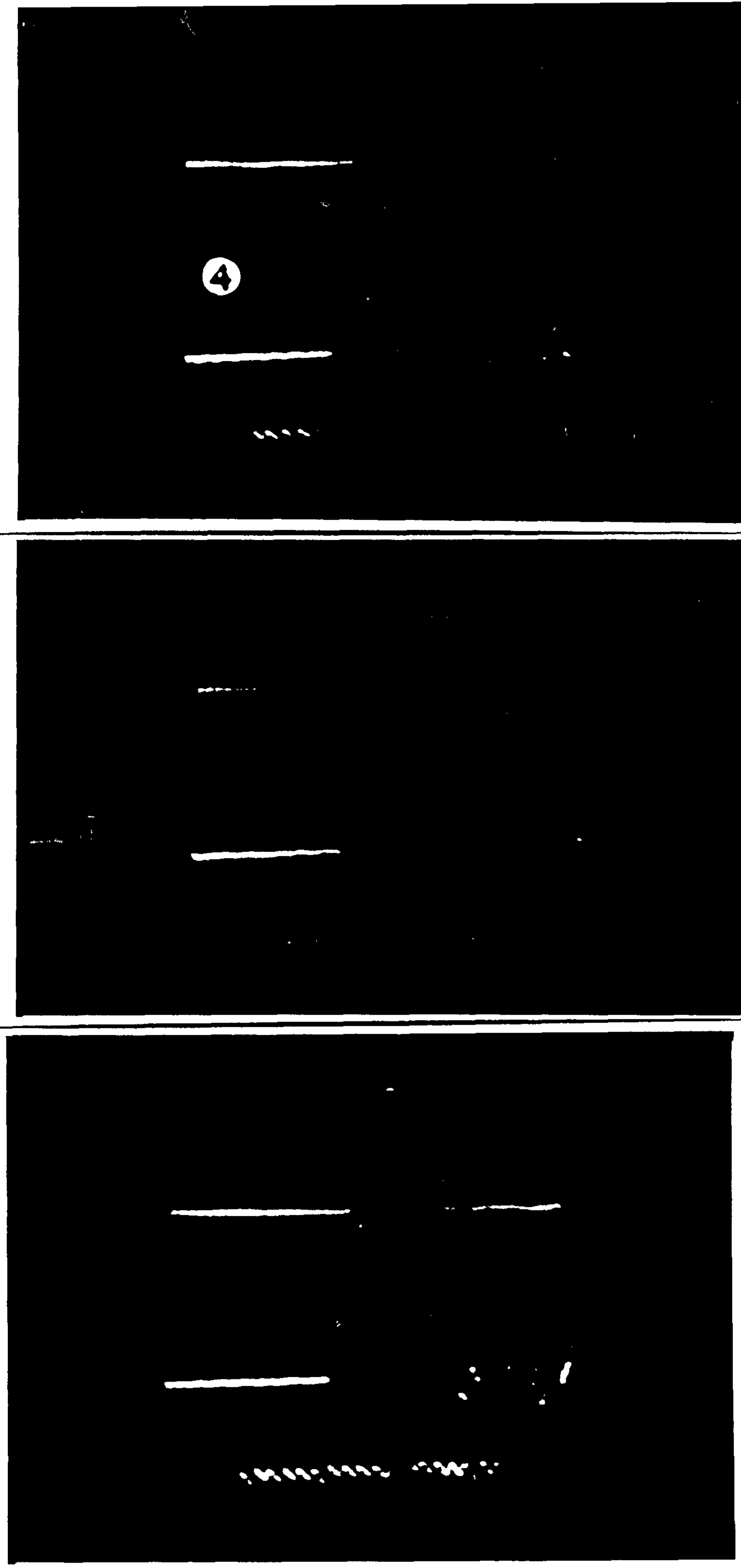



FIG. 21

concerns oscillograms 1, 2, 3, that phenomena of resonance occur between the pressure fluctuations and the needle vibrations.

This does not hold for what concerns oscillograms 4, 5, 6, owing to the low frequency of the pressure fluctuations.

At the lowest fuel flow rates, when also the speed is low, the engine seems to behave as instable. The following chain of consi= derations can be made:

1) At the very beginning the gradient of the pressure increase is smooth;
2) after a while the needle rises, but the consequent pressure drop makes it fall down again;
3) finally the true injection starts.

Summing up, conditions of imperfect injection, able to promote deposit formation, take place at both high and low loads, (respec= tively see oscillograms 1, 2, 3, and 4, 5, 6).

The results of the series of eight engine tests, performed following the described test conditions, are contained in the diagrams of the figures 22 to 29.

The numbers, which distinguish each test, are followed by the letters A or K according that the corresponding test has been per formed using water or kerosene as cooling fluid.

In each figure are plotted, versus test hours:

a) The values of the ratio:

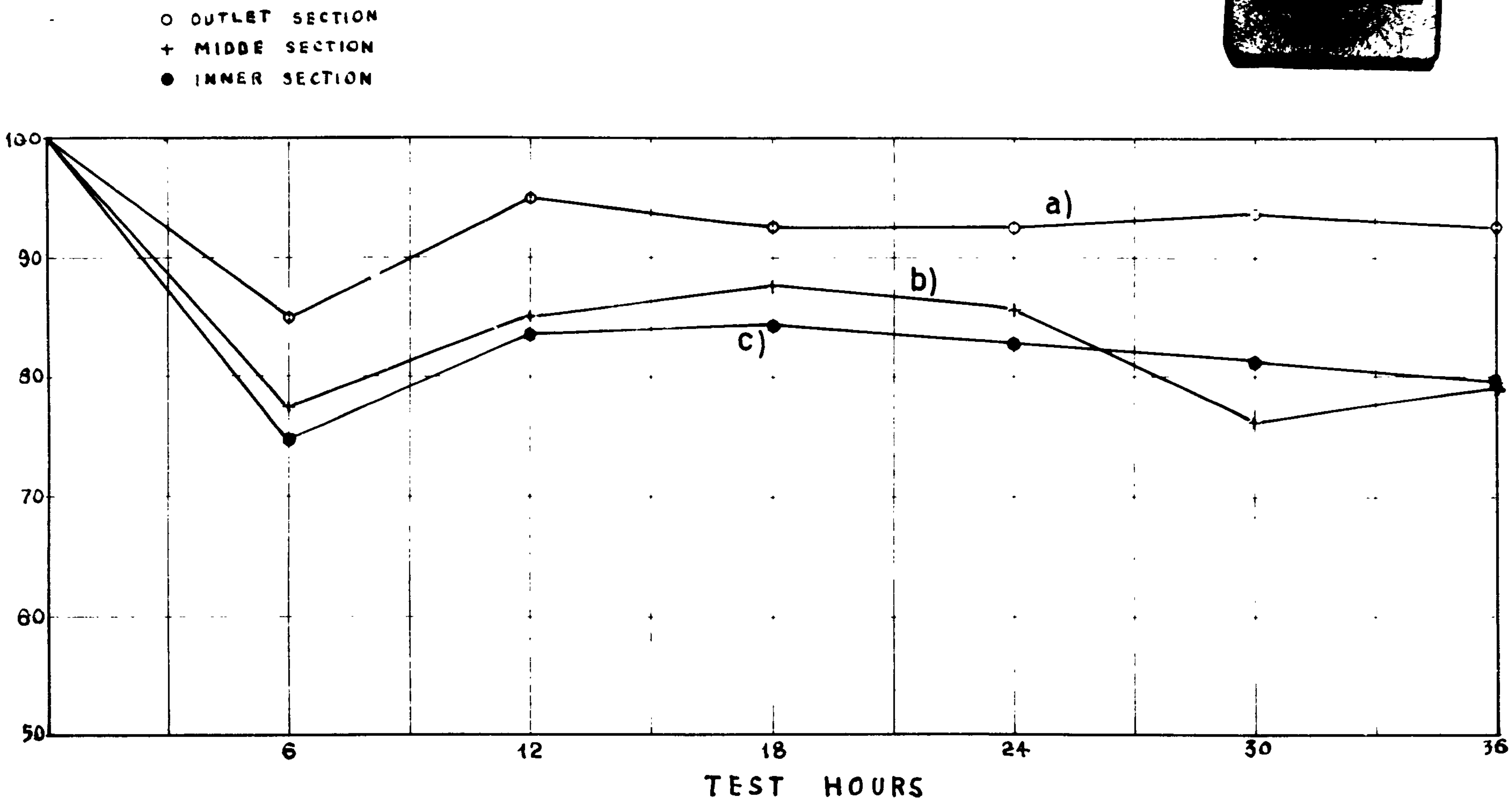
$$100 \frac{S_{u,i}}{S_{u,o}}$$

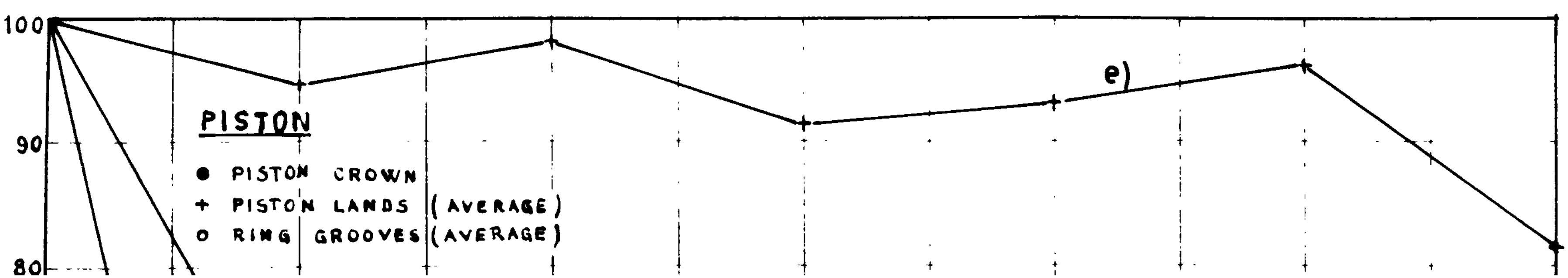
where:

