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MASTER

**BASIC ELECTRICAL DISCHARGE MACHINING
CHARACTERISTICS AND ASSOCIATED ELECTRODE
MATERIALS AND COOLANTS**

D. R. Alford

**UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE Y-12 PLANT**

operated for the **ATOMIC ENERGY COMMISSION** *under* **U. S. GOVERNMENT Contract W-7405 eng 26**

**UNION
CARBIDE**

OAK RIDGE Y-12 PLANT
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Y-12 PLANT

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With the US Atomic Energy Commission

BASIC ELECTRICAL DISCHARGE MACHINING CHARACTERISTICS AND ASSOCIATED ELECTRODE MATERIALS AND COOLANTS

D. R. Alford

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ABSTRACT

Electrical discharge machining (EDM) characteristics of some commonly machined materials, such as uranium, aluminum, steel, and tungsten, have been studied and tabulated at the Y-12 Plant. To a lesser extent, the characteristics of magnesium, titanium carbide, tungsten carbide, and Type 304L stainless steel have also been determined.

Data obtained from 15 different electrode materials applied on the workpiece materials in various combinations have been arranged to give shop personnel the information necessary to select and design an electrode, estimate the job time, and set up the power supply.

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SUMMARY

Electrical discharge machining (EDM) characteristics of some materials that are commonly machined at the Y-12 Plant have been determined. The data that have been obtained can serve as a guide for shop personnel in their selection and design of electrodes, in estimating the job time, and in setting up the power-supply requirements. In addition, data have been obtained to aid in evaluating various commercial grades of graphite as electrode material for steel, the use of coolants, and the effects of electrode rotation.

Small-hole work using EDM methods has also been studied.

Exhaustive testing of each condition would undoubtedly lead to some modification of the results shown; however, due to the care given during these tests, it is felt that the errors would be small. The cuts listed in the data may not be the best cuts obtainable on each metal, again due to the limited amount of testing time available, but each cut shown will work under the conditions indicated. Changing any of the conditions could easily affect the result. For example, when using the power-supply setting listed, changing any of the parameters of the setup will affect the result. Flushing arrangement, electrode shape, and electrode size are especially important conditions which affect EDM cutting characteristics for a given tool-workpiece combination.

Because of these conditions, it is intended that the performance data included in this report be used as a starting point only. After initial setup, final tuning should always be necessary to obtain the best cut; however, the final setup would not be expected to be drastically different from the initial setup.

In addition to the cuts made to procure data, several small EDM jobs were performed. These jobs included the fabrication of two injection molds; small, deep-hole cuts in aluminum turbine blades; and small, deep-cavity cuts in Type 304L stainless steel.

INTRODUCTION

This study was proposed to determine the EDM characteristics of some of the metals which are normally handled in the Y-12 Plant, but are not common in industry. Data, unavailable from other sources, were needed to evaluate three new EDM power supplies which were considerably different from older power supplies, and electrode materials and EDM fluids which had not been used in Y-12 to any great extent.

The entire scope of the program could cover a tremendously large number of variables, and it would have been very desirable to have covered each variable completely; however, with the limited amount of manpower and number of machines available, it would have taken an extremely long time and been impractical from the standpoint of deriving any immediate benefit from the study. It was decided to concentrate the study on those materials most often requiring EDM work, on those electrodes most common to industry, and on those electrodes most often used in Y-12. Determinations needed most were: (1) the metal removal rate at a given finish for a given metal and electrode, (2) electrode wear ratio, and (3) power supply settings which would work effectively for a given set of conditions.

To obtain these data within a reasonable time, only a limited number of cuts were to be made on each metal and electrode combination. Although every effort would be made to insure the accuracy of the data, the number of cuts under each condition tested was to be kept low.

EXPERIMENTAL PROGRAM

OVERALL PLAN

All work was performed on an Ex-Cell-O 248B machine tool equipped with an Ex-Cell-O 221-41S, 80-ampere, dual power supply, (a) shown in Figure 1. The measured frequency of this power supply at each of its six transformer taps is shown in Figure 2 and Table 1 as a function of the frequency knob setting.

