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ABSTRACT

The work reported here is a continuation of that reported in UCRL-1962. Approximate breakdown voltages and spark damage estimates have been made for the metals Ag, Ti, Aluminum Alloy 52-S0, Stainless Steel 316 and various combinations of Inconel and Cu.

The geometry and experimental conditions are the same as previously employed, i.e., a cylindrical electrode centrally located between parallel plates all within a 14 megacycle cavity. A strong magnetic field (8,000 gauss) is directed along the common normal to the side plates and stem. Voltages of the order of one megavolt are applied.

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INTRODUCTION

The experiments reported here are efforts to measure: (a) the relative breakdown voltage of the metals tested, and (b) the damage to the metals resulting from sparks. Procedure for runs and terminology used is the same as those reported in UCRL-1962.

New metals tested were: silver, titanium, Duraluminum (Type 52-S0), and Stainless Steel (Type 316).

Much of the effort since the last report has been concerned with the testing of combinations of metals and the testing of treatments given to the metals which have been suggested for use in accelerators. These include:

1. Inconel with molybdate* on the reverse side.
2. Inconel with hydrogen admitted to the tank.
3. OFHC copper overlay plug welded over DHP copper.
4. Special treatment of DHP and OFHC coppers.
5. Inconel - DHP copper permutations.

NEW METALS

1. Silver (5-3/8 in. gap)

The highest voltage reached during this run was 790 KV. Below 790 KV the sparking rate was quite low indicating a very abrupt breakdown threshold (see Fig. 15). OFHC copper is at least 290 KV better than this.

*See report on molybdate, Spec. No. 173

Damage to silver resulting from sparking is more severe than copper in that the spark craters formed are deeper and larger in diameter (see Fig. 1).

2. Titanium (2-1/16 in. gap)

A breakdown voltage was not reached for titantium. The maximum voltage reached during the run was 880 KV. This limit was due to the power which the oscillator could supply to the rf cavity. For Inconel an interpolation of the breakdown voltage for this gap is 875 KV.

At 875 KV the sparking rate was high (100-1000 sparks per minute) for Inconel and low (50-80 sparks per minute) for titanium. Titanium appears slightly superior to Inconel on the basis of this limited information.

The spark damage incurred was similar to Inconel. Further tests of titanium are planned.

3. Duraluminum (Type 52-S0) (1-15/16 in. gap)

During this run the highest voltage reached was 850 KV. The apparent breakdown voltage decreased markedly with running time. After raising the voltage level several times, the highest voltage that could be reached was 645 KV (see Fig. 16). Much metal was sprayed across the gap, most of which was adherent.

The spark damage was similar to copper in appearance.

4. Stainless Steel (nominal 2-3/8 in. gap) (Figure 5)

There have been three runs made with 316 Stainless Steel. Results of these three runs have not yielded consistent results. Another run with 316 Stainless Steel is in progress. The metal sprayed from the side plates was considerably more magnetic than metal sprayed from Inconel plates.

COMBINATIONS AND SPECIAL TREATMENT OF METALS

1. Inconel with Nickel Molybdate Backing

In an experiment to study spark damage electrodes were faced with an Inconel skin. These facings could not conveniently be cooled by affixed water tubes or placed in good thermal contact with the existing cooled surfaces.

Nickel molybdate was used to raise the emissivity of the back surfaces of the Inconel skins to increase radiant heat transfer.

The emissivity of molybdate coated Inconel is about 0. 6 while Inconel itself is approximately 0. 1.

The initial behavior with these facings indicated that the cavity appeared to be very gassy and a greater number of sparks were observed at low voltages.

Untreated Inconel tested in the XC cavity had proven itself superior to copper in all respects and had never exhibited a gassy behavior.

It was, therefore, pertinent to test nickel molybdate coated Inconel in the XC cavity in order to establish the following:

(a) whether the molybdate coating exhibited a gassy behavior and could be baked out in a finte length of time,

(b) whether an increased number of sparks encountered in an extended bake-in might integrate the damage to the electrodes to a point where they were as badly damaged as copper.

It has been possible to establish these facts.

A run conducted with molybdate backed Inconel side plates versus an Inconel center electrode gave the following results:

A total bake-in time of 600 minutes was observed in contrast to a normal value of 100-200 minutes. The untrapped tank pressure gauge did not read significantly higher than usual at the beginning of the run, but did exhibit correlative changes with rf on and off. These fluctuations were of the order of 5×10^{-7} during the early part of the run and became negligible during the later stages of the run.

20, 500 sparks without the magnetic field and 23, 000 sparks with the magnetic field were recorded during this run. A normal run on Inconel accumulates approximately 2500 sparks with the field off and 5000 with the field on. The sparking rates during normal bake-in decays rapidly and monotonically at voltages below breakdown. This was not the case with molybdate backed Inconel. The sparking rate decayed much more slowly. If the rf was turned off for a short period of time, the sparking rate increased rapidly when turning on again to a value several times higher than the value just before the voltage was turned off. The decay time to establish the original rate was comparable with the off time. This effect did not disappear until the value of 1100 KV was reached with the magnetic field on.

The maximum voltage reached was 1130 KV which is in agreement with the experimental value for uncoated Inconel.

The spark damage is illustrated in Figs. 6 and 7. It is noted that the area sparked to is larger than usual, but the total amount of damage done is not as great as to copper electrodes, in fact not much more than the damage done to uncoated Inconel with approximately one-fifth the number of sparks.

Inspection of the cavity after the run revealed the presence of a bluish film on the side walls. This film was left intact for the next run with uncoated Inconel and we again observed an extended bake-in.

After this run, the cavity walls were cleaned with emery paper, water and acetone, which completely removed all visible traces of this deposit. Subsequent runs behaved normally with regard to bake-in.

The presence of the molybdate coating then was directly responsible for the long bake-in period and the accompanying increased number of sparks. Any material that either increases the total number of sparks that are likely to occur before attaining a given voltage or outgases slowly is to be regarded as undesirable.

We have not determined whether the evolute from the molybdate coated is a direct decomposition product or a contaminate introduced in the plating process. The molybdate itself appears to be quite involatile. In any case not much can be done with molybdate surfaces except to outgas them before use and the effect may not be permanent.

The x-ray level for the nickel molybdate run was about twice as high as in previous runs. This effect carried over to the next run where the x-ray loading was approximately 6 times normal (see Fig. 14). Since the power input on both runs, within the limits of experimental error, is the same as that for normal operation, neither the additional skin loss from the molybdate residue or the x-ray loading represent a large percentage of the total power loss.