$S_{u,o}$ = outlet section of the spray hole of the injector

# TEST № 1A – MERIT RATINGS

SPRAY HOLE OF THE INJECTOR NOZZLE



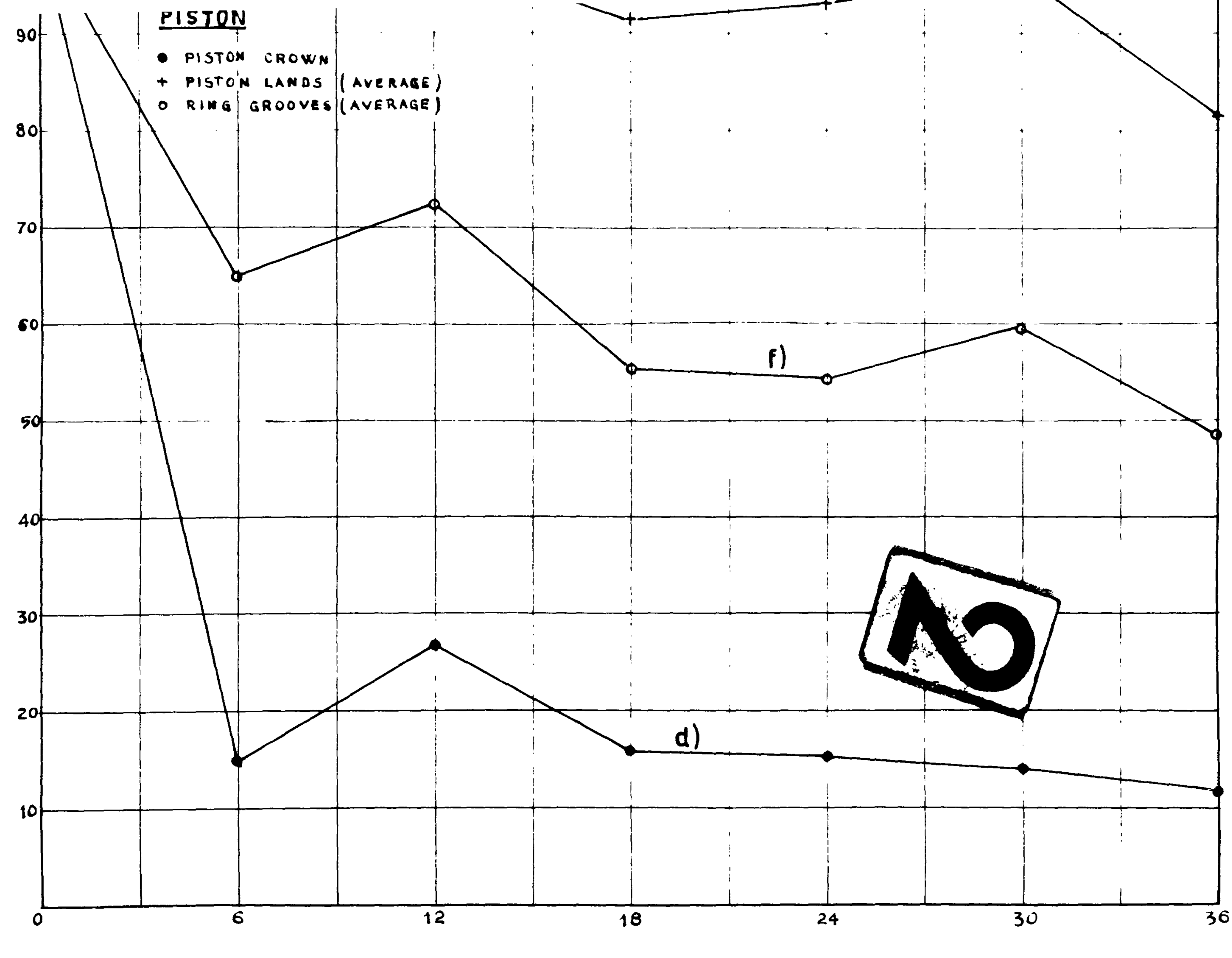
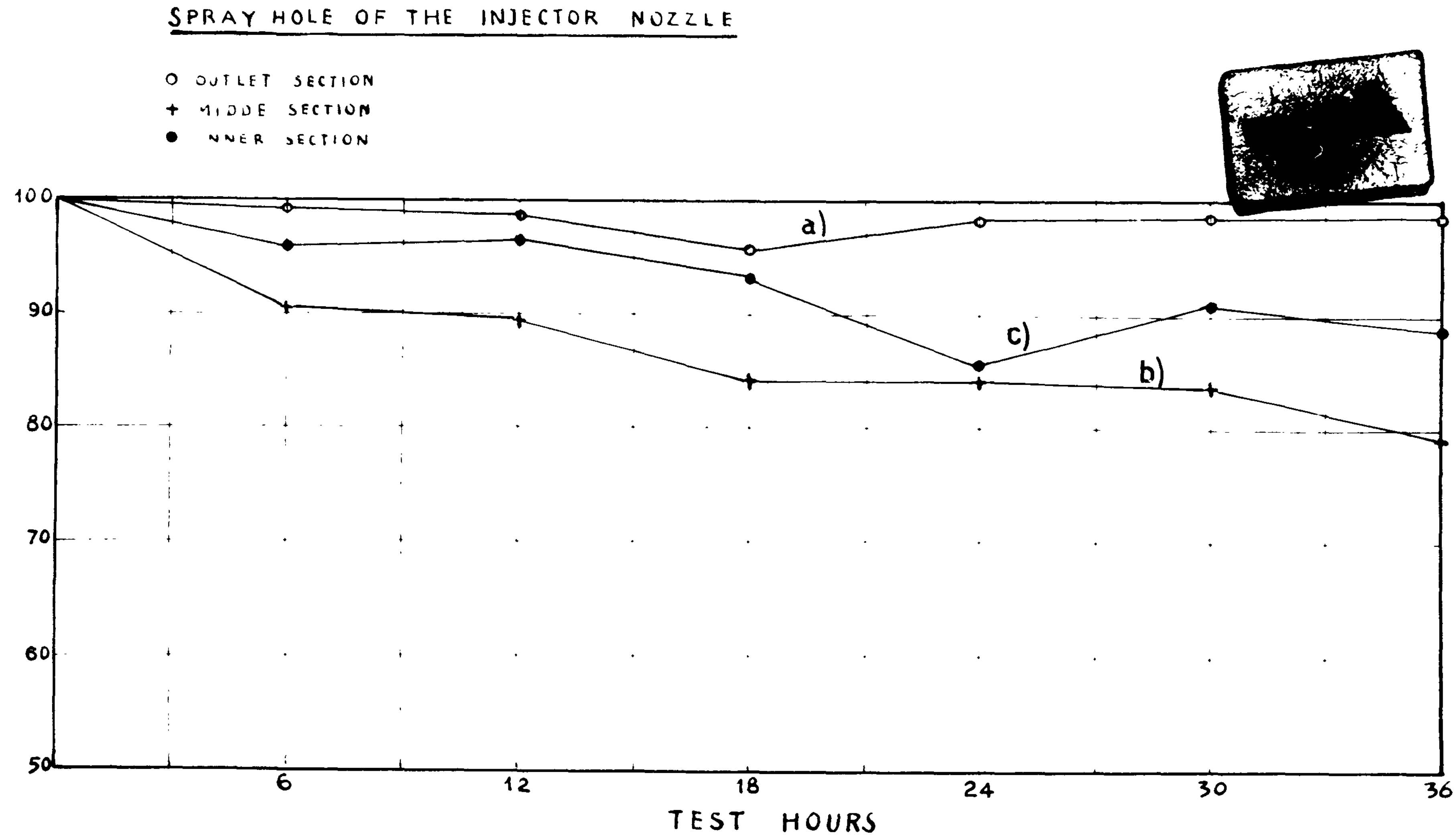
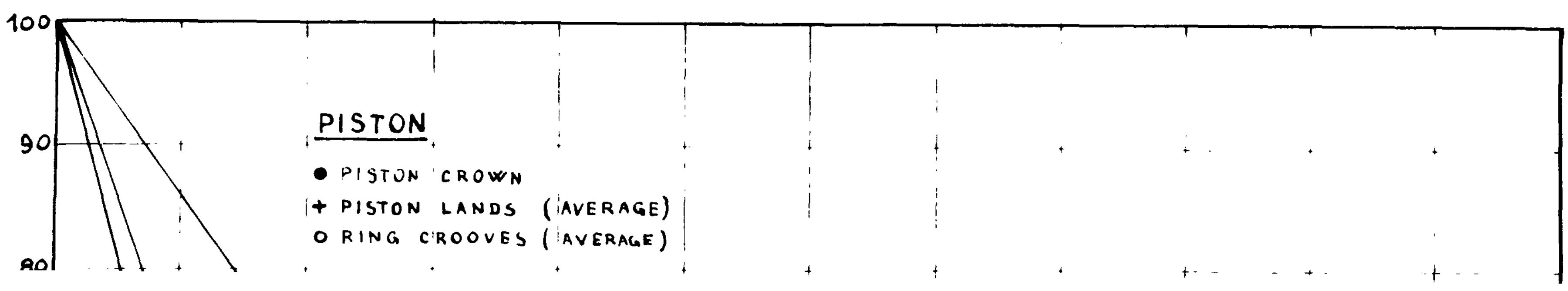

PISTON
● PISTON CROWN
+ PISTON LANDS (AVERAGE)
o RING GROOVES (AVERAGE)
90
80
70
60
50
40
30
20
10
0
6
12
18
24
30
36
f)
d)
TEST HOURS
2

FIG. 22

# TEST N°1K – MERIT RATINGS



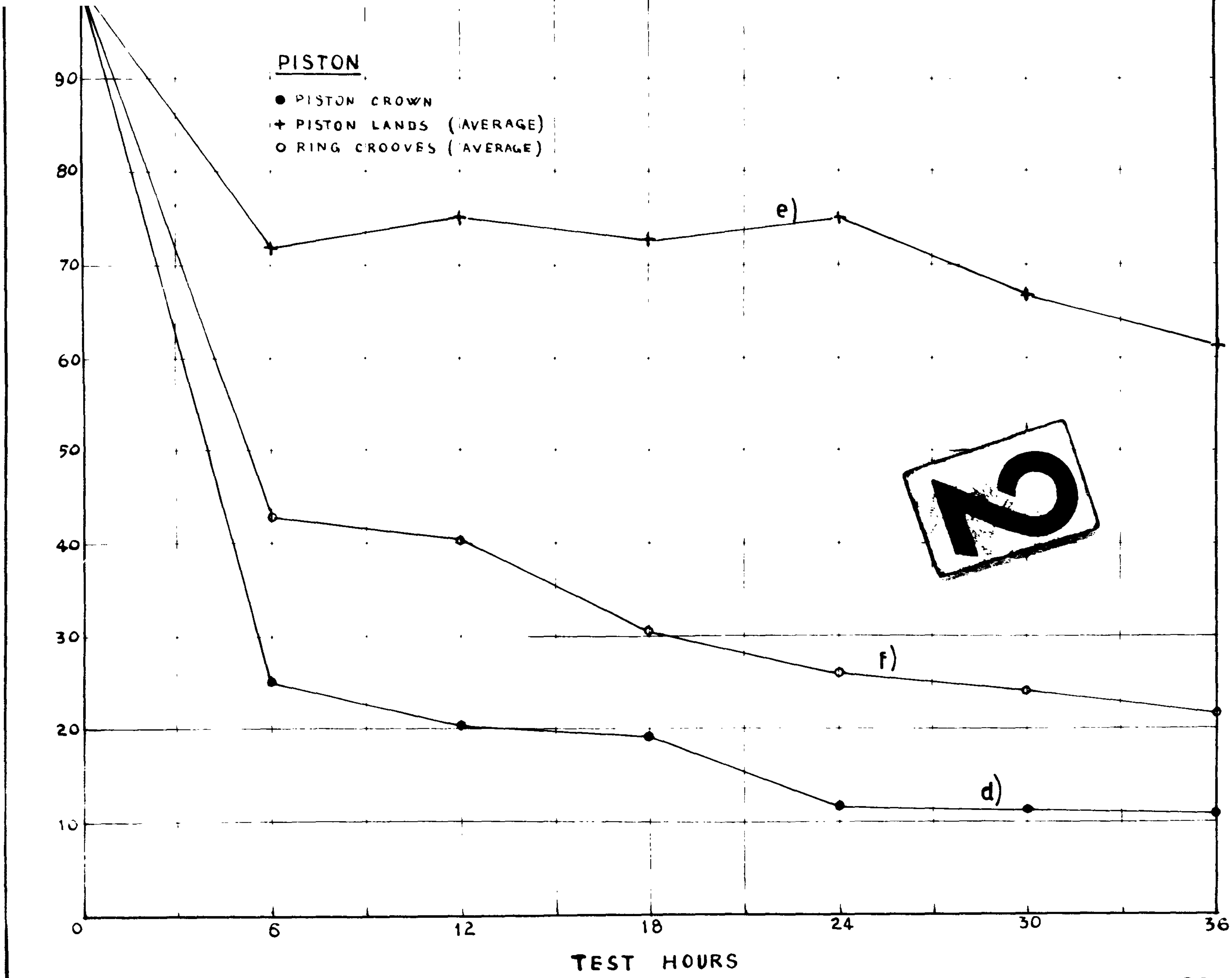
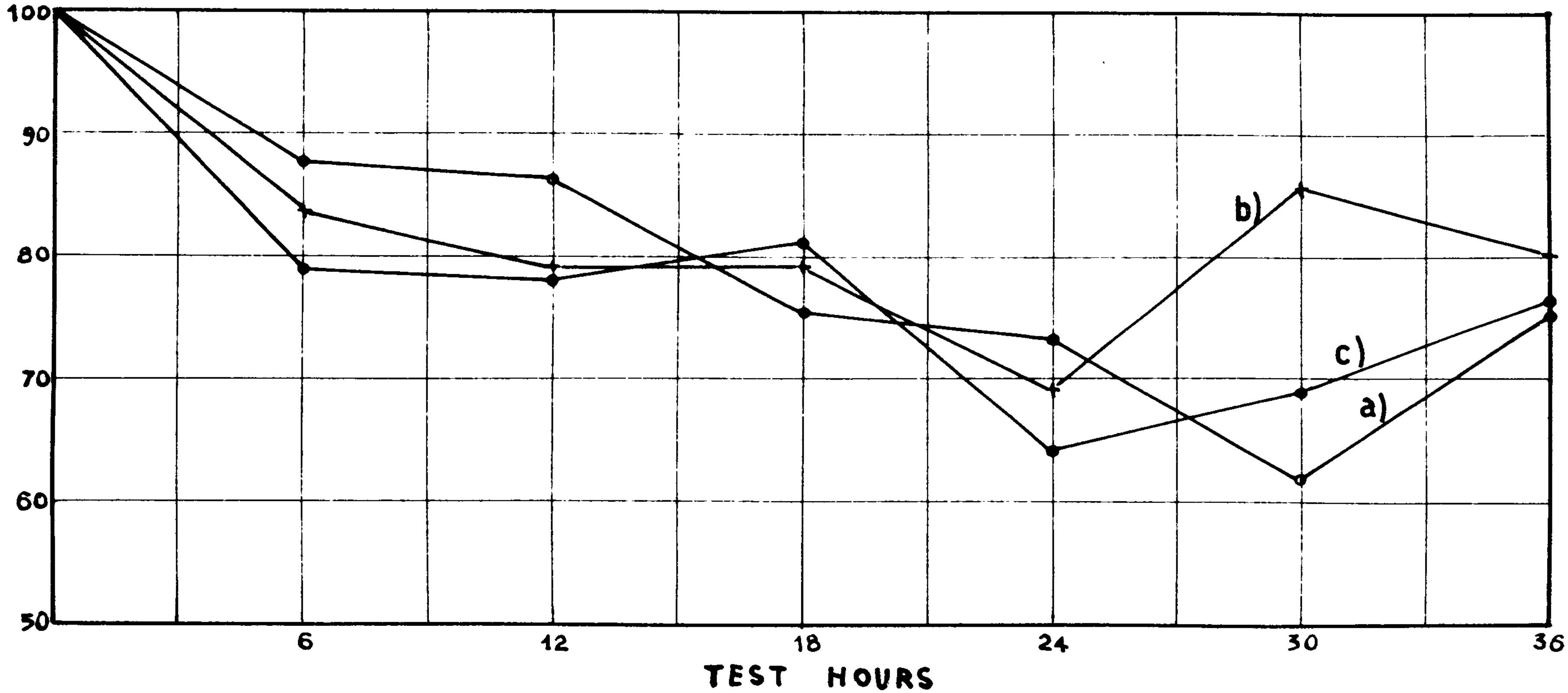