The major workpiece materials were: uranium, aluminum, steel, and tungsten. Studied to a lesser extent were: magnesium, titanium carbide, tungsten carbide,

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Figure 1. EX-CELL-O 248B MACHINE TOOL AND 221-41S POWER SUPPLY.

(a) Manufactured by the Ex-Cell-O Corporation, Detroit, Michigan.

Figure 2. POWER-SUPPLY FREQUENCY FOR GIVEN TAP AND FREQUENCY ADJUSTMENT SETTINGS. (Ex-Cell-O 221-415)

Table 1
MEASURED MULTIVIBRATOR FREQUENCY OF AN
EX-CELL-O 221-415 POWER SUPPLY
(Values in Kilocycles)

Frequency	Tap					
	1	2	3	4	5	6
0	103	91	82	64.5	15.9	7.8
1/2	114	98	87	68.1	16.8	8.2
1	125	106	92	71.8	17.8	8.7
1 1/2	136	113	98	75.4	18.7	9.1
2	146	120	103	79.0	19.6	9.5
2 1/2	157	128	108	82.6	20.5	10.0
3	168	135	113	86.3	21.5	10.4
3 1/2	179	142	118	89.9	22.4	10.8
4	190	150	123	93.5	23.3	11.2
4 1/2	201	157	128	97.2	24.3	11.7
5	212	164	134	100.8	25.2	12.1
5 1/2	222	172	139	104.5	26.1	12.5
6	233	179	144	108.0	27.1	13.0
6 1/2	244	186	149	111.7	28.0	13.4
7	255	194	154	115.3	28.9	13.8
7 1/2	266	201	159	118.9	29.8	14.3
8	276	208	164	122.5	30.8	14.7
8 1/2	287	216	170	126.2	31.7	15.1
9	298	223	175	129.8	32.6	15.5
9 1/2	309	231	180	133.3	33.6	16.0
10	320	238	185	137.0	34.5	16.4

and Type 304L stainless steel. Electrode materials included: brass, four types of graphite, copper, tellurium-copper alloy, copper-tungsten alloy, silver-tungsten alloy, nickel-tungsten alloy, tungsten carbide, copper graphite, aluminum, and zinc. Data on the performance characteristics of the various workpiece and electrode combinations are given in Tables A-1 through A-28 in the Appendix.

The electrode sharp-corner wear ratio was determined by measuring to the point where there is no evidence of sparking on the sharp edge. The wear ratio of tool to workpiece was obtained by dividing the wear by the part thickness and rounding off to the higher one-half value to give a conservative ratio. Side-wear ratio was determined in the same manner. Although this method is somewhat more stringent than that commonly used, it was chosen because EDM applications in the Y-12 Plant usually have close tolerance requirements in sharp corners and edges. End-wear ratio is self explanatory.

Normal polarity is defined as the negative power supply lead attached to the electrode and the positive lead attached to the workpiece. Reverse polarity is the opposite arrangement.

Normal flushing utilizes a hollow electrode to bring the coolant to the parts, as shown in Figure 3; reverse flushing utilizes a coolant box to bring the coolant to the parts through a hole in the part to a solid electrode. Reverse flushing was used where

Figure 3. COOLANT FLUSHING ARRANGEMENT.

possible during the test primarily to cut down on the electrode fabrication time. Reverse flushing also made it simpler to measure the electrode wear, as the coolant hole in the part left an untouched portion on the electrode which served as a handy reference.

The coolant used in this study was standard EDM oil, except where noted.

URANIUM WORKPIECE

Uranium is difficult to cut by the EDM process, but cutting can be successful if the proper precautions are taken. In general, uranium requires a much lower frequency and a higher capacitance to maintain a steady cut at a given amperage than most metals. The tolerance of uranium for either over or under capacitance is small. Using brass as an electrode, the cutting rate per ampere is slightly less than that of steel under good conditions; but, due to the low-frequency and high-capacitance requirement, the finish is much rougher.

The maximum metal-removal rate is limited by the maximum capacitance of the power supply. In the case of the Ex-Cell-O 221-41S power supply, it is 137 microfarads, represented in the tables as $97 + 2R$. The "R" represents the "roughing" switch which is a 20-microfarad capacitor with a balancing inductance. The "2" is obtained from the capacitance doubler "X1-X2" switch. The "roughing" mode works best on Tap 6, with the frequency adjustment knob set on zero.

