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ELECTRONICS AND GUIDED WEAPONS DIVISION

A.R.D.E. REPORT (L) 31/57

"Smears"

A Second Report

A. G. Warren

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Fort Halstead, Kent.

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Ministry of Supply

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A.R.D.E. REPORT (L) 31/57

"Smears"

A Second Report

A. G. Warren (L6)

Summary

Experiments carried out subsequent to the issue of the first report (ADE Report 8/53) are outlined. The use of bore surface thermocouples has thrown more light upon the action of a smear. Although a wide range of materials has been tried, nothing has been found which is so effective as silicone oil. Experiments show that smears are many times better than any cartridge case lining tried.

The lines along which future work might be directed are discussed.

Approved for issue:

Ewen M'Ewen, Director

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1. INTRODUCTION

In concluding the first report on smears[1] the writer quoted from the Annual Report of the Gun Erosion Panel for the period ending 31st July 1953. Two sub-paragraphs of that report merit quoting again:-

(1) "The way in which a smear functions is not understood and it is one of the major objectives of the work of the Panel to review the scientific aspects of the behaviour of such films, and to try to break down this problem into scientific investigations which might be suitable for extra-mural researches"

(2) "During experimental investigation it has been shown that smears can be applied by means of a simple addition to the round: the method is therefore no longer of academic interest only, it may be profitable to apply it to service equipments, particularly in cases such as repeat-fire operations, where heating of the barrel presents very serious problems"

Considering the second sub-paragraph first, the practical application of a smear is being actively pursued in Branch S.1, A.R.D.E.

The first sub-paragraph quoted suggested a programme of some magnitude, which the writer felt at the time had little chance of being completed. But it was considered important to pursue the work to the point of obtaining the basic data conducive to the production of an efficient and practical smeared round. To some extent that has been accomplished. Experiments continued, at a diminishing tempo after the first report was published, and the results were reported to, and discussed by, the Gun Erosion Panel until its dissolution. Since then experiments have been very few and, with increasing pressure on a diminishing staff, have now stopped completely.

The purpose of the present report is to discuss the work done subsequently to the issue of the first report, and to review the problem in general terms. With the diminishing interest in guns it may have lost some of its importance, but the technique may have a wider application than that which called for its development. Guns are not unique in presenting a heat transfer problem.

2. EXPERIMENTAL WORK

At a meeting held on January 29th, 1953 to discuss "Flash heating in relation to the molecular structure of barrier films" (MOS Unpublished report) the results of the earlier experiments were reported. It was hoped that fruitful suggestions for suitable smears would be forthcoming. Opinion was divided regarding the properties conducive to effective operation under gun conditions; experiment alone could decide which were the most important properties. Among the materials suggested were visco-elastic substances, metal soaps, and materials of high molecular weight. Appropriate films might be formed in situ. For instance a monomer might be very rapidly polymerised at the operating temperature and pressure. Trials 7 and 8 in the first report were the first stages of the programme thus suggested. A summary of the further trials follows; the results are discussed later.

Trial 8 - June 8th, 1953: Gun - 2 pr Mk. 8

Most of the findings of this trial were given in the first report but the measurements of muzzle velocity were not recorded. Due to the smear the muzzle velocity was increased from 1810 to 1895 ft/sec - an increase of 4.7%. At the same time the mean deviation of the muzzle velocity was reduced by about one third. Probably the principal factor contributing to this was the sealing action of the smear.

Trial 10 - August 12th, 1953: Gun - 17 pr

As pointed out in the previous report, makeshift arrangements had to be made to mount the smear in the 17 pr because of the awkward shape of the cartridge case. Pistons of different shapes and of different materials were tried. Using an aluminium piston with a domed head, a loose silicone smear of 105 c.s., gave a heat reduction near C. of R. of 38%, which fell to 16% at 4 feet forward. With a rubber piston efficiency was about 20% less. Enclosure of the smear in a polythene bag reduced the efficiency by about one third near C. of R. but had little effect further forward.

The smear increased the muzzle velocity from 2910 to 2962 ft/sec, the mean deviation being reduced by about one third.

Trial 11 - November 23rd, 1953: Gun - 2 pr Mk. 8

Part of this trial was concerned with trying to find a piston shape which would be more effective as a smearing agent than the simple form shown in the first report. No significant improvement was effected.

The second part of the trial was devoted to testing a number of 'cosmetics' prepared by Dr. Schulman and Professor Ubbelohde. Some of these were more effective than any tried previously, except silicones. In the table below the figure in the second column is the estimated percentage efficiency in comparison with silicone.