PISTON
● PISTON CROWN
+ PISTON LANDS (AVERAGE)
O RING CROOVES (AVERAGE)
e)
f)
d)
90
80
70
60
50
40
30
20
10
0
6
12
18
24
30
36
TEST HOURS

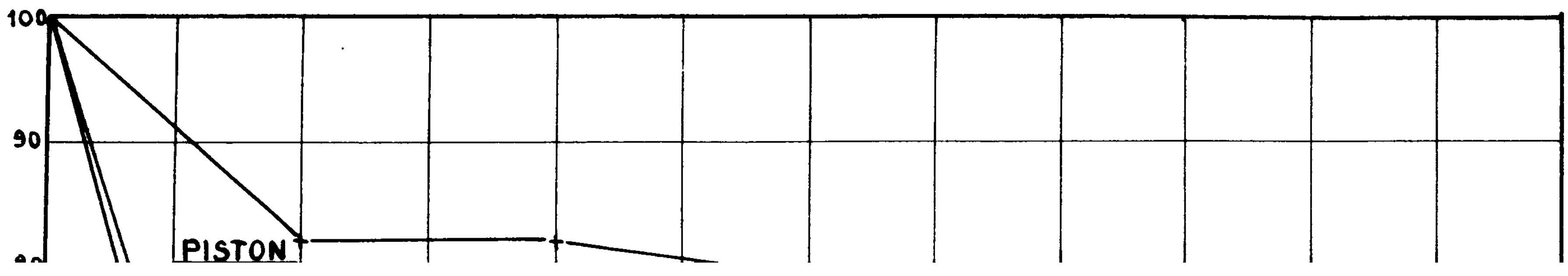
FIG. 23

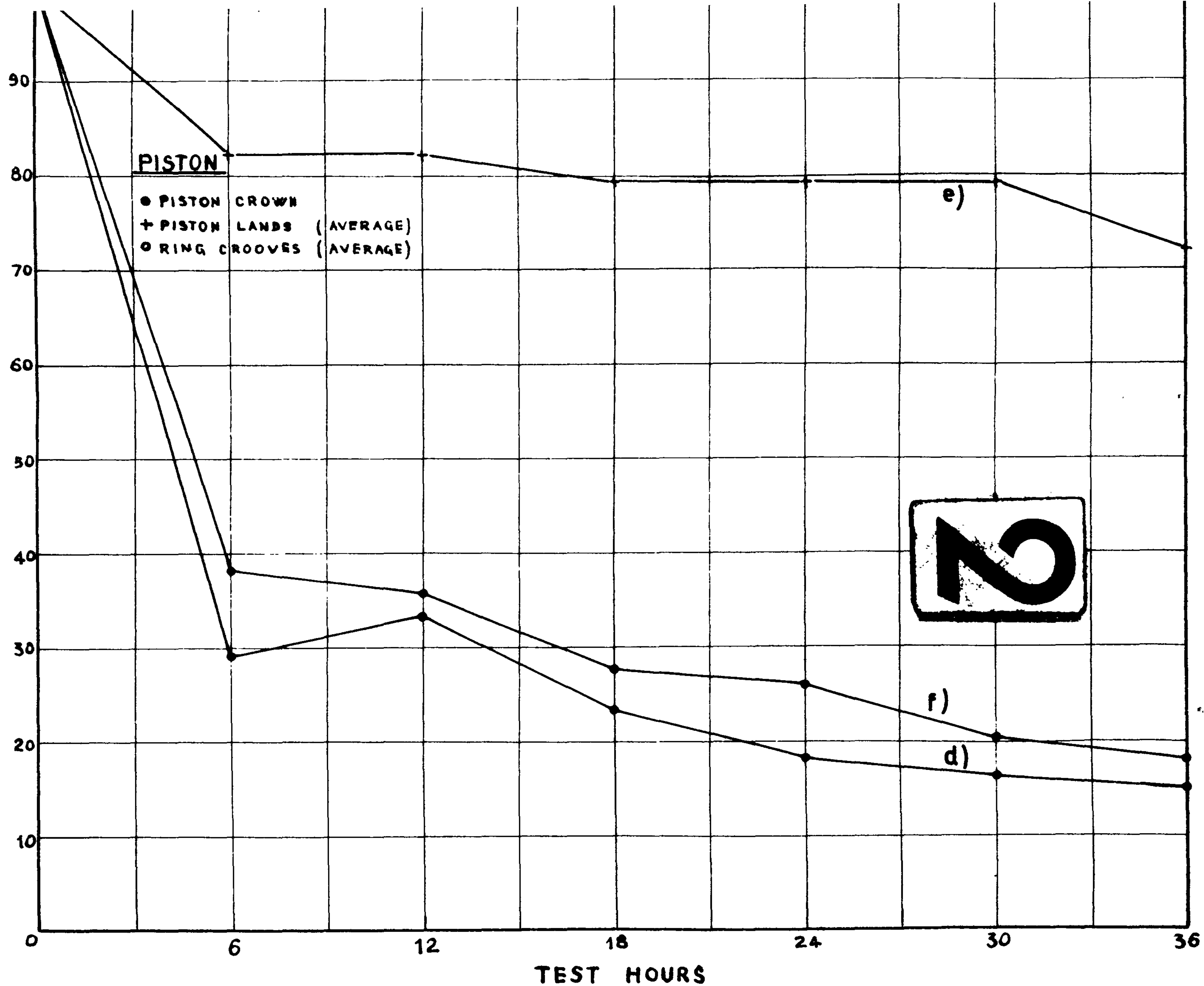
# TEST N°3A — MERIT RATINGS

SPRAY HOLE OF THE INJECTOR NOZZLE

o OUTLET SECTION
+ MIDDE SECTION
● INNER SECTION



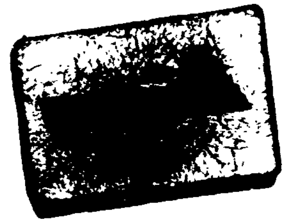



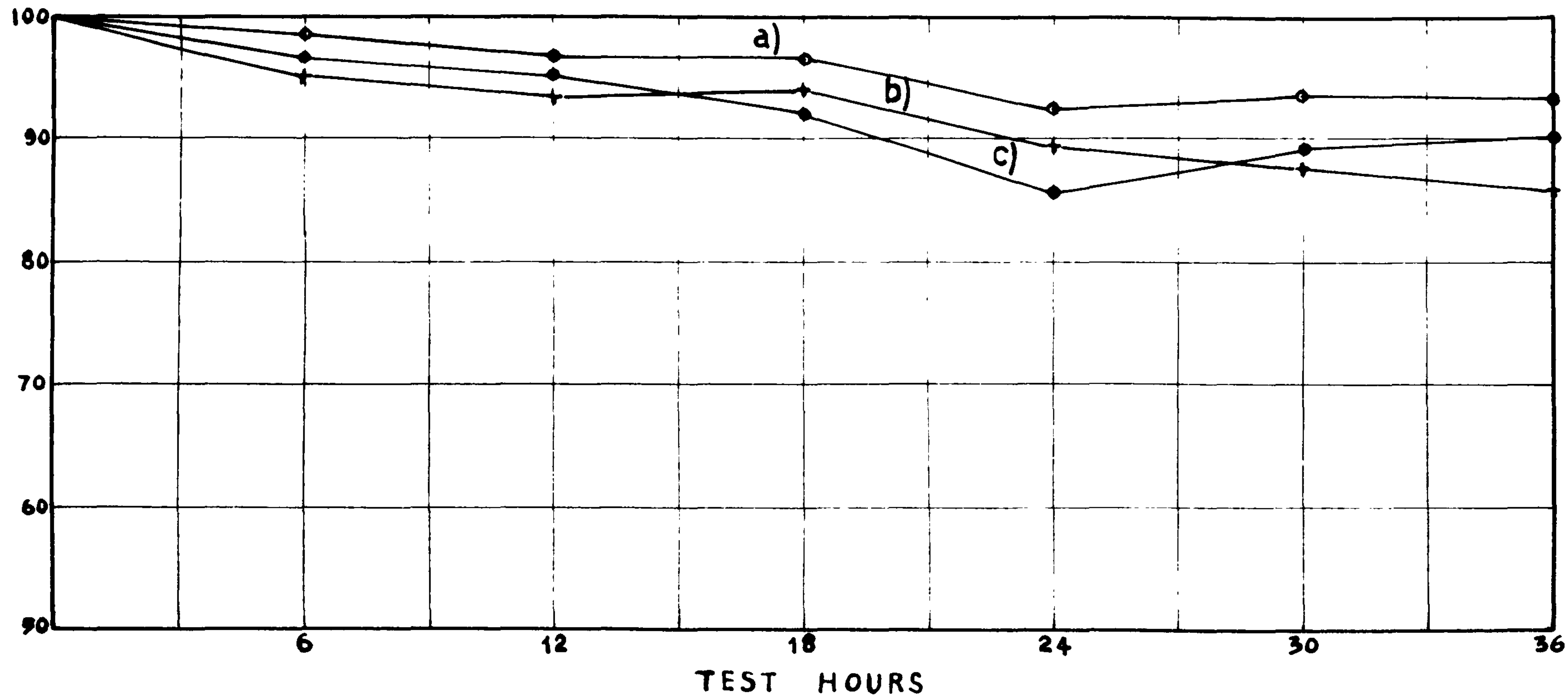


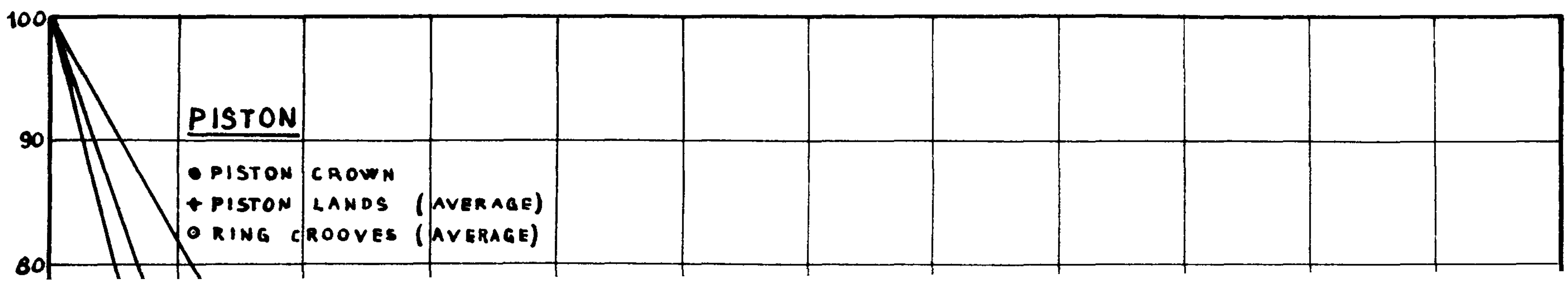
PISTON
● PISTON CROWN
+ PISTON LANDS (AVERAGE)
○ RING GROOVES (AVERAGE)
e)
f)
d)
2
90
80
70
60
50
40
30
20
10
0
6
12
18
24
30
36
TEST HOURS