2. Inconel with H_2 (3-3/8 in. gap)*

The purpose of this run was to determine whether admission of hydrogen into the cavity would aid the bake-in or result in any reduction in the sparking rate as has been surmised at various times.

There were two methods devised for testing the effect of hydrogen. The results were determined by the effect of H_2 on the sparking rate both during bake-in and subsequently. Electrodes were first baked-in without magnetic field. During a second bake-in with the magnetic field, hydrogen was bled into the tank to a pressure 7 - 10 times the normal operating base pressure (i.e., to approximately 10^{-5} mm Hg.) When a low sparking rate was obtained just below maximum voltage, the hydrogen was turned off. The sparking rate at this voltage was carefully monitored as a function of time until it was established that the previous equilibrium pressure had been reached. There was no statistically significant variation in the sparking rate during this interval, (i.e., sparking rate did not increase or decrease as a result of turning off the H_2).

Next the initial sparking rate was observed after the rf had been turned on following a 15 - 30 minute rf off period with no hydrogen admitted to the system and then when hydrogen had been admitted to the vacuum system. There was no statistically significant difference in the sparking rate.

We have been unable to show that the admission of H_2 has any effect on bake-in or sparking rate. The time required to bake-in with H_2 was not notably different than usual.

3. OFHC Copper Overlay Plug Welded onto DHP Copper

The purpose of this run was to determine whether plug welds in the surface of an OFHC copper overlay would be weak areas on the electrode surface.

The results of the run indicate that the spark density does not show any preference as to location on the overlay (see Figures 9 and 10).

The highest voltage reached was compatible with OFHC copper. The damage to areas of weld metal were no different than to the base metal. More sparking was encountered at lower voltages than is usual with OFHC copper.

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*These runs were performed for CRandD because of a particular interest in these specific methods of treating metals. CRandD has furnished material and personnel assistance for these tests. The CRandD personnel directly associated with these tests were D. Cummings, L. C. Foster and R. Vetterlein.

4. Further Copper Runs with Special Treatment[2] (3-3/8 in. gap)

Several tests have been made with copper which has been given special treatment.

a. Copper* not work hardened. Here flurries started at 790 KV and the highest voltage reached was 880 KV.

b. OFHC copper which has been work hardened. With this treatment flurries were encountered above 905 KV and the highest voltage reached was 980 KV.

c. DHP copper which had been work hardened and then cleaned by CRand D using the cyanide deplating technique proposed for cleaning the drift tubes in the Mark I cavity. Flurries were encountered above 810 KV and the highest voltage reached was 905 KV.

5. Inconel - Copper Permutations (3-3/8 in. gap)

In order to estimate whether trouble might be expected in the second gap (Inconel opposite copper) in the Mark I cavity a series of experiments were performed using DHP copper and Inconel. These two metals were used as noses and side plates in the four possible permutations.

From the run with Inconel on nose and side plates the highest voltage reached was 1100 KV with very low sparking rate.

With several samples of DHP copper for side plates and an Inconel nose, one (work hardened) DHP sample gave maximum voltage of 1040 KV and a second sample (not work hardened) gave 960 KV.

Photomicrographs of these two DHP copper samples were made (see Figures 11 and 12). The sample holding the most voltage had been subjected to work hardening annealing cycles. The other sample was not work hardened. The grain size of the first of these samples has a grain structure several times larger than the non-work hardened sample. The process of work hardening and annealing is known to increase crystal growth. This suggests that crystalline structure effects the voltage holding capacity of a material as was previously noted in UCRL-1962.

With the second DHP copper sample on the side plates and a DHP copper nose the maximum voltage reached was 925 KV. These runs are plotted in Figure 18.

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*It was not possible to definitely identify this copper as to type. It was either DHP or poor OFHC.

With Inconel side plates and DHP copper nose the maximum voltage reached was 740 KV. Subsequent to the first rise in voltage the highest value reached was 670 KV. Inspection of the copper nose after this run revealed that Inconel had been sprayed on it from the side plates. This sprayed metal was so loosely attached that it could easily be rubbed off with one's finger.

The main conclusion drawn from this is that the substitution of copper for Inconel on either electrode reduces the maximum voltage that can be reached. As before, the damage which occurs appears on the electrode of lowest gradient. With copper side plates the voltage obtained was about the same as with a completely copper geometry. When Inconel side plates were used with a copper nose the maximum voltage reached was several hundred kilovolts below that for the completely copper geometry and this maximum voltage dropped continuously with running.

The hypothesis is that the loose Inconel dust on center electrode is responsible for aggravating the sparking rate.

These experiments were carried out by a group consisting of: R. L. Anderson, P. R. Byerly, Jr., W. W. Chupp, H. G. Heard, C. W. Jensen, E. J. Lauer, E. J. Lofgren, W. W. Salsig, H. L. Smith, H. W. Vogel and others.

TABLE I

CLASSIFICATION OF METALS BY BREAKDOWN VOLTAGE

Metal	Closest Gap	Max. Gap KV	Remarks
Silver	5-3/8	790	Spark damage more severe than copper
Titanium	2-1/16	880	Spark damage comparable to Inconel
Duraluminum (Type 52-S0)	1-15/16	600-850	Spark damage similar to copper
Stainless Steel (Type 316)	2-3/8	1110	Spark damage similar to Inconel
Inconel (Molybdate coating)	3-3/8	1170	Sparking induced by coating material
OFHC copper (Plug welded)	2-3/8	1020	Copper plug welds have no effect
Inconel (Previous data)	3-3/8	1170	--------------
Inconel nose DHP Side Plates	a 3-3/8 b 3-3/8	1040 960	Behaves like all DHP copper geometry
DHP copper	3-3/8	925	--------------
DHP nose (Inconel side)	3-3/8	740	Loose Inconel dust contributes to sparking