10% Polyisobutylene in Xylene	55
20% Polyisobutylene in Xylene	60
10% Polystyrene in Xylene	55
70% Phosphate Glass 696 (33)	35
5% Sodium Kurrol	30
5% Potassium Metaphosphate	45

Trial 12 - November 26th and 27th, 1953: Gun - 17 pr

Various mountings of the smear were tried but nothing better was found than a simple piston within an artificial parallel at the mouth of the cartridge case.

Trial 13 - April 7th, 1954: Gun - 2 pr Mk. 8

This was a test of smears of high molecular weight. The silicones have molecular weights in the neighbourhood of 50,000 to 100,000, the rubbers up to 300,000.

Polythene bags were used in all cases with aluminium skirted pistons. There is no doubt that the bags are a cause of inconsistency and loss of efficiency. Some more effective method of applying the smear should be found. In all cases the maximum reduction is given, as well as the average, in the table below. Under good conditions at least the maximum recorded should be attained.

Smear	Percentage reduction in heat input at distances from C. of R. of					
	1 in.		6 in.		17 in.	
	Max	Average of 8	Max	Average of 4	Max	Average of 8
Silicone 100,000	50	37	72	49	53	34
Silicone 60,000	77	44	73	41	44	35
Silicone 12,500	81	44	64	54	49	32
Silicone 1,000	58	34	52	50	31	25
25% Silicone (60,000) in Xylene	31	21	23	19	23	14
Revertex	26	22	22	17	24	19
Revultex	22	18	17	13	21	15
Revultex thickened	25	18	13	8	20	16
7.5% Nylon in Formic Acid	26	17	24	19	19	11
15% Nylon in O-Chlorophenol	23	17	24	22	16	13
15% Nylon in Formic Acid	27	18	28	24	21	16
8% Terylene in O-Chlorophenol	21	17	23	20	18	14

Admitting the inconsistencies it is clear that silicones are superior to any other smears tried. Viscosity is not of such importance as was thought at first.

Trial 14 - 18th May, 1954: Gun - 2 pr Mk. 8

This trial extended the range of viscosities of silicones tried. It gave no further information than was given by Trial 13.

Trial 15 - 6th July, 1955: Gun - 2 pr Mk. 8

A trial with Butyl Titanate. As a smear this was found to be less effective than lubricating oil. (See Reference 1)

Trial 16 - 12th and 28th July, 1955: Gun - 2 pr Mk. 8

Bore surface thermocouples, presented by the Midwest Research Institute, Kansas City, were used at this trial in the hope of securing information of the mechanism of a smear. These couples had been designed for use with low pressure R.C.L. weapons, and it was found, unfortunately, that they were not sufficiently robust to withstand the working pressure of our 2 pr gun without deformation, and the records obtained were inaccurate. The pressure therefore had to be considerably reduced.

Two good time-temperature records were then obtained - one for a normal round and one for a smeared round. These records are reproduced in Fig. 1. It is seen that the effect of the smear is to inhibit heat transfer almost completely for the first millisecond or more after firing, and then to limit the peak temperature. The peak temperature was 990°C above ambient for the standard round and 820°C for the smeared round.

3. SUMMARY AND COMMENTS

3.1 Objects of the Work

When the work on smears was started we had two objectives in view (i) to ease the cooling problem of high rate of fire guns by reducing the heat input to the barrel, (ii) to reduce wear. Hardly had the work been

started when a third objective became even more important, namely, to reduce the thermally induced stresses. Barrels were failing by mechanical rupture before the wear life was complete.

3.2 Bore Surface Temperature and Heat Transference on Firing

When a round is fired in a gun the bore surface temperature rises rapidly to a high value, which may in some cases exceed the melting point of steel. If this peak temperature can be reduced, wear may be reduced to a small fraction of its normal value, even though the reduction in the total heat transferred is small. It is known that in the early stages of combustion of the propellant the rate of heat transfer is much greater than would be estimated from steady flow conditions, for the rate of build up of a protecting boundary layer is relatively slow. If the propellant gases can be surrounded by a cooler layer, the peak bore surface temperature can be reduced. Col. Probert of A.R.E. found that by the use of 'stockings' such a cooler layer could be provided, with a reduction in wear. After our work on smears had been reported, work was done at C.A.R.D.E. with cartridge case linings of foamed P.V.C. These gave a big reduction in wear. Some of the C.A.R.D.E. experiments were repeated by us and the results compared with those for smears. In the 17 pr gun it was found that a foamed P.V.C. lining in the cartridge case reduced the heat transfer to the barrel at C. of R by about 7%, compared with 30-35% reduction with a silicone smear.