FIG. 24

# TEST N°3K – MERIT RATINGS





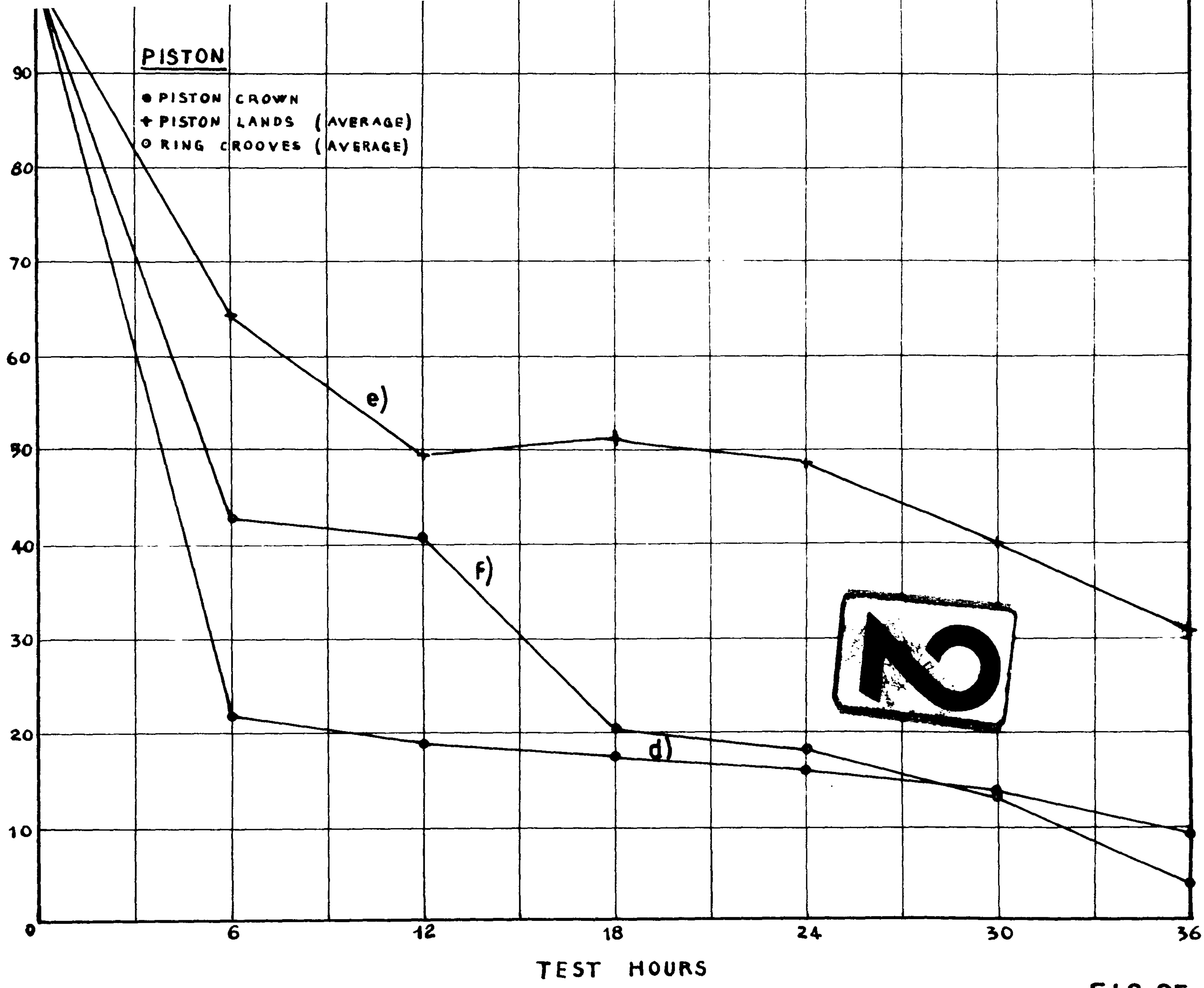
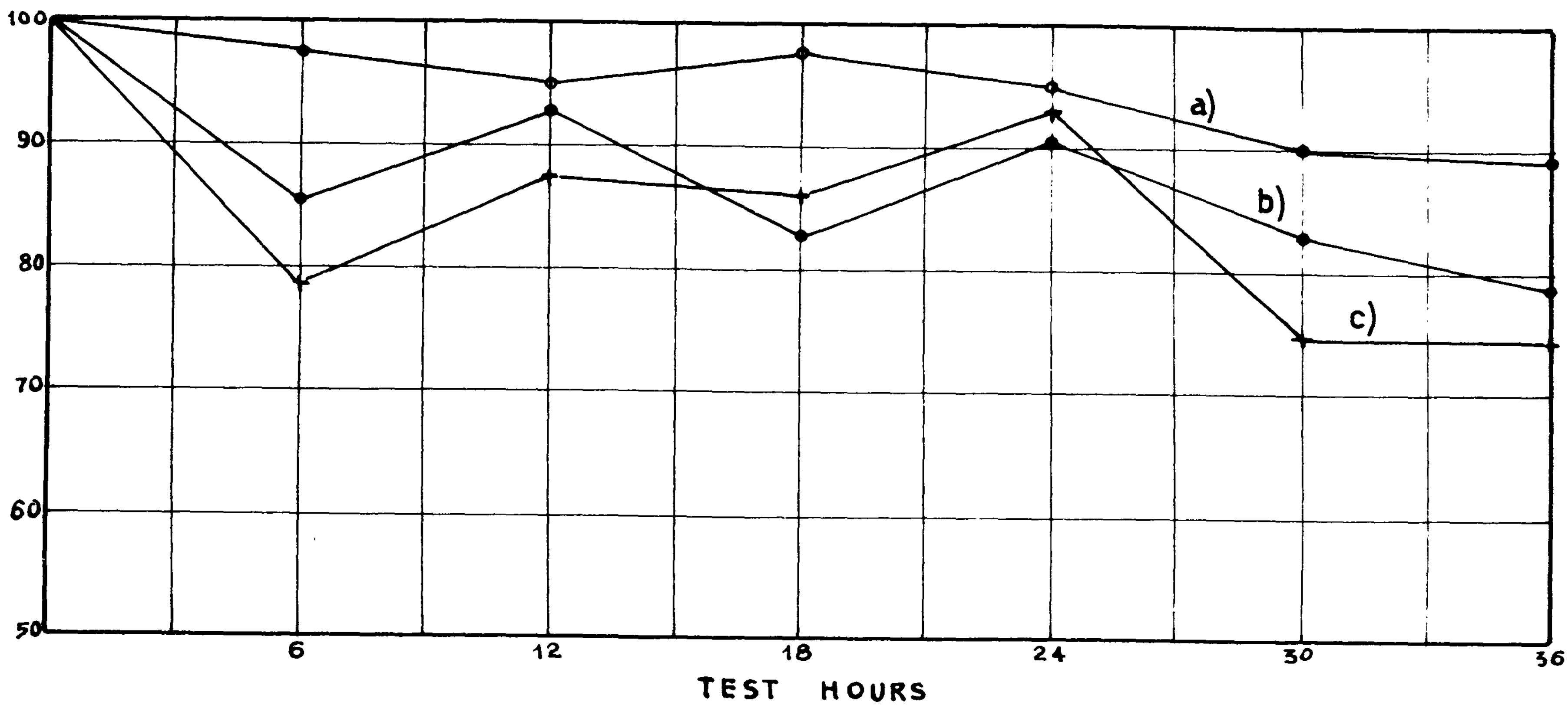

PISTON
● PISTON CROWN
✚ PISTON LANDS (AVERAGE)
○ RING CROOVES (AVERAGE)
90
80
70
60
50
40
30
20
10
0
6
12
18
24
30
36
TEST HOURS
e)
f)
d)