Electrodes

Although nine different electrode materials were tested, only five were worthy of serious consideration. These materials are discussed in the sections that follow.

Brass - Generally, brass is the best material for uranium, as indicated in Table A-1. The metal-removal rate is adequate and is relatively stable, making the power-supply setup easy. It has a fairly good wear ratio and is readily available in the shop.

Graphite^(b) - EDM grades of graphite, presented in Table A-2, work well with uranium when all conditions are optimized, but care must be taken when setting

(b) Unless otherwise indicated, the graphite used in this study was a moderate-cost EDM grade, Kostkutter 10, manufactured by the Speers Carbon Company, Division of Air Reduction, St. Mary's, Pennsylvania.

up the power supply because graphite tends to arc readily with uranium. Under good cutting and similar surface-finish conditions, graphite will remove 40 to 60 percent more metal than brass. Graphite machines easily and can be shaped with hand tools.

Silver-Tungsten Alloy - Silver-tungsten alloy (see Table A-3) offers very good electrode wear at metal-removal rates slightly lower than brass. It is difficult to stabilize the power supply with uranium; consequently, all controls are critical, and good flushing is essential.

Silver-tungsten alloy worked well with Cimjet-20. The cuts were stable and the wear ratio was very good. Metal-removal rates were not determined.

Copper - Copper (see Table A-4) is the most stable material with uranium. Metal removal is comparable to brass at given finish conditions. The chief difficulty with copper is its poor machining characteristics. Moderately priced tellurium-copper alloy is now available as an electrode material. This alloy has machining characteristics nearly as good as brass and maintains the EDM characteristics of copper.

Copper Graphite - Copper graphite (see Table A-5) works well with uranium, it stabilizes easily, and it does not arc readily. Its EDM characteristics offer no advantage over the other materials discussed, although it does machine well and can be shaped with hand tools.

Copper-Tungsten Alloy - Copper-tungsten alloy is usually associated with moderately fast metal-removal rates, a very good wear ratio, good stability in the proper polarity, and good machining characteristics. However, with uranium, in reverse polarity the metal-removal rate is low and electrode wear compares with brass, as shown in Table A-6. In normal polarity, the stability is very poor, it is difficult to start, and the metal-removal rate is higher than in reverse but not as high as brass. Since the wear ratio of this material is good, it should be considered for difficult-to-fabricate electrodes where a good wear ratio is desired; but, in such a case, silver-tungsten alloy would probably be a better choice despite its higher cost.

Nickel-Tungsten Alloy - Nickel-tungsten alloy is relatively difficult to machine,

it is unstable as an electrode, has poor wear characteristics, and has low metal-removal rates. It should not be considered as an electrode material.

Aluminum - Aluminum offers very little as an electrode material other than its ease of fabrication. Its wear rate is very poor and its metal-removal rate is low.

Zinc - Zinc is in the same category as aluminum. Only under unusual circumstances should either be considered.

ALUMINUM WORKPIECE

Aluminum can be machined at a very fast rate with the EDM process, but fine surface finishes are difficult to obtain. Since aluminum hand finishes very easily it is recommended, in most cases, that the final finish be obtained by this method or other conventional methods. The fast metal-removal rate of the EDM process can, thereby, be utilized to obtain the desired size and shape, then conventional methods can be used to obtain the finish. This procedure may also be successfully applied to other metals.

Electrodes

Brass - Brass (see Table A-7) is a very good electrode material with aluminum. Metal-removal rates, surface finish, and electrode wear are considered good.

Graphite - Graphite (see Table A-8) has a metal-removal rate about 1/3 greater than brass and a somewhat better wear ratio. The one disadvantage in using graphite with aluminum is that it can arc if the flushing conditions are not correct. Because it handworks easily, it is frequently possible to shape radii and corners without special cutters.

Copper Graphite - Copper graphite (see Table A-9) offers lower metal-removal rates than graphite and somewhat poorer wear ratios. It does not arc readily and it can be cut with hand tools.