Whilst we were working on smears it appeared that very similar work was proceeding in the U.S.A. In January, 1953, Dr. G. A. Hawkins of Purdue University told the writer that work on smears was being done at Cornell. Some months later a report[2] on this was obtained. This report is interesting. It is extraordinary to find how similar were the early ideas in this country and in the U.S.A. The basic experimental pressure, and inertia, projectiles made in America were exactly similar in principle to those used by us, and figures in the American report could have been interchanged with figures in the A.D.E. report without loss. The smears used by Cornell were mixtures of beeswax and lanolin. Such smears must have been effective, though not as good as silicones. Apparently the work was discontinued for, after many changes in the basic experimental projectile, it was found that "none of these modifications produced any coatings in the barrel ..... Approximately 110 variations of the basic designs shown in Figure 1 "(similar to Figures 1 and 2 of Ref. 1.)" were tried. In all cases the results were negative."

This read strangely to the present writer who had, some years earlier, been very involved in 'oily bore' damage and had, in consequence, laid it down as a firm principle that no trace of the smear should be detectable in the bore after firing. Had measurements of heat input to the barrel been made at Cornell, it is certain that it would have been found that the results were positive, not negative. Why these measurements were not made is not known. Possibly it was because, (as the writer found later in the same year). gun calorimetry had not advanced in the U.S.A. to the extent that it had in A.D.E.

3.3 Wear

The only wear trials which have been made with smears have been in the 17 pr gun and have been very limited. The results are shown in Fig.2. It is seen that although the wear produced by 13 service rounds was ten thousandths of an inch, the wear caused when first 19 smeared rounds, and later 12 smeared rounds, were fired was too small to be detected.

3.4 Properties of a Good Smear

There is little difficulty in specifying in general terms many of the properties desirable in a smear. It must wet steel; it should be sufficiently mobile to be spread easily, but must be sufficiently viscous to resist removal

as spray; it should be a poor conductor of heat; it should have a low vapour pressure; it should have a high decomposition temperature; the vapour or the products of decomposition should themselves be effective as a thermal barrier; the life should be a big fraction of the "time up the barrel" but should not exceed it. These requirements have to be met in the "in-barrel" environment, which is so far removed from laboratory conditions that even qualitative extrapolation is difficult. Many physical and chemical factors are involved: what their relative contributions to the final result are is hard to estimate. Such considerations explain the wide range of materials tried.

3.5 Silicones as Smears

No certain explanation of the superiority of silicones as smears has emerged from the experimental work which has been done so far. The obvious physical properties have been copied in other materials but the efficiencies of these other materials, as thermal barriers, have been disappointing. It has been suggested that "the effect of silicone fluids might be due to the formation of a silicone film achieved by reaction with the surface" (Bowden 29.1.53). This seems likely, but probably difficult to prove. The examination of the bore surface by X-ray or electron diffraction has been suggested. This was one of the obvious lines of work which had to be dropped because the effort was not available. What one wishes to know is what exists on the surface between 1 and 10 milliseconds after shot start. Whether an inquest would provide the answer is doubtful.

Bore temperature measurements indicate that it would be beneficial if the life of the smear could be prolonged beyond the 1 or 2 milliseconds for which it exists as a liquid. This should probably not exceed 10 milliseconds but the nearer it is to this limit the better. Some effort was expended in trying to obtain stable silicone resins, but we were unable to obtain them in this country. A further effort might be worth while.

3.6 Application of a Smear

During development, the smear was most successfully applied in the 2 pr Mk. 8 gun, the ammunition for which has a parallel portion at the front of the cartridge case in which the light metal piston can operate. The smear fluid was loose. Enclosure of the smear in a plastic bag reduced its efficiency somewhat in the initial stages. The requirement that there shall be no discard militates against efficient application. From a practical point of view some discard must be accepted; it may be made comparatively innocuous. The real problem to be faced is that smears had not been invented when the guns to which one wishes to apply them were designed, and so makeshift methods of incorporating the smear in the round have had to be adopted. Very minor modifications to chamber shape in a new weapon would make the application much easier. Fig. 2 shows that virtual elimination of wear can be effected if the smear is properly applied.

3.7 Future Work

If opportunity presents several investigations are worth while.

As has been indicated above further basic work on the operation of silicones might be undertakem, directed particularly to prolonging the life of the smear.

Wear trials should be made, and the nature of bore surface changes should be investigated. A small weapon, such as the 2 pr Mk. 8, should be supplied from the beginning with nothing but smeared rounds. Throughout its life the bore should be examined visually and magnetically. The writer

is prepared to believe that crazy cracking may be much reduced by the action of the smear; but demonstration is necessary. Finally the barrel should be cut up and a detailed bore examination made.