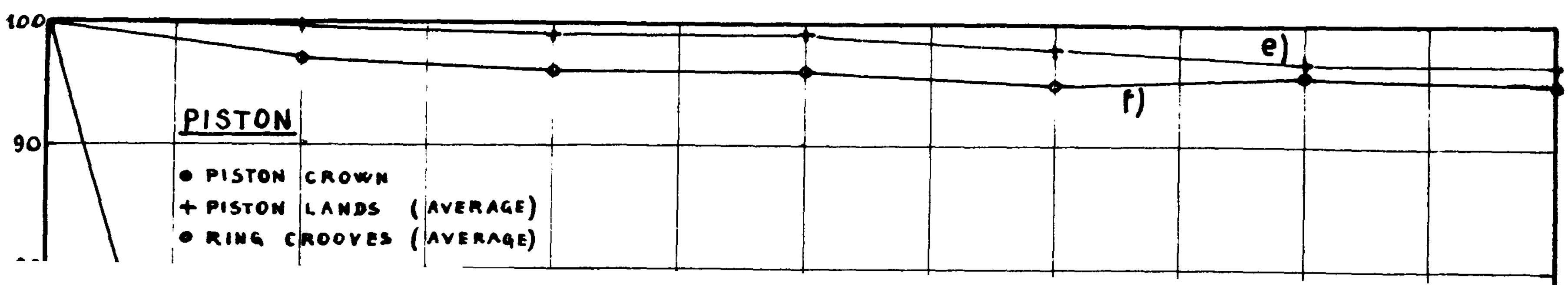
FIG. 25

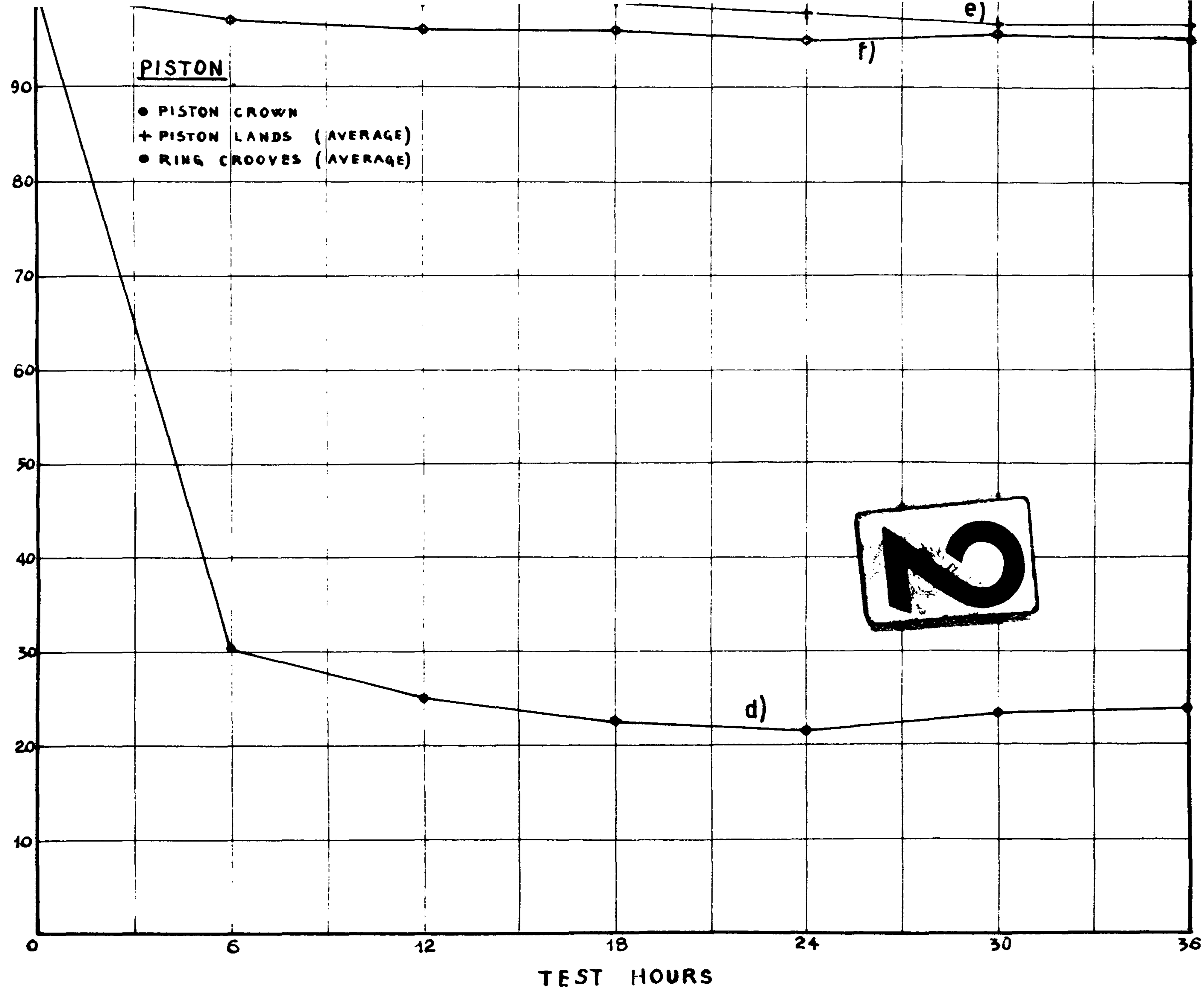
# TEST N° 4A — MERIT RATINGS

SPRAY HOLE OF THE INJECTOR NOZZLE

o OUTLET SECTION
+ MIDDE SECTION
• INNER SECTION



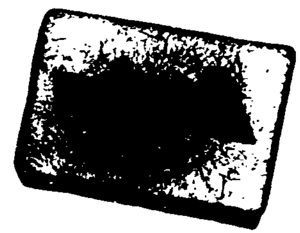





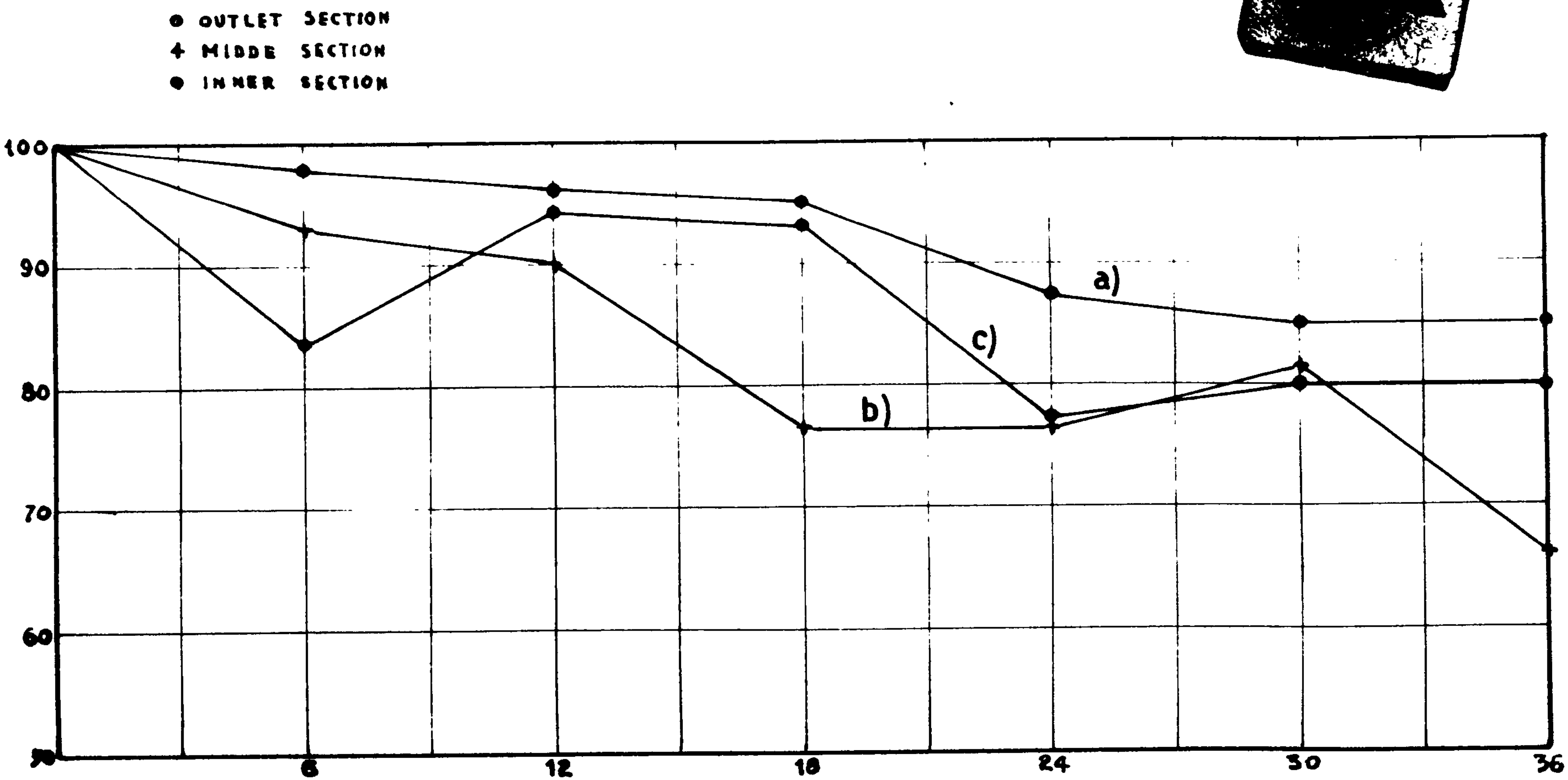
PISTON
● PISTON CROWN
+ PISTON LANDS (AVERAGE)
● RING GROOVES (AVERAGE)
e)
f)
d)
90
80
70
60
50
40
30
20
10
0
6
12
18
24
30
36
TEST HOURS
2