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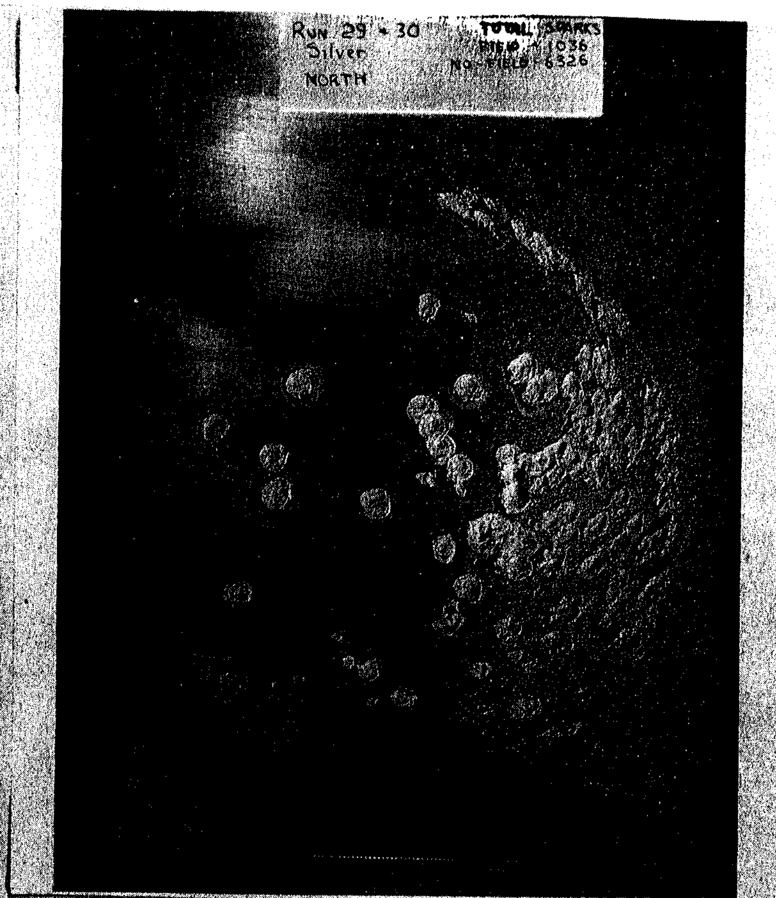