4. ACKNOWLEDGEMENTS

The author gratefully acknowledges the interest shown, and the help given, by members of the Gun Erosion Panel until its dissolution, and later by the Chairman, Professor A. R. Ubbelohde, F.R.S. He regrets that pressure of other work prevented the investigation being carried to its natural completion.

The later experimental work was organised by Mr. S. G. Owen and was carried out by Mr. S. Morris.

References

1. Warren, A.G. ""Smears", an attempt to reduce Gun Heating". Report No. A.D.E. 8/53.

2. Cornell Aeronautical Laboratory — Final Report on Heat Transfer Studies for Item 2, Phase 1. Research in Heat Transfer and Obturation for Small Arms Weapons. Report No. GA-740-D-12. Jan 31st 1953.

FIG.1

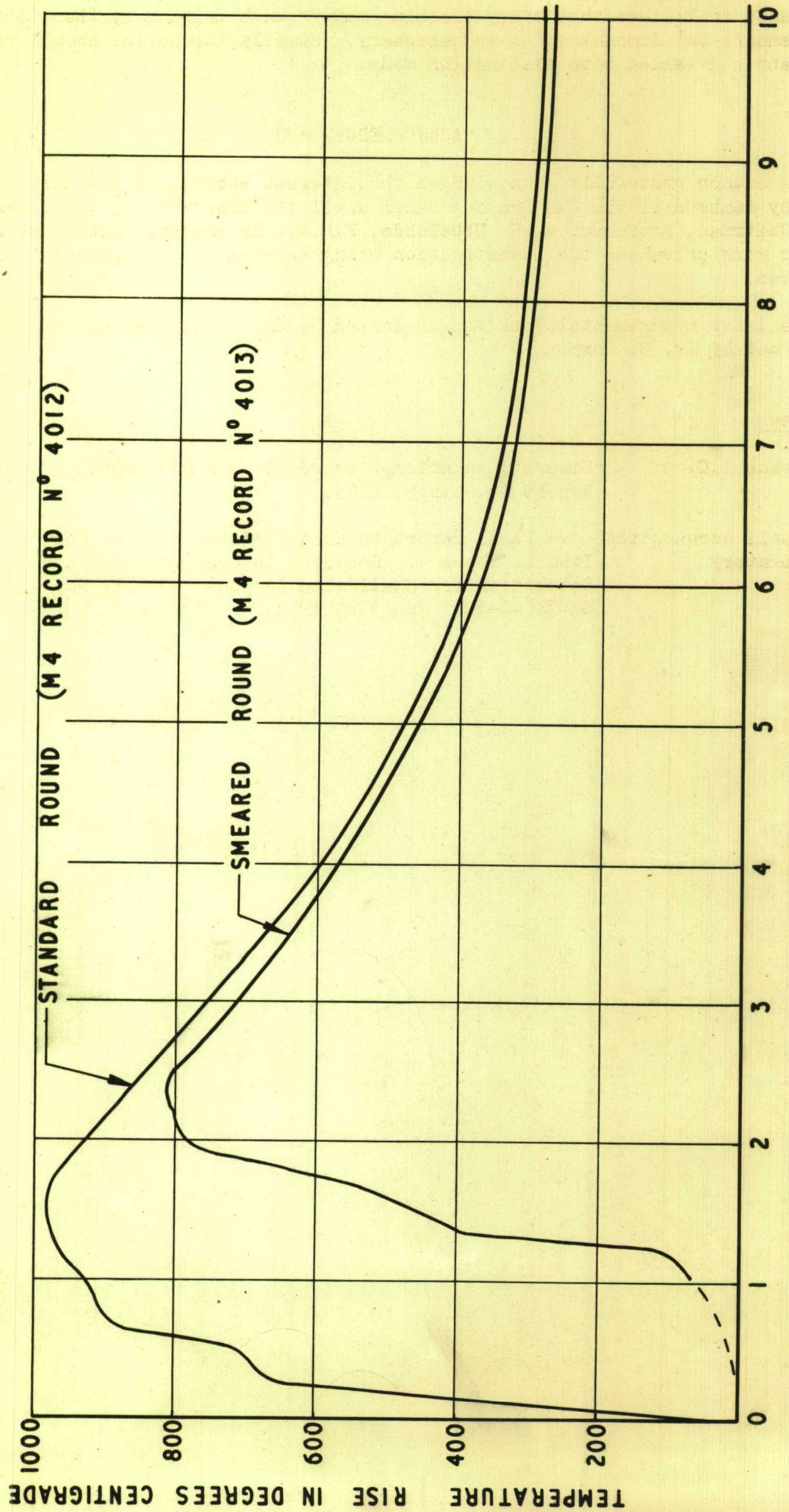
STANDARD ROUND (M4 RECORD N° 4012)
SMEARED ROUND (M4 RECORD N° 4013)
TEMPERATURE RISE IN DEGREES CENTIGRADE
1000
800
600
400
200
0
1
2
3
4
5
6
7
8
9
10
TIME IN MILLISECONDS