FIG. 26

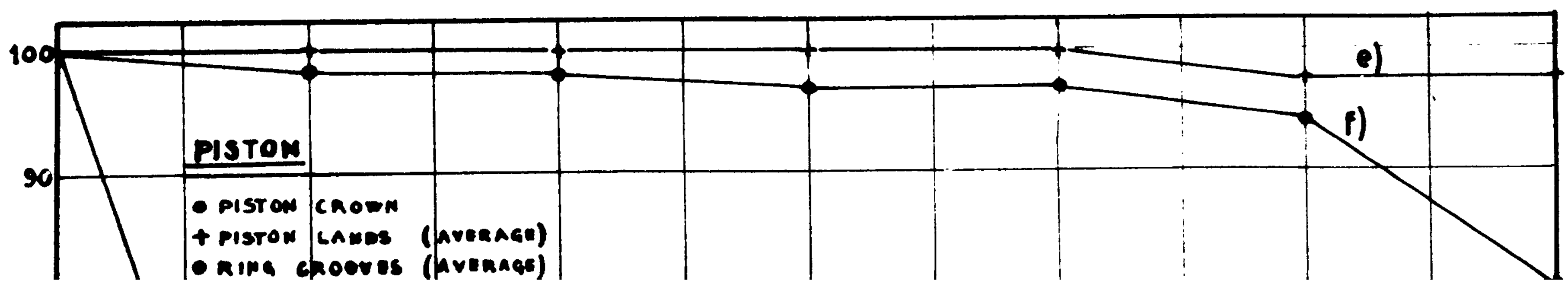
# TEST N° 4K — MERIT RATINGS



SPRAY HOLE OF THE INJECTOR NOZZLE




TEST HOURS



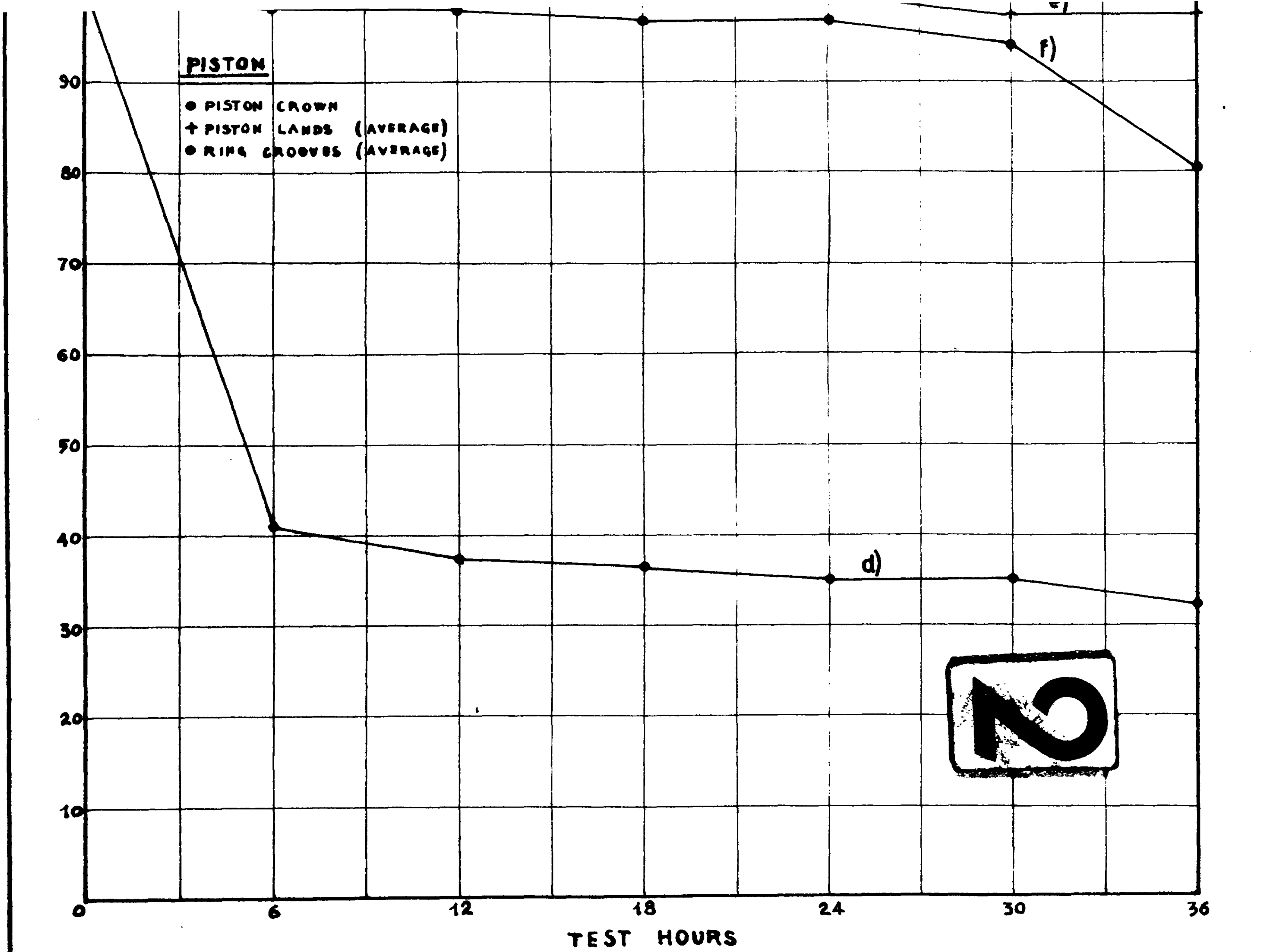
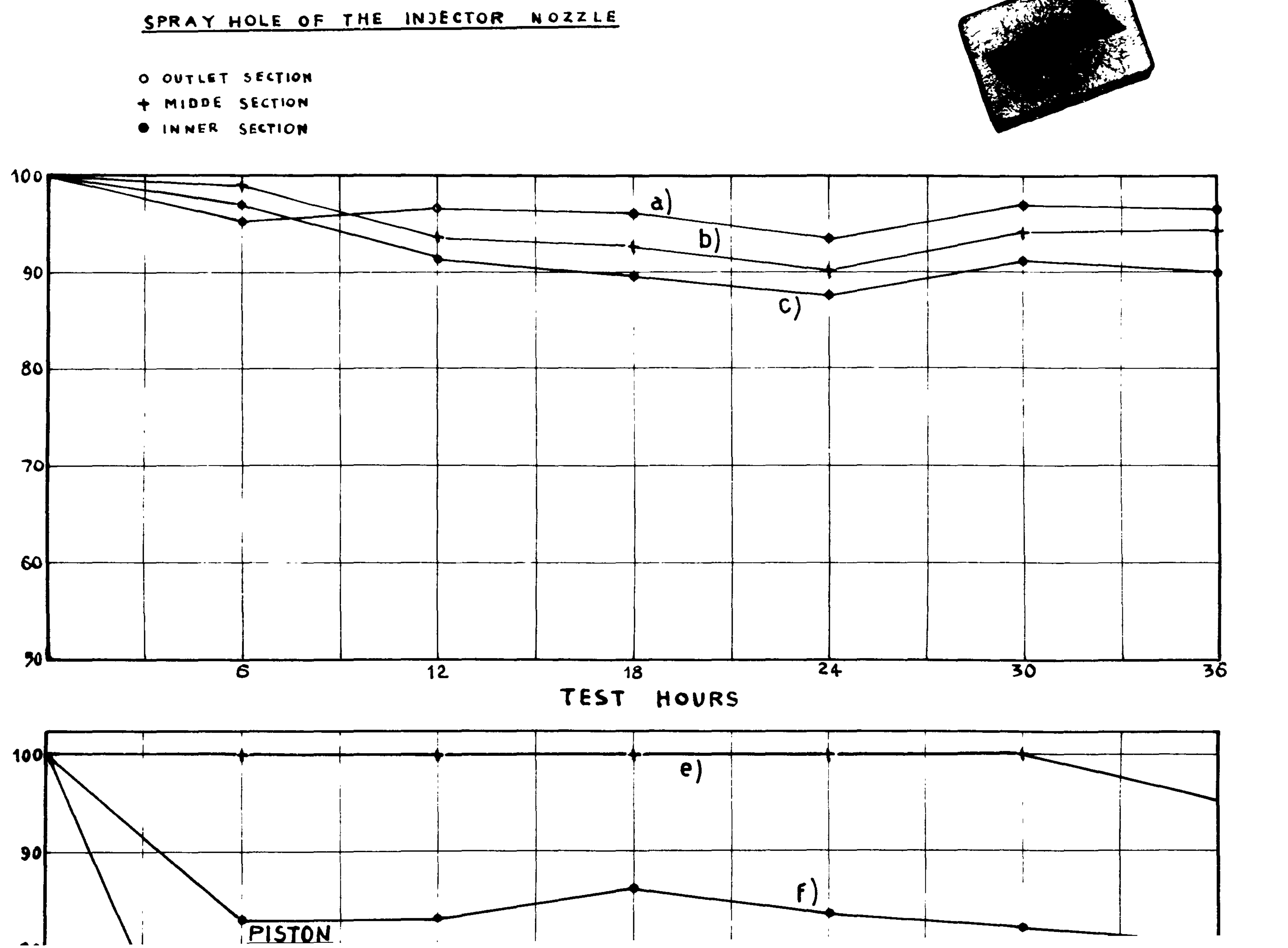
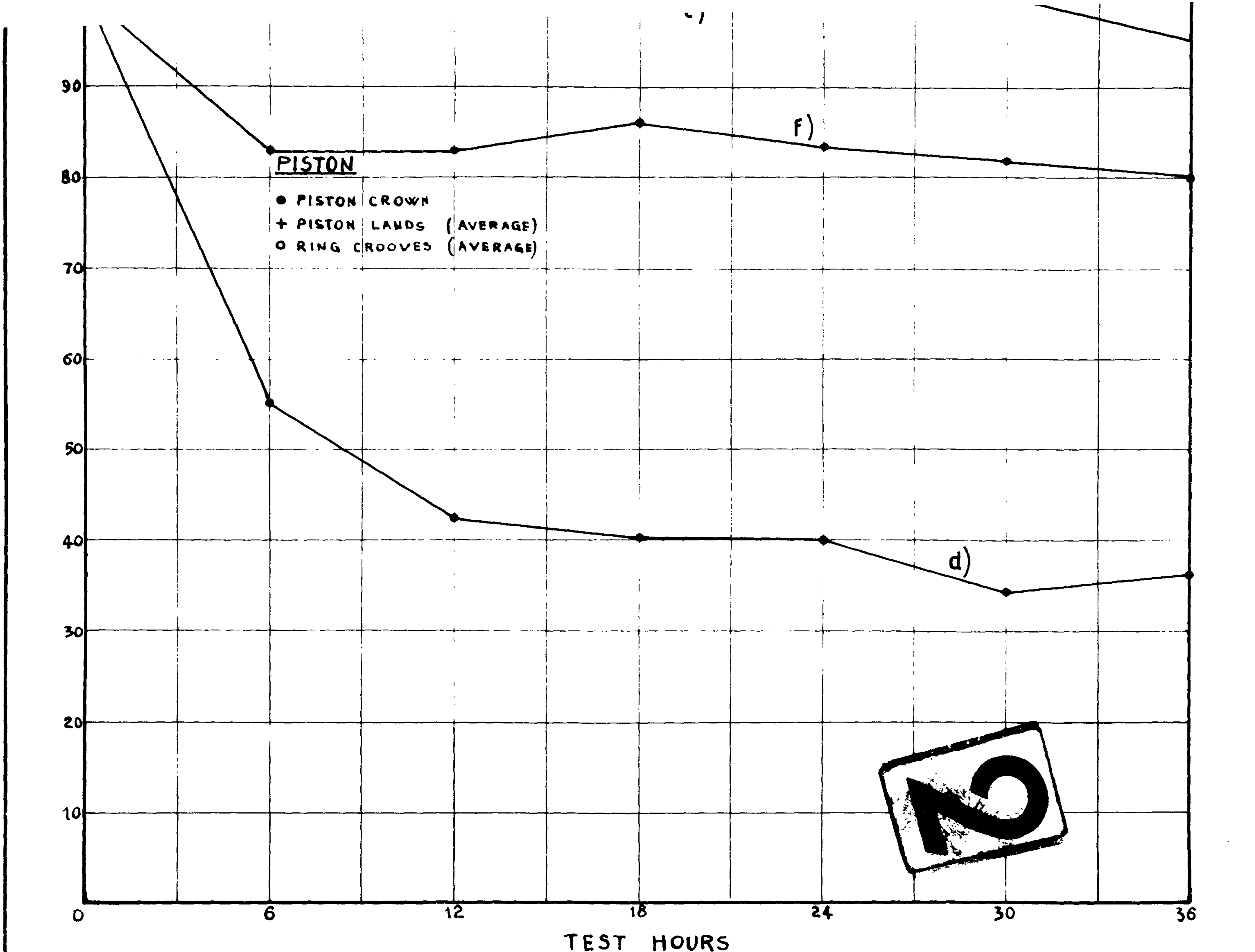

PISTON
● PISTON CROWN
+ PISTON LANDS (AVERAGE)
● RING GROOVES (AVERAGE)
f)
d)
90
80
70
60
50
40
30
20
10
0
6
12
18
24
30
36
TEST HOURS
2

FIG. 27

# TEST N° 6A — MERIT RATINGS

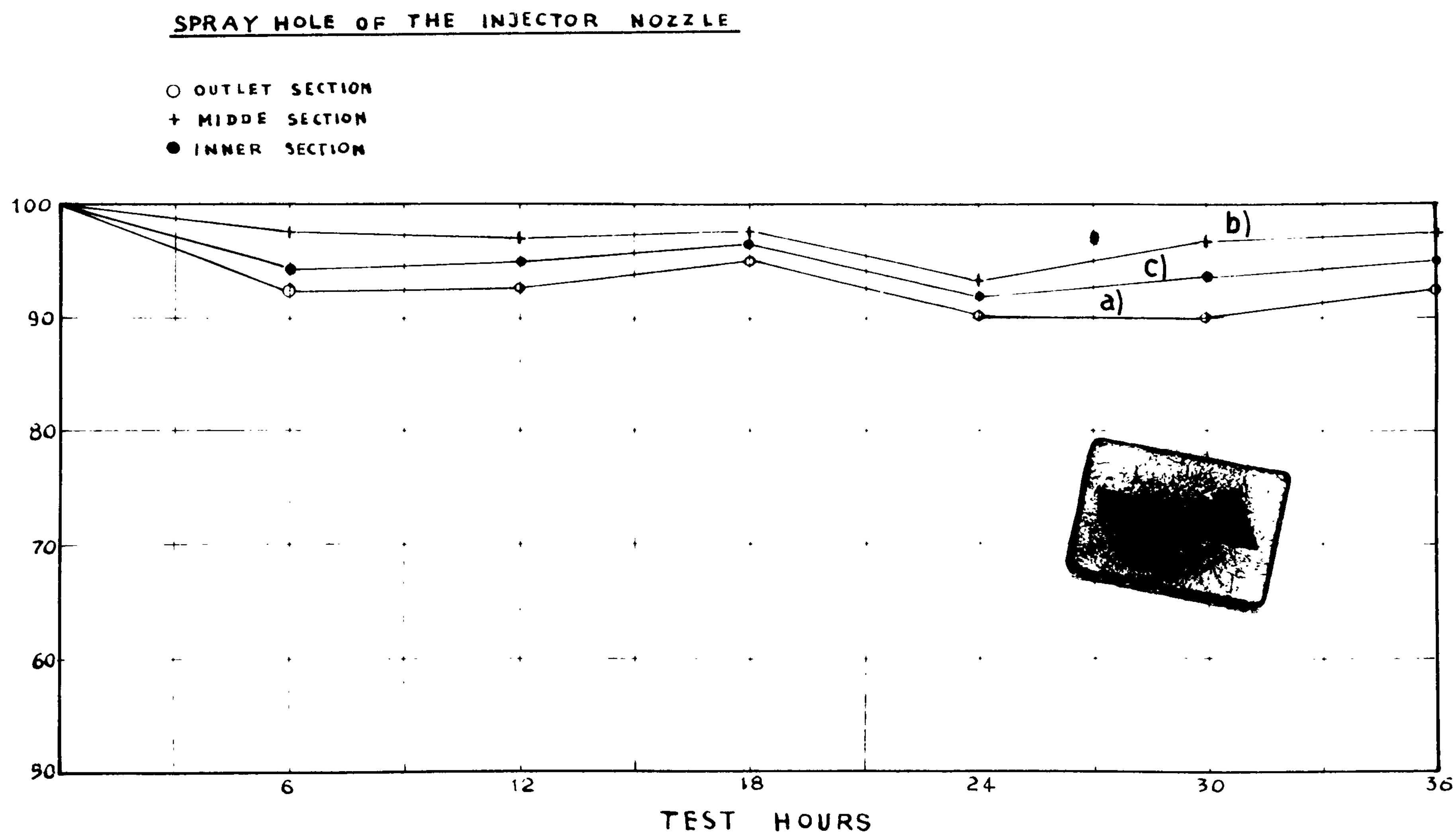


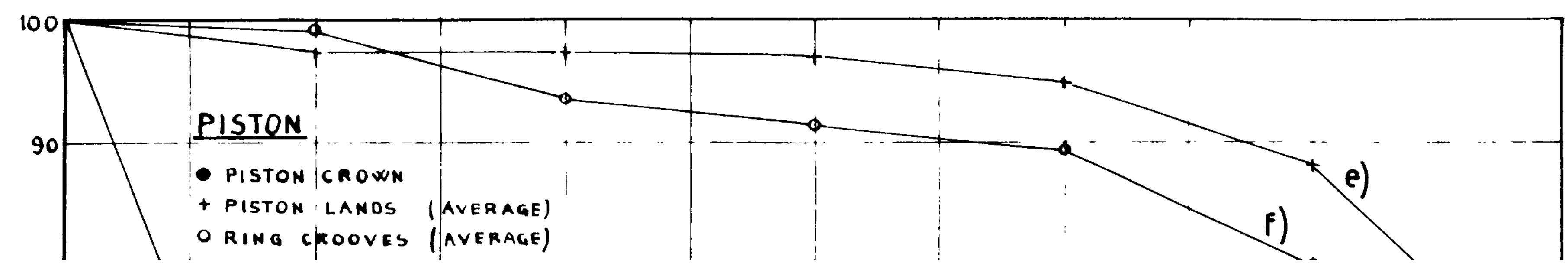


PISTON
● PISTON CROWN
+ PISTON LANDS (AVERAGE)
O RING CROOVES (AVERAGE)
f)
d)
90
80
70
60
50
40
30
20
10
0
6
12
18
24
30
36
TEST HOURS