Fig. 1

Silver north side electrode

Fig. 2

OFHC copper stem electrode showing spark damage at a

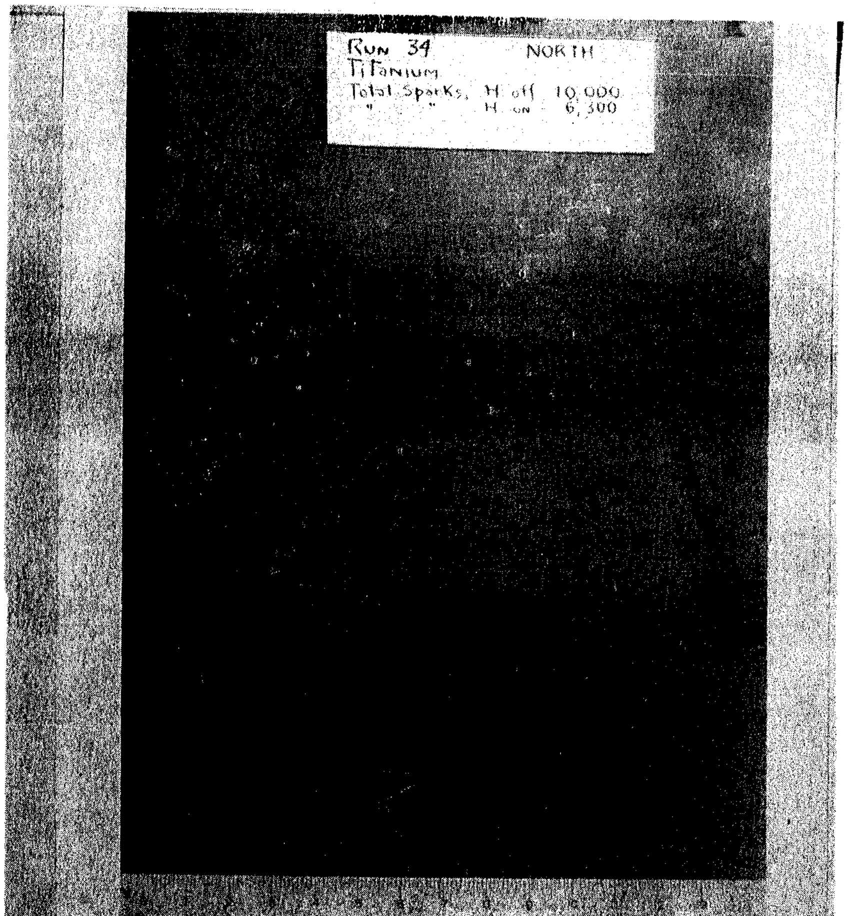


Fig. 3

Titanium north side electrode

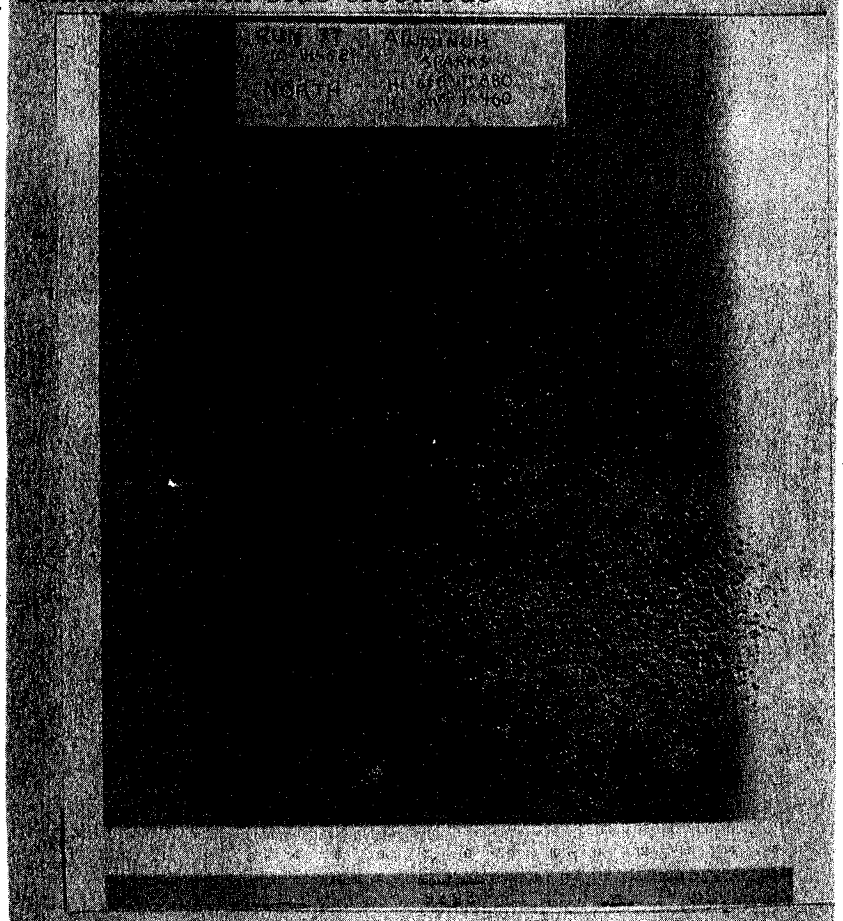


Fig. 4

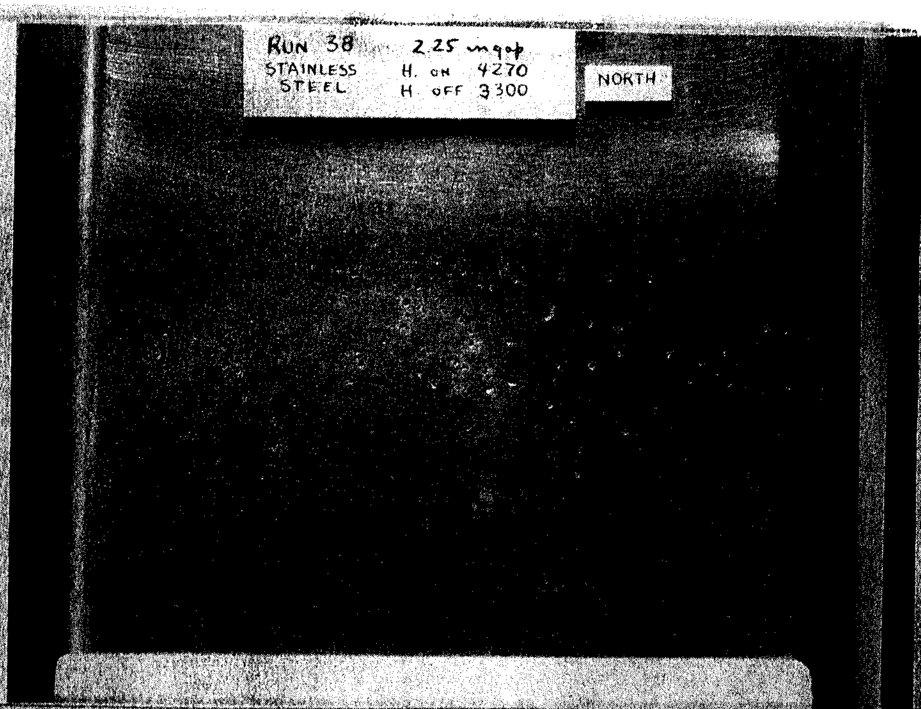


Fig. 5
Stainless steel (type 316) side electrode

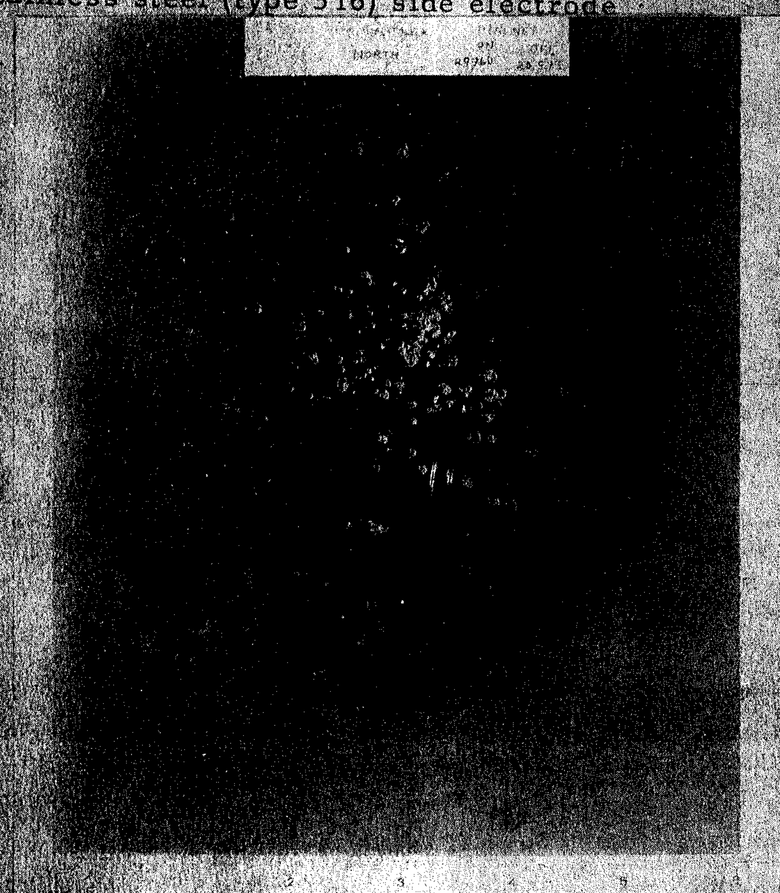