Copper-Tungsten Alloy - Copper-tungsten alloy (see Table A-10) has a very good end-wear rate when used in reverse polarity. It tends to be unstable at low amperage, but performs well above 10 amperes.

TUNGSTEN WORKPIECE

Although it is a comparatively slow process, tungsten can be machined successfully

using EDM methods if all conditions are correct. Flushing conditions are especially important. A good surface finish is obtained readily with tungsten.

Electrodes

Silver-Tungsten Alloy - Silver-tungsten alloy is very stable, has good wear ratios, and a good metal-removal rate (see Table A-11). It is recommended for tungsten applications wherever possible. It is not available in tubing form.

Copper-Tungsten Alloy - Copper-tungsten alloy is nearly as good an electrode material as the silver-tungsten alloy (see Table A-11). It is not quite as stable as the silver-tungsten alloy and the setup is more critical. It is recommended as a good second choice.

Brass - Brass is very stable, but it cuts at less than one half the speed of the copper-tungsten or silver-tungsten alloys (see Table A-12). Since its wear ratios are low, electrode fabrication and setup costs may be high due to the large number of electrodes which must be prepared.

Graphite - Graphite (see Table A-13) machines tungsten at a good rate, but it does tend to arc readily at currents over nine amperes. Coolant pressure is very critical to avoid arcing. It is an acceptable electrode material if used properly and its limitations recognized.

STEEL WORKPIECE

Electrodes

Graphite - Since graphite is the generally accepted material for cutting steel, a limited study was made to evaluate the various grades in use at Y-12. The graphites used were: Kostkutter 10, Grade C-18,^(c) Grade ATJ,^(c) and a fuel-element grade of extruded graphite.

The basis for comparison was their wear ratios, metal-removal rates at a given finish, and maximum metal-removal rate using a 0.500-inch-square electrode on a Type 01 oil-hardening tool-steel workpiece. Performance data for the graphites are presented in Tables A-14 through A-18.

(c) Manufactured by the National Carbon Company, Division of the Union Carbide Corporation, New York, New York.

Based on the wear ratio, there is very little difference between the graphites; consequently, there is not much reason to choose one over the other. A better corner wear on one is offset by a better end wear on another. However, it is felt that more data would show EDM graphite to be more advantageous than the limited test data indicated.

The metal-removal rate at a given finish is presented for each graphite in Figure 4, compiled from the data in Tables A-14 through A-18. For example, using Figure 4 as a reference and a finish of 150 rms, the metal-removal rate would be:

Grade	Metal-Removal Rate (in ³ /hr)	Percent of Kostkutter 10 Rate
Kostkutter 10	0.50	100
C-18	0.29	58
ATJ	0.25	50
Extruded Graphite	0.19	38

The data indicate that it would take twice as long to produce a steel part with a 150 rms finish using Type C-18, ATJ, or extruded graphite, as it would using Kostkutter 10 graphite.

Figure 4. METAL-REMOVAL RATE AS A FUNCTION OF THE SURFACE FINISH FOR BRASS AND FOUR GRADES OF GRAPHITE.

From the data in Tables A-14 through A-17, the maximum metal-removal rate was:

Grade	Maximum Metal-Removal Rate (in ³ /hr)	Percent of Kostkutter 10 Rate
Kostkutter 10	1.91	100
Extruded Graphite	1.43	75
C-18	1.31	69
ATJ	1.15	60

In addition to obtaining faster metal removal, the finish obtained from the Kostkutter 10 is far better. However, since the size of the electrode limited the maximum current that could be used on the electrodes, larger or smaller electrodes could show different results. As the extruded graphite electrode was larger than the others, it probably enjoyed some advantage on this test.

Flaking off of particles which causes arcing and loss of definition was encountered with the ATJ, C-18, and extruded graphite electrodes. Arcing is expensive because not only can it damage the surface of the part at entry; but, to clear up an arc, the electrode must be dressed and the part cleaned in the arc area.

Because of instability, more care was required to prevent warping with C-18 and ATJ graphites during electrode fabrication. Extruded graphite electrodes were not evaluated as to their relative machining stability.