FIG. 2

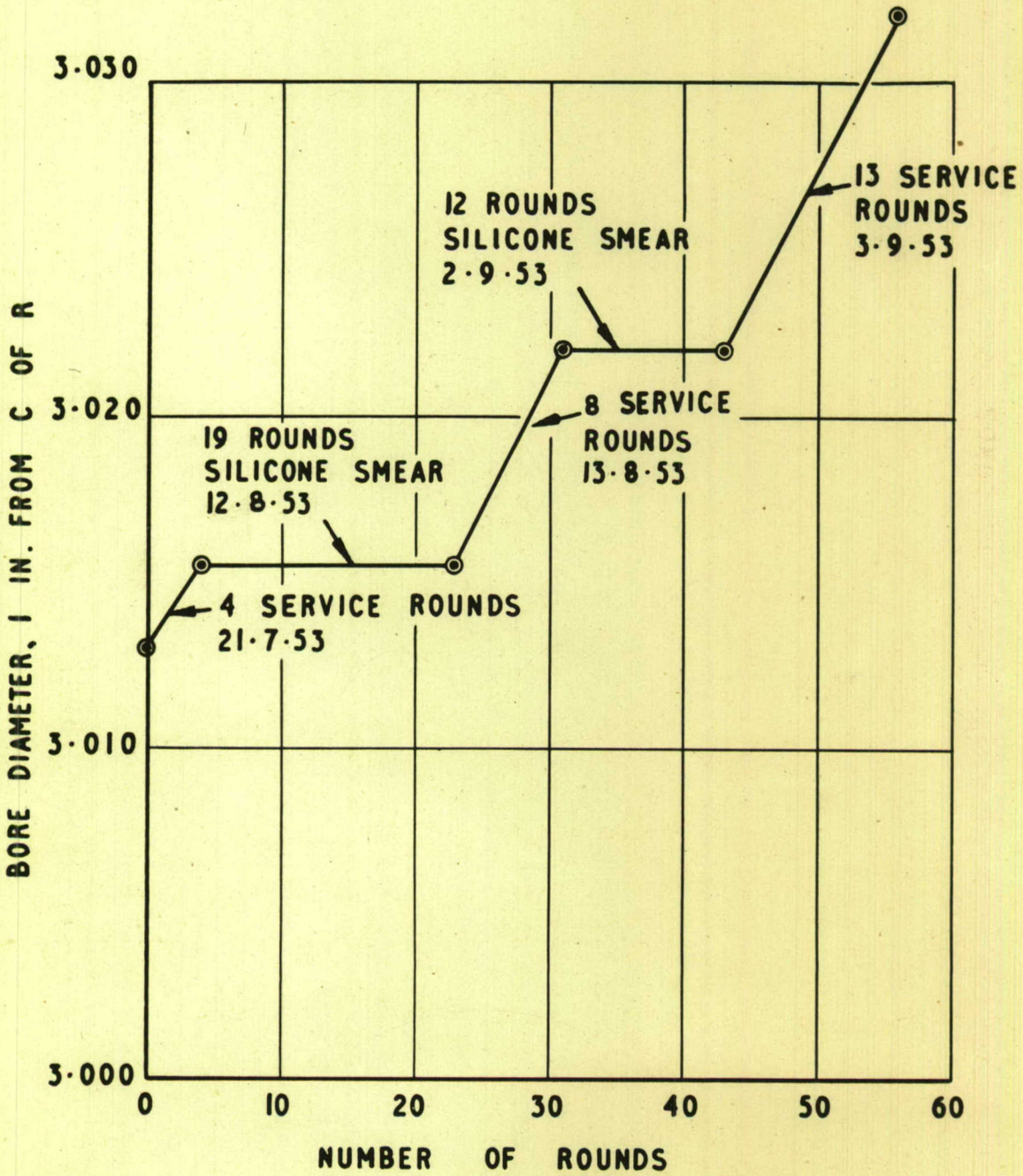

FIG. 2 LIMITED WEAR TRIAL ON 17 PDR.

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