FIG. 28

# TEST Nº6K — MERIT RATINGS



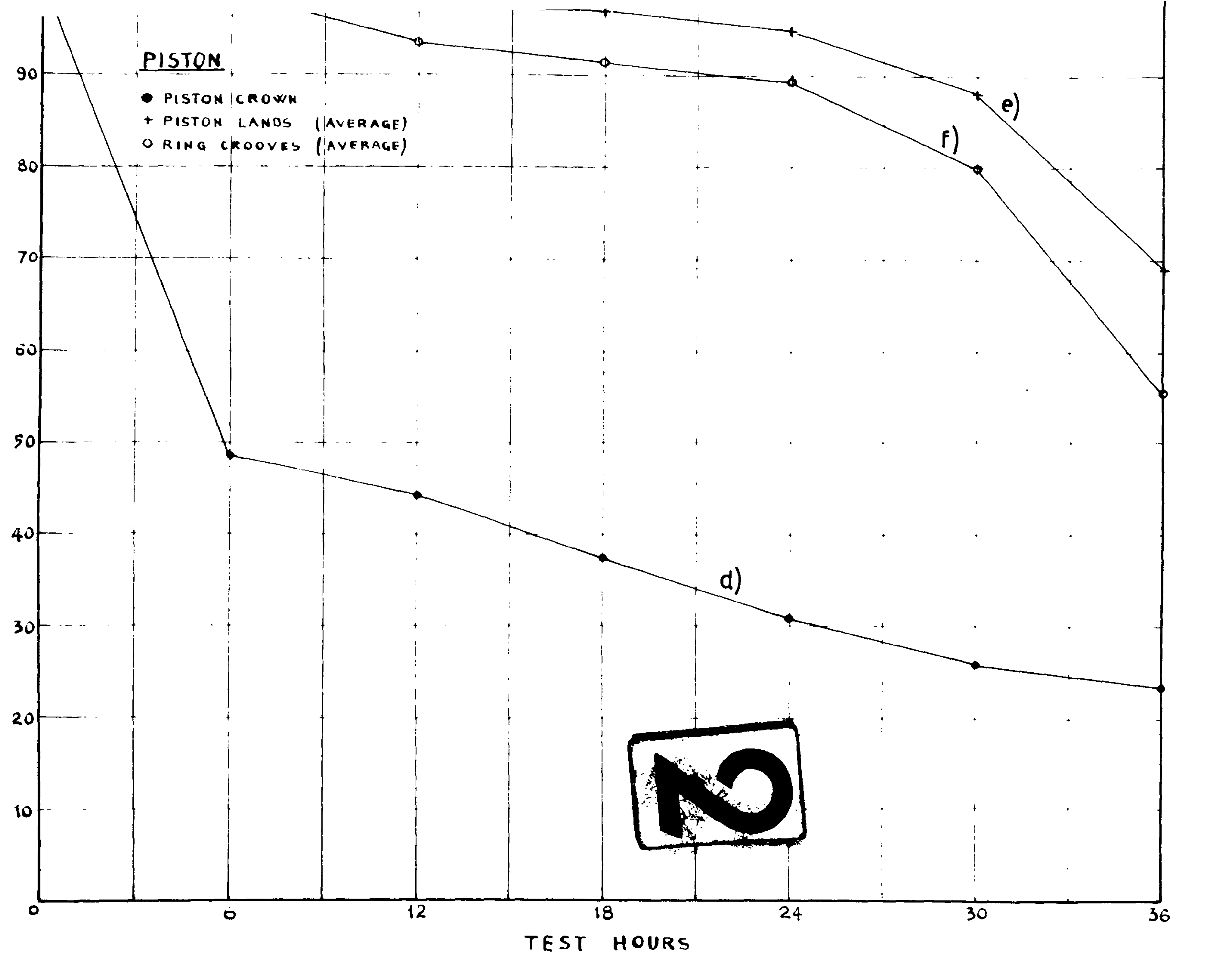

PISTON
● PISTON CROWN
+ PISTON LANDS (AVERAGE)
O RING GROOVES (AVERAGE)
e)
f)
d)
90
80
70
60
50
40
30
20
10
0
6
12
18
24
30
36
TEST HOURS
2

FIG. 29

nozzle at the beginning of the test.

$S_{u,i}$ = the same, after "i" test hours.

b) The values of the ratio:

$$100 \frac{S_{m,i}}{S_{m,o}}$$

where:

$S_{m,o}$ = middle section of the spray hole of the injector nozzle at the beginning of the test.

$S_{m,i}$ = the same, after "i" test hours.

c) The values of the ratio:

$$100 \frac{S_{in,i}}{S_{in,o}}$$

where:

$S_{in,o}$ = inner section of the spray hole of the injector nozzle at the beginning of the test.

$S_{in,i}$ = the same, after "i" test hours.

d) The merit ratings of the piston crown, evaluated at the end of each six hours period, following the described procedure.

e) The average of the merit ratings of the piston lands.

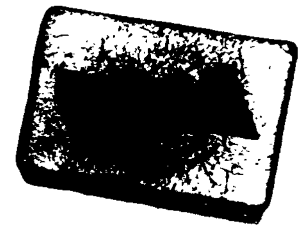
f) The average of the merit ratings of the ring grooves.

To summarize the evaluations on the severity of the test conditions, in fig. 30 are reported for each test, versus test hours, the arithmetical means of the values corresponding to the injector hole and to the piston.

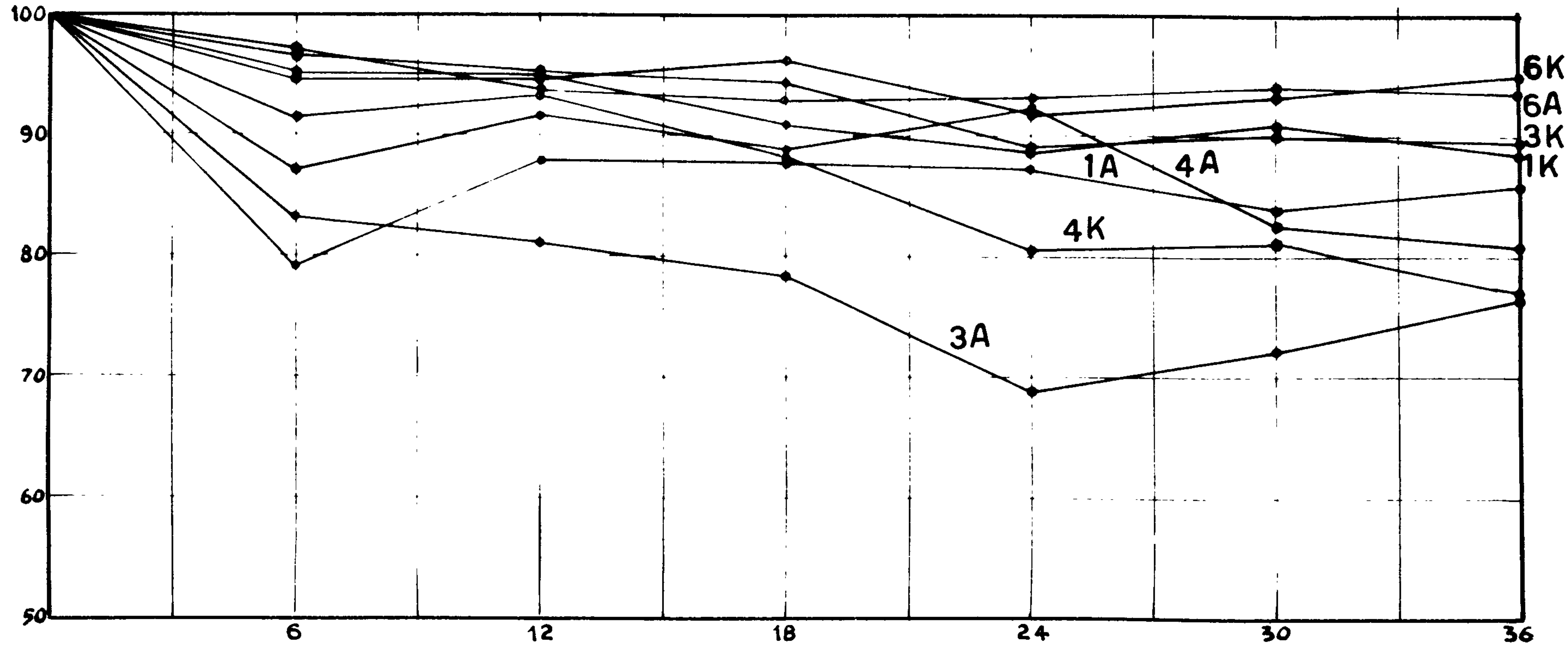
From fig. 30 it results that:

1) The deposits formation on the piston surface grows rapidly during the first test period, while its growth proceeds more gradually during the following test periods.