When a graphite electrode is used in reverse polarity, at a low frequency, and with no capacitance on a steel workpiece, very low electrode wear is experienced. However, the surface finish is very rough and the metal-removal rate is about 40 percent of a normal setup. A two-kilocycle circuit has been placed on the market under the trade name of No Wear^(d) to take advantage of this phenomenon. This circuit was tested at the Elox Corporation's Demonstration Laboratory. The results are reported in Table A-18. Also shown in Table A-18 are the results of two tests performed in Y-12 with an Ex-Cell-O power supply at its lowest frequency of 7.8 kc.

Brass - Brass (see Table A-19) is probably the most commonly used electrode material due to its availability in most shops and its good machinability. Neither the power-supply setup nor coolant conditions are critical. However, metal-removal rates are

(d) Manufactured by the Elox Corporation, Troy, Michigan.

low compared to other materials available, and electrode wear is only fair. Because of its wide-spread use, data are readily available on brass as an electrode on a steel workpiece. Therefore, little experimental time was spent obtaining data. With the exception of the 16-ampere cut, the data shown in Table A-19 was furnished by the Ex-Cell-O Corporation. The data plotted in Figure 4 merely illustrate the vast difference in the metal-removal rate of graphite compared to brass.

Copper-Tungsten Alloy - Copper-tungsten alloy (see Table A-20) used in reverse polarity has good metal-removal rates accompanied by a very good electrode wear rate. Copper-tungsten alloy is a very good electrode material for steel. It should be chosen when the electrode is costly to fabricate or the EDM setup is slow and it is desirable to reduce the number of setups.

Silver-Tungsten Alloy - Silver-tungsten alloy (see Table A-21) is usable with steel in reverse polarity, but it is unstable and difficult to start. The corner wear ratio is slightly better than with copper-tungsten alloy although the data in Table A-21 do not show this due to the rounding off of the values. The metal-removal rate is not as good as for the copper-tungsten alloy. In reverse polarity it is more stable but the very good end wear ratio is lost. Silver-tungsten alloy is not a good choice of electrode material. If good wear ratios are required, copper-tungsten alloy is a better choice.

STAINLESS STEEL WORKPIECE

A limited number of tests were performed on a Type 304L stainless steel workpiece in the course of cutting several deep-cavity-type parts.

Electrodes

Graphite - Graphite cuts Type 304L stainless steel at a rate slightly lower than it cuts steel (Table A-22). It must be used cautiously as it will arc if flushing conditions are not good. It will cut in reverse polarity with no capacitance; however, no rates were determined.

Copper-Tungsten Alloy - Copper-tungsten alloy cuts Type 304L stainless steel at a rate somewhat slower than it cuts steel and with somewhat poorer wear ratios, as indicated in Table A-22.

MAGNESIUM WORKPIECE

Graphite (see Table A-23) worked so well with magnesium that no other electrode material was tried. Metal-removal rates were high and the wear rates were also very good.

TITANIUM CARBIDE AND TUNGSTEN CARBIDE WORKPIECES

The results, reported in Table A-24, were obtained during the course of machining several carbide parts. In general, carbides can be cut very smoothly using the EDM process. Surface finish is good for a given amperage cut, but metal-removal rates are low. Brass was used as the electrode because it was available in the sizes required. Good EDM grades of graphite electrode material can also be used if coolant conditions are good. Tungsten carbide can be used as an effective electrode material.

EFFECTS OF ELECTRODE ROTATION

Three experiments were performed to illustrate the effects of electrode rotation on the cutting current and metal-removal rate. In each case, the power supply was set up and a stable cut made with a nonrotating, round electrode. Next, a rotating electrode of the same size was set up, keeping the power-supply settings as close as possible to the original.

In the case of brass on uranium, the power-supply gap voltage dropped four volts on the rotation cut with the adjustment knob in the same position as for the nonrotating cut. Based on this information (see Table 2), electrode rotation tends to increase the current and metal-removal rate for a given power-supply setup. Surface finish may be slightly improved by electrode rotation, but it is difficult to be certain of this fact on such a small number of tests and the limitation of surface-finish measurements.