Fig. 6
Inconel (molybdate coating on reverse side) north side electrode

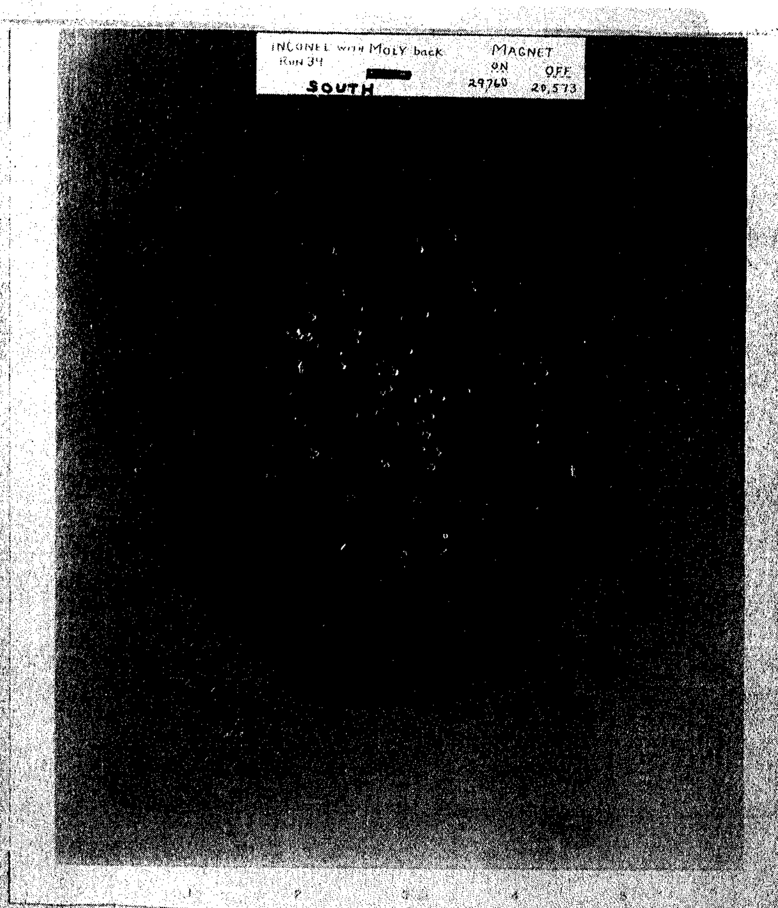


Fig. 7
Inconel (molybdate coating on reverse side) south side electrode

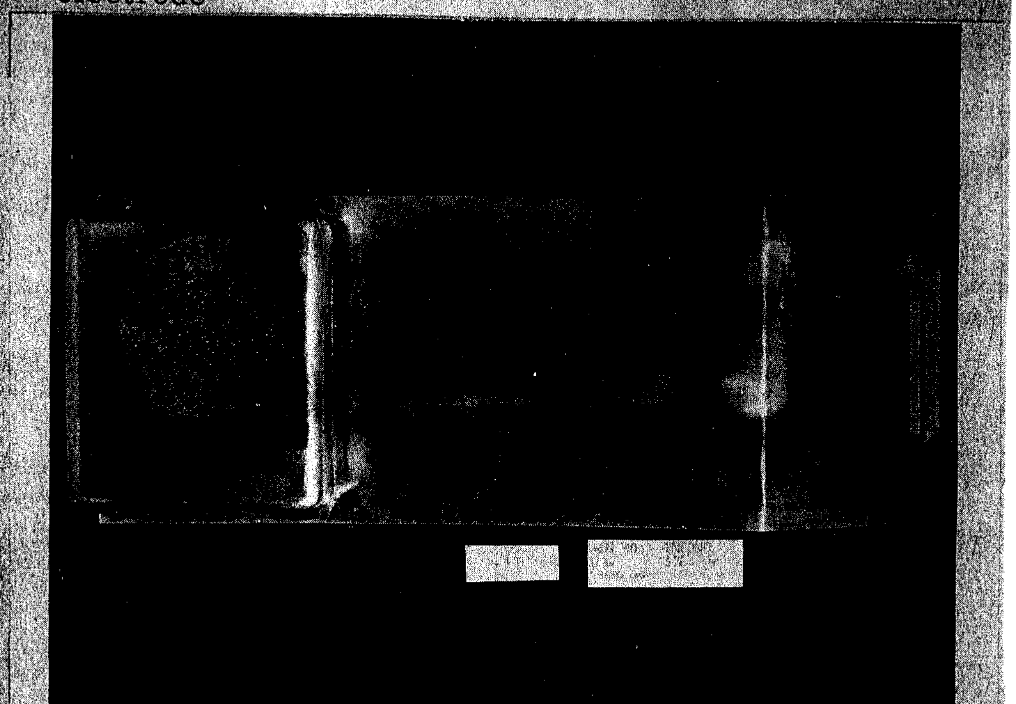


Fig. 8
Inconel side electrode used on run following inconel molybdate run

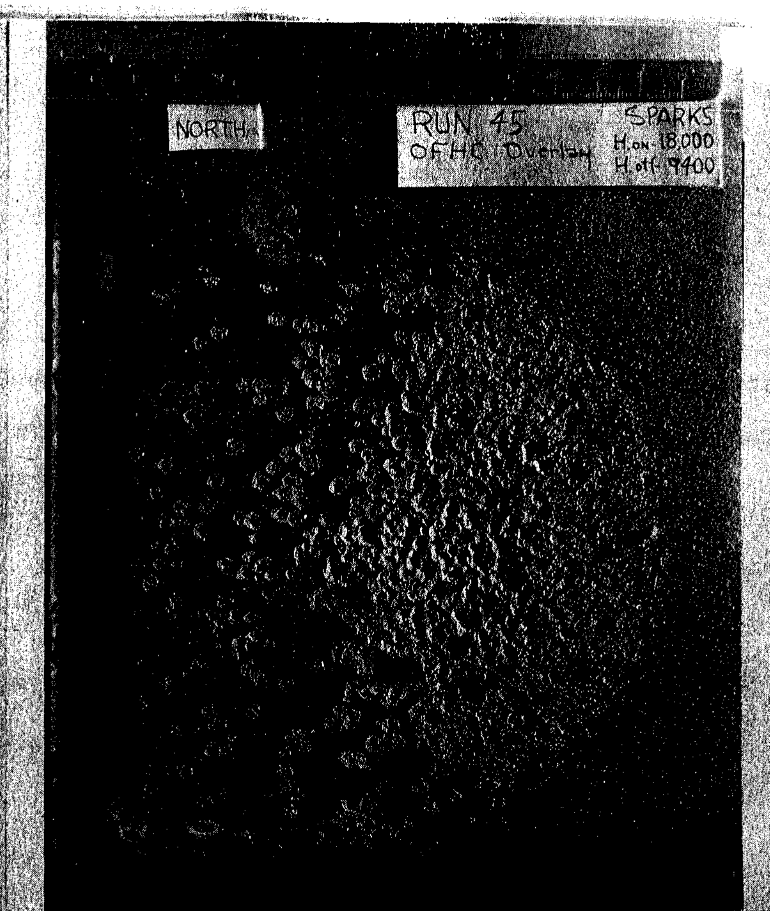