# ARITHMETICAL MEANS OF MERIT REATINGS

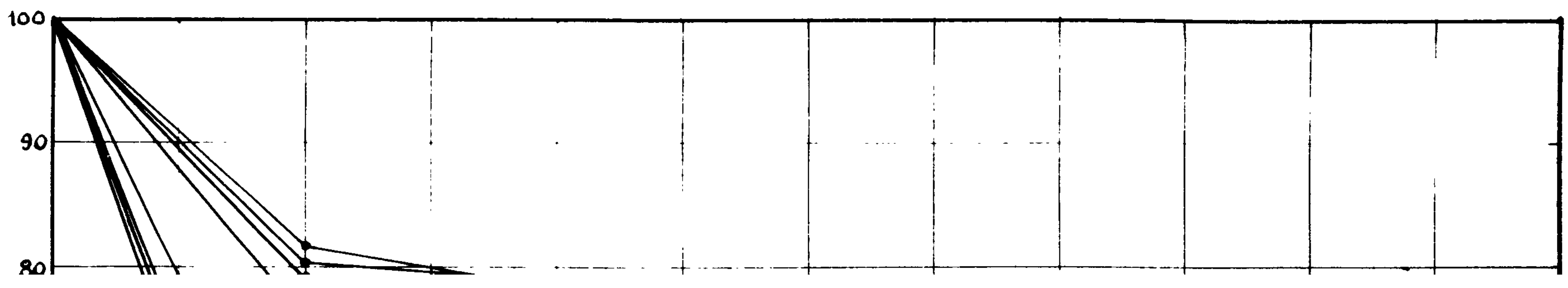


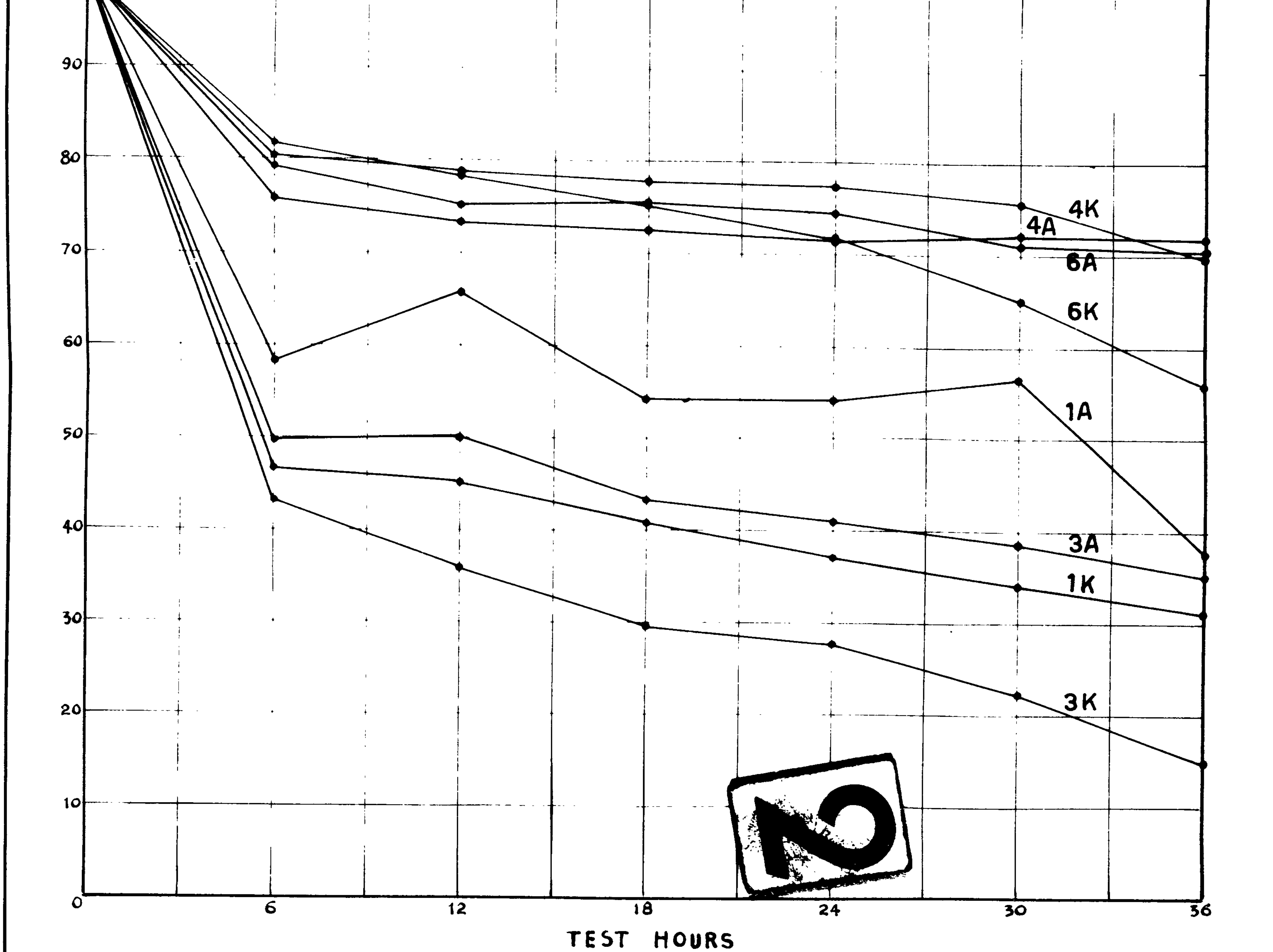
## SPRAY HOLE OF THE INJECTOR NOZZLE




TEST HOURS

## PISTON





90
80
70
60
50
40
30
20
10
0
6
12
18
24
30
36
TEST HOURS
4K
4A
6A
6K
1A
3A
1K
3K


FIG. 30

2) In all the eight performed tests the pattern of the formation of the deposits on the piston is continuous and tends asympto tically, more or less rapidly, following the severity of the test conditions, to the total coating of the analyzed surfaces.
3) As far as concerns the deposits on the spray hole of the injector nozzle, such deposits cause remarkable decrease of the three examinated sections only after the first test period. Du ring the remaining test periods the decrease of the sections of the spray hole has no continuous pattern, so as the said section may increase or decrease during the test, assuming va- lues having no relation with the amount of the deposits on the piston.
4) The most severe test conditions, as far as is concerned the de posits formation on the piston, are those followed in the test 3 K, which lead, after 36 test hours, to an avarage merit of 15%, which corresponds to 85% of the examined piston surface coated by deposits.
5) On the contrary the above said test conditions do not lead to remarkable reductions of the section of the injector nozzle spray hole.
It is interesting to note that in the above said test condi- tions the flow rate of the injection pump is the highest, which we experimented, and that the flow of the gasoil through the spray hole has for itself a cleansing action.
6) For equal flow rate of the injection pump (test couples N°1 and 3 or N° 4 and 6, s. table I) the most severe test condi - tions, as far as deposits formation on the piston surface is concerned, are those corresponding at highest r.p.m. This result

follows logically from the consideration that for equal test duration the number of the engine cycles is proportional to r.p.m. and that the amount of the formed deposits must be proportional to the number of the engine cycles, if all the other test conditions are unaltered.

7) The same consideration is not valid as far as deposits on the injector nozzle spray hole are concerned, for the above mentioned (s. item 5) cleansing action of the gasoil flowing through the injector nozzle. On this point it is to be noted that the reductions of the sections of the injector nozzle spray hole in the tests 4K and 4A (lowest gasoil flow rates and r.p.m.) are between the most remarkable encountered.

8) As far as the influence of the cooling liquid is concerned, it has been noted that at the end of the 36 test hours, in all the tests, higher percentages of the piston surface coated with deposits have been experienced, when, for the same other test conditions, kerosene has been used as cooling liquid. The relatively high temperatures of the surfaces have promoted the deposits formation.

From all the preceding considerations we may deduce the following conclusions:

a) Of the two engine parts examinated during the tests - piston and injector nozzle - the former has been experienced to be a sure ground for evaluation of test conditions severity, while on the contrary the latter, the injector nozzle, owing to the discontinuous pattern of the growth of the deposits during the tests, caused by the cleansing action of the gasoil, gives no definite ground for judgement.

b) The test conditions severity increases with the increase of the gasoil flow rate, of r.p.m. and of the temperatures of the engine.

## - TEST CONDITIONS FOR DETERGENT ADDITIVES FOR GASOILS -

On the basis of the tests performed, it seems logical to assume as test conditions to evaluate the detergent action of gasoil additives the ones followed in the test 3K, which are corresponding to the highest flow rate of the injection pump, to the highest r.p.m. and to the highest temperatures of the cylinder walls.

We report in what follows a synthesis of the operations for the engine preparation, of the test conditions and of the analysis of test results.

<u>Engine preparation</u>

1°) Cleaning with kerosene of the parts of the engine and of the lubricating oil circuit.

2°) Control of the following parts of the engine:

a) <u>Liner</u>: clearance between liner and piston, measured across two diameters at right angles, in three positions axially, less than 0,08 mm; ovality less than 0,04 mm.

b) <u>Cylinder head</u>: decarbonise; grind the valves in the seating; valve pocketing less than 1,25 mm.

c) <u>Cylinder</u>: control the clearance between the piston and the cylinder head at T.D.C. (Bumping clearance). This clearance must be 0.9 to 1.0 mm, otherwise replace the shims between the cylinder block and the crankcase.

d) Crankshaft: after each twenty tests group control the ovality of the main journals and of the crankpin; maximum ovality must not exceed 0,08 mm; if exceeding re-ground. Control the main journals coaxiality: fault of the coaxiality must be less than 0.03 mm.

e) Main bearings: examine at each 10 tests group and replace if scraped or bedded in, or if crankshaft has been re-grounded.

f) Connecting rod: replace the small end bush, if clearance between bush and pin exceeds 0.02 mm. Replace at each 5 tests the big end bearing shells. Control connecting rod aligmment.

g) Injector: replace the injector and control the release pressure (165 + 185 kg/sq.cm) and the time necessary for the pressure to decrease from the release pressure to a pressure of 70 kg/sq.cm: this time must not be less than 15".

h) Fuel pump: control injection timing (24° B.T.D.C.)

i) Timing system: control the timing system and the valves clearances (0.18 mm).

3) Piston replacement: replace after the following controls:

α) Axial height of the grooves measured with feelers.

β) Rings height.

γ) Ring side clearance, and ring lapping to obtain a clearance of 0.05 mm for the compression rings and of 0.075 mm for the scraper ring.

δ) Set the top compression and scraper ring gaps to 0.35 - 0.40 mm in a jig, eventually by lapping on the periphery.

4) Charge of lubricating oil: 3,5 litres to fill the crankcase and the lubricating oil circuit.
5) Charge of cooling liquid: kerosene.
6) Control of the flow rate of the injection pump: set the position of the pump rack so as the delivery time for 100 $cm^3$ of gasoil at 1500 r.p.m. is 160 ± 2 sec.
7) Control of the flow rate of cooling liquid: set the flow rate of kerosene at 1100 l/h.

At the end of the engine preparation the test may be initiated and the complete test duration of 36 hours may be obtained either continuosly or by 9 hours periods.

The test conditions will be the following:

R.p.m. ...................... 1500 ± 50

Consumption time for
100 $cm^3$ of gasoil .......... 160 ± 2 sec

Cooling liquid flow rate ........ 1100 ± 50 l/h

Cooling liquid temperature: inlet = 78°C
outlet = 85°C

Crankcase oil temperature ............ 55°C

Oil pressure ........................ 0,5 kg/sq.cm

At the test end the piston and the injector nozzle will be dismounted to analyze the results.

CONCLUSIONS

From the considerations exposed in the precedent paragraphs may be concluded:

a) In an engine test of relatively short duration (36 hours) it is possible, if the charge and cooling conditions are particularly severe, to obtain deposit formation, specially on the piston, of such amount that the detergent action of an additive may be well emphasized.

b) The test is comparative, as to establish the efficacy of a detergent additive it is necessary to run two tests, the former on gasoil without additive, the latter on the same gasoil with additive.

The comparison of the results of both tests will give the elements to evaluate the detergent efficacy of the examined compound.

c) Of the two engine parts examinated - piston and injector nozzle - only the former has been experienced to give sure grounds of evaluation as far as deposit formation is concerned. This is true although test condition have been experiensed in which the injector nozzle works imperfectely.

d) The amount of the deposits formed at the end of engine tests is stricty dependent, for the same test conditions, from the amount of the gasoil injected during each cycle.

e) The high temperatures of the cylinder walls promote deposit formation, for the same other test conditions.

All the performed tests have been run using only one type of gasoil, and therefore from the obtained results no conclusion may be derived about the influence of the gasoil characteristics on the phenomenon of the deposit formation. As, on the other side may be supposed an influence of the gasoil parameters (sulphur content, specific, gravity, Cetane Number) on the phenomenon, an amplification of the research has been proposed and approved and it is now being carried out with the aim to investigate the influence of the above said parameter.

Naples, 30 June 1962

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Il Direttore

STATEMENT OF THE AMOUNT OF THE EXPENSES SUSTAINED IN THE PERIOD
1st APRIL - 30 JUNE 1962

| | | |
|---|---|---|
| 1) N°5 revisions of the Petter AV1 engine (5 x 37.200) | £ | 186.000 |
| 2) Fuel and lubricating oil | " | 25.000 |
| 3) Personnel: | | |
| a) Research Director (3 x 50.000) | " | 150.000 |
| b) 1 half-time engineer (3 x 70.000) | " | 210.000 |
| c) 1 half-time technician (3 x 35.000) | " | 105.000 |
| d) 1 half-time worker (3 x 30.000) | " | 90.000 |
| | £ | 766.000 |

<u>Residual expenses from</u>

| | | |
|---|---|---|
| 1st Report | £ | 150.000 |
| 2nd Report | " | 134.000 |
| 3th Report | " | 123.800 |
| 4th Report | " | 134.000 |
| 5th Report | " | 76.600 |
| | £ | 618.400 |

**Total expenses (766.000 + 618.400) = £ 1.384.400**

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