Fig. 9

OFHC overlay on DHP copper side electrode

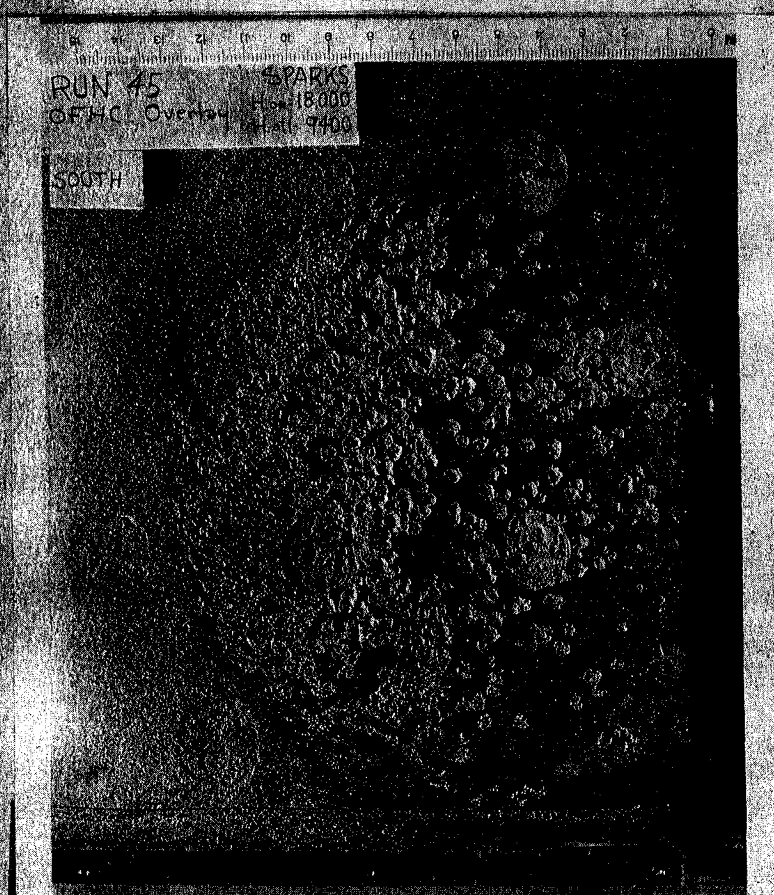


Fig. 10

OFHC overlay on DHP copper side electrode

Fig. 11

Photomicrograph (68x) of grain structure in work hardened sample of DHP copper (surface shows spark craters)

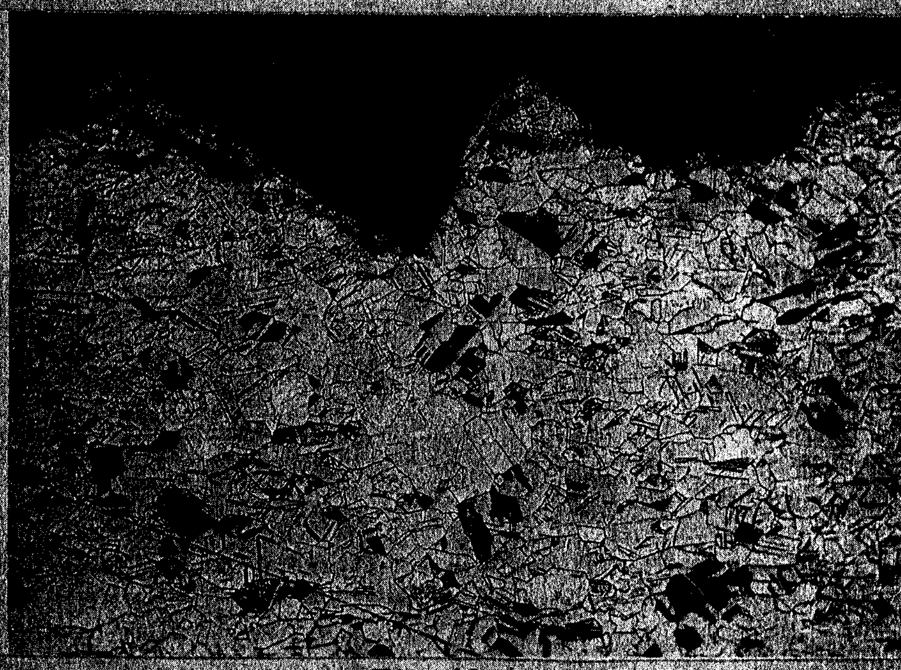
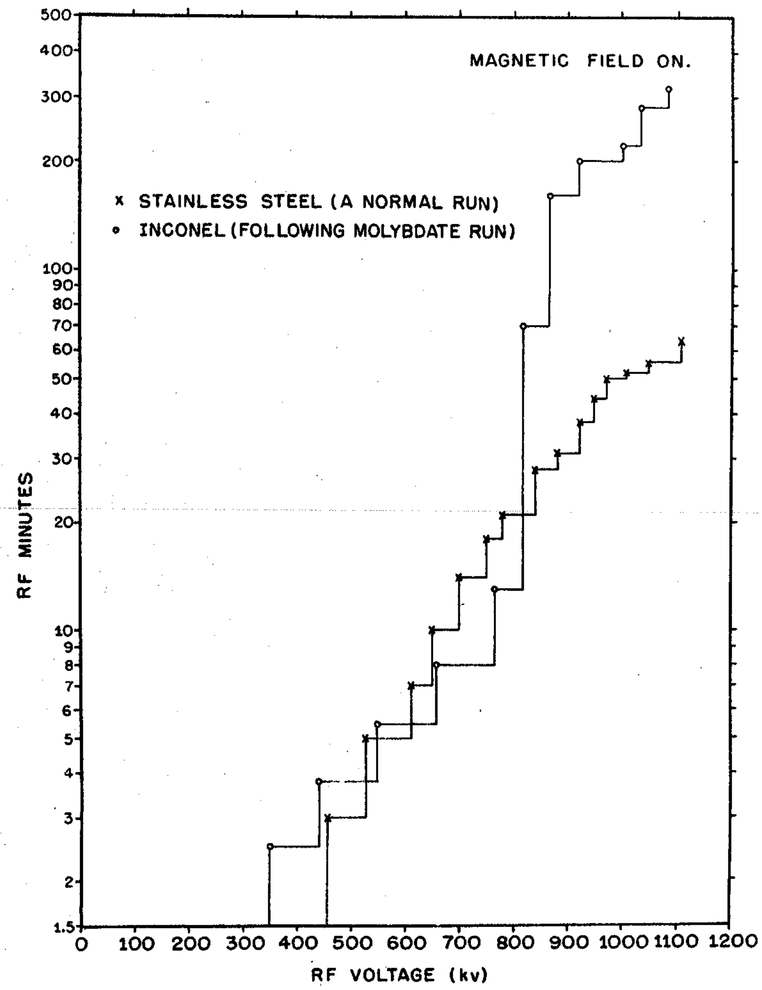


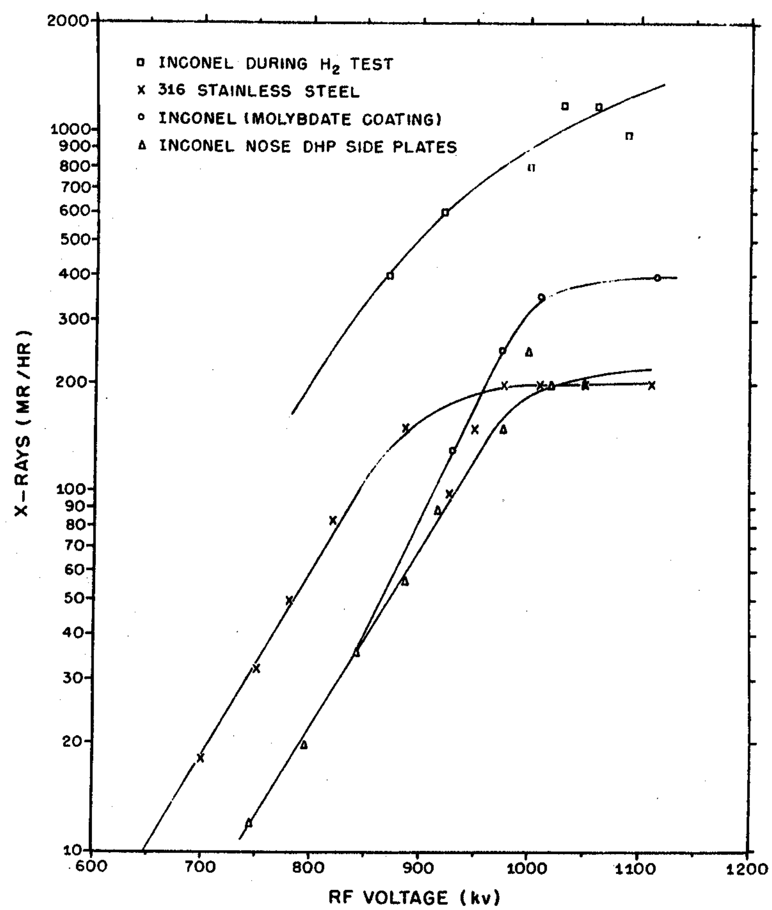
Fig. 12

Photomicrograph (68x) of grain structure in non-work hardened sample of DHP copper (surface shows spark craters)



TIME NECESSARY TO REACH MAXIMUM VOLTAGE vs. VOLTAGE.

Figure 13



X-RAY LEVEL VS. VOLTAGE.

Figure 14

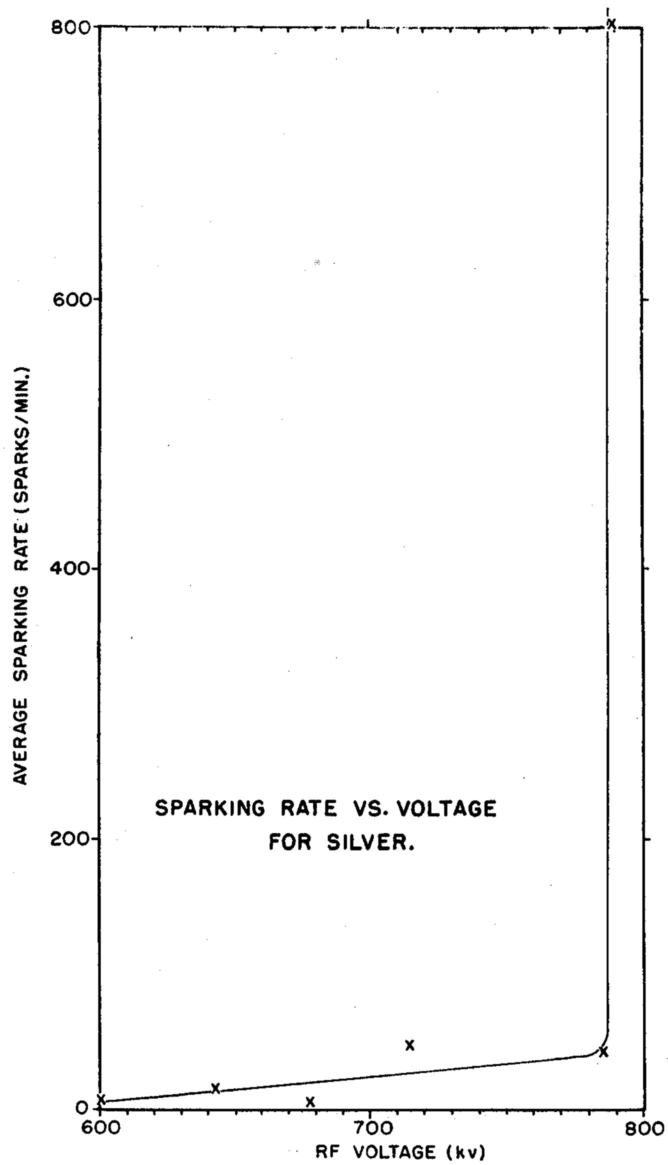
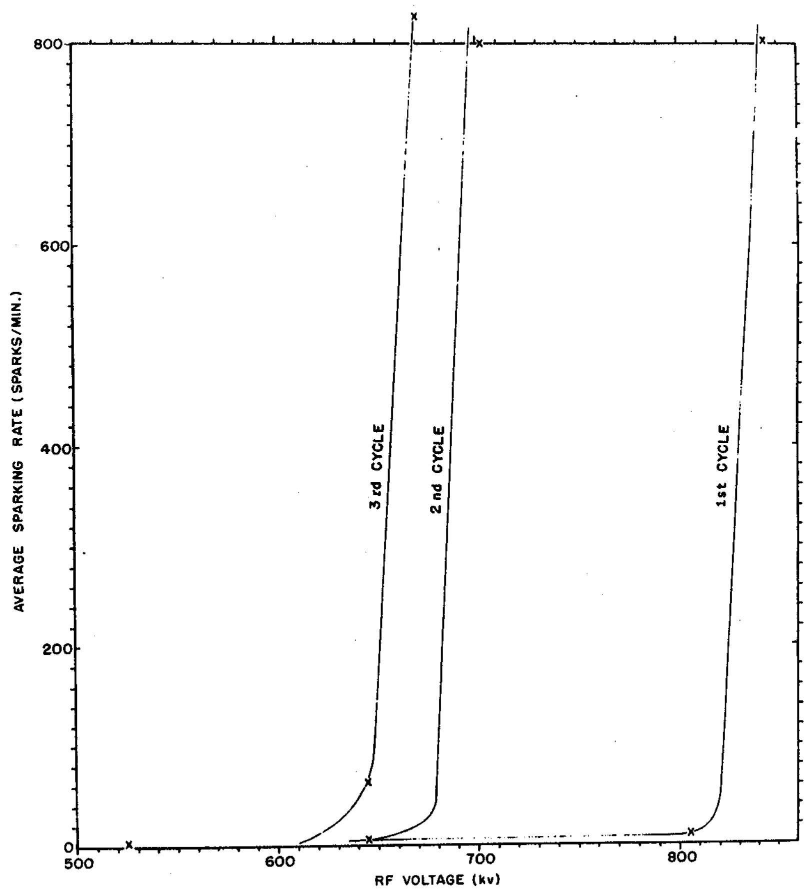
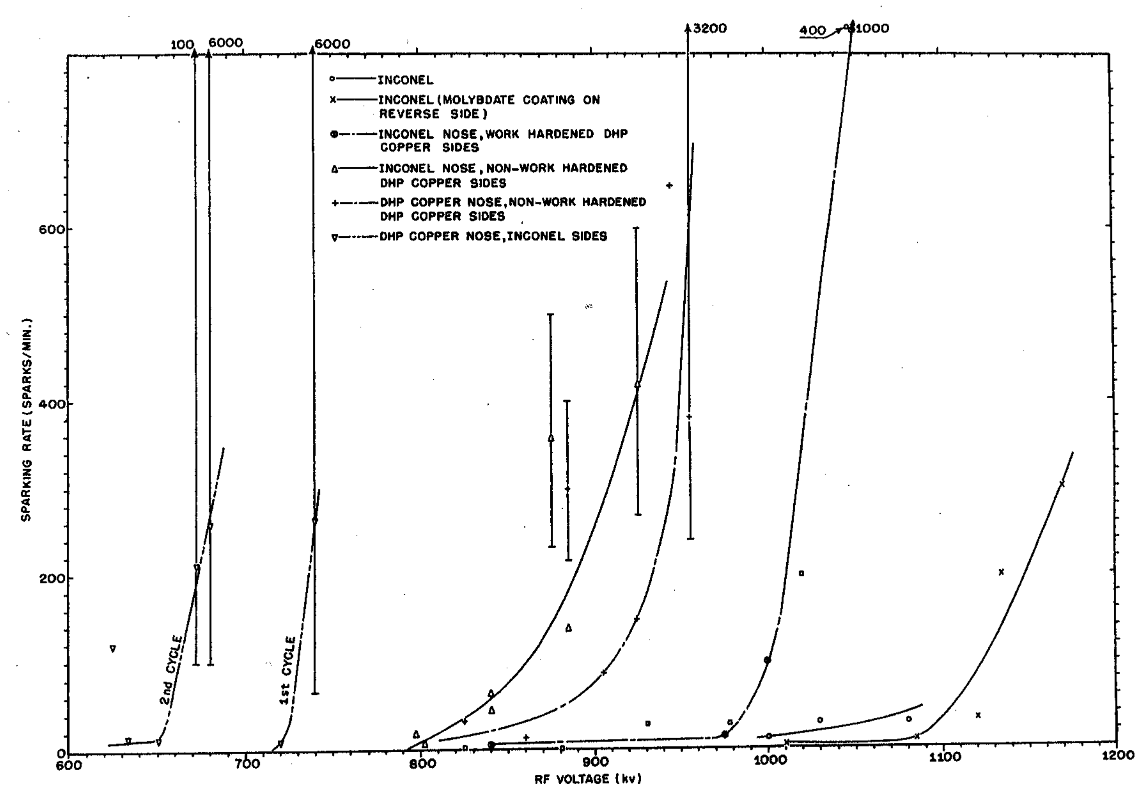

800
600
400
200
0
AVERAGE SPARKING RATE (SPARKS/MIN.)
SPARKING RATE VS. VOLTAGE
FOR SILVER.
600
700
800
RF VOLTAGE (kv)

Figure 15



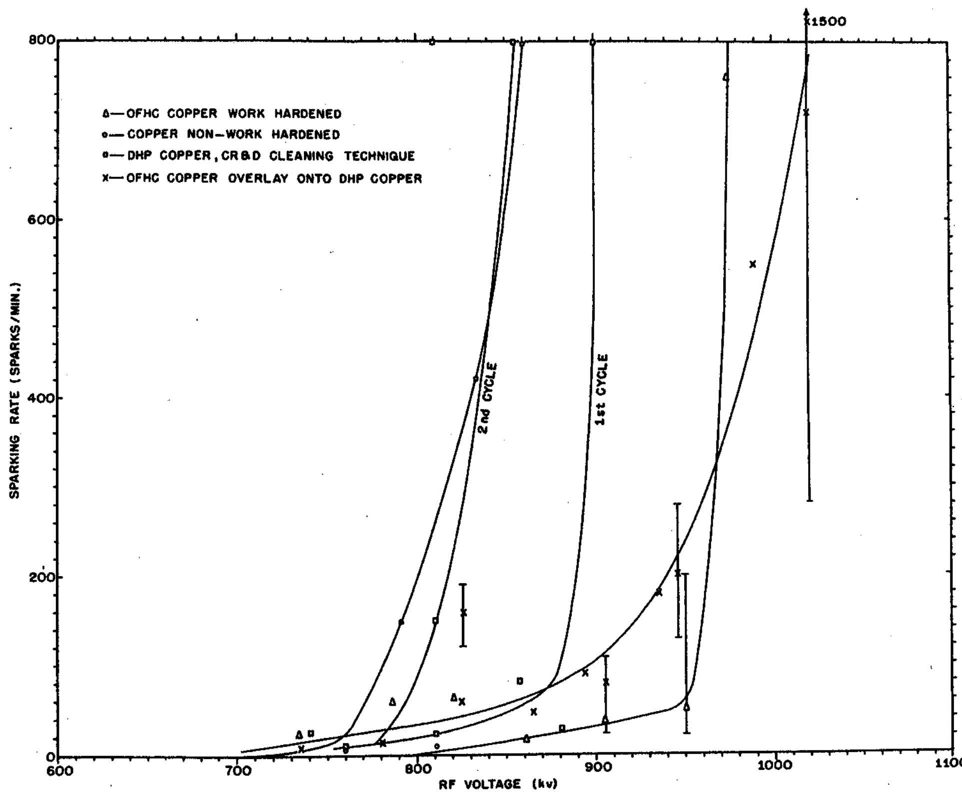
SPARKING RATE VS. VOLTAGE FOR DURAL (52-SO)

Figure 16



SPARKING RATE VS. VOLTAGE FOR SEVERAL COMBINATIONS OF METALS.

Figure 17



SPARKING RATE VS. VOLTAGE FOR COPPER WITH VARIOUS TREATMENT.

Figure 18