SMALL-HOLE CUTS

Cutting small, deep holes in uranium is a good field for the EDM process, since the metal-removal time is usually faster than that obtained with conventional machining methods. It also offers the advantages of not risking the breakage of a small drill deep in a part. When small drills break, the standard practice is to set up on an EDM machine to remove the drill. This practice is risky because EDM conditions are not always ideal in these instances and leadoff or arcing into the finished part are chanced. Copper and brass-tubing electrode materials are available at reasonable prices and delivery, down to as small as 0.005 inch in diameter.

Sizing to close tolerances can be a problem with EDM due to the problem of taper and the many parameters that affect small electrodes in uranium. The remedy in these instances is usually to machine the hole undersize by EDM and then drill, ream, or lap to the finish size. The results and the power-supply settings for the materials used are presented in Table 3. The results and power-supply settings shown

Table 2
EFFECTS OF ELECTRODE ROTATION ON THE CUTTING
CURRENT AND METAL REMOVAL RATE

Description	Performance					
	Workpiece/Electrode					
	Uranium/Silver-Tungsten Alloy		Uranium/Brass		Steel/Brass	
	No	Yes	No	Yes	No	Yes
Rotation						
Metal-Removal Rate (in ³ /hour)	0.134	0.172	0.119	0.149	0.119	0.126
Metal-Removal Rate (in ³ /min-amp)	0.00020	0.00024	0.00020	0.00022	0.00021	0.00020
Current (amperes)	11	12	9.8	11.5	9.5	10.5
Power Supply and Mechanical Setup						
Tap	5	5	5	5	4	4
Verniers Up	2	2	2	2	3	3
Capacitance (microfarads)	19	19	16.5	16.5	3.5	3.5
Frequency Control Set	4 1/2	4 1/2	10	10	1	1
Power Supply Frequency (kc)	24.3	24.3	34.5	34.5	71.8	71.8
Servo Control Set	4 1/2	4 1/2	4	4	3	3
Voltage Control Set	3 3/4	3 3/4	4	4	3	3
Gap Voltage	37	34	38	34	38	38
Polarity	Normal	Normal	Normal	Normal	Normal	Normal
Flushing Arrangement	Normal	Normal	Normal	Normal	Normal	Normal
Electrode Size (inch diameter)	1/2	1/2	1/2	1/2	1/2	1/2
Number of Tests	1	1	1	1	1	1

may not be the best that can be obtained, since they represent only one or two cuts for each setup. They are intended only as a guide in job setup.

It is important in small-hole work to use an insulated guide (see Figure 5) for the flimsy electrode that is approximately one electrode diameter above the part. Electrode rotation will aid in the speed of the cut, electrode wear, and hole roundness. An oil-through tubing chuck was used on all tests. Use of this chuck is essential for efficient deep-hole work since an additional length of electrode can be stored in the hollow spindle and pulled down as needed. The OD of the tubing is effectively sealed inside the chuck to insure good coolant flow through the ID. In cases where the coolant cannot be injected through the electrode, the cycle interrupter and electrode vibrator may be utilized to improve the flushing condition.

Aluminum machines quite readily by EDM with either copper or tungsten carbide. The guide seen in Figure 5 is not always necessary. Good flushing is essential, however, as with all other materials.

Tantalum machines easily with brass. Graphite, although not listed in Table 3, was tried but was dropped due to the tendency of the material to arc. The small slits were cut using the Ex-Cell-O finishing circuit Lectra Lap with Circuit 1, which is a low-amperage RC circuit.

Figure 5. SMALL-HOLE MACHINING ARRANGEMENT.

The holes cut in tungsten and tungsten carbide were made with no great difficulty, although electrode wear was poor. The oil-through chuck aids tremendously on this type of cut because of the stored electrode length.

CIMJET-20 COOLANT WITH ELECTRODE MATERIALS

Cimjet-20 is an EDM coolant developed and patented by The Cincinnati Milling Machine Company; however, it was not marketed. A supply of the coolant (165 gallons) was purchased at a cost of \$4.45 per gallon. (Normal EDM oil costs \$0.53 per gallon.) The coolant was purchased to evaluate the EDM process for an Apollo Project aluminum part which could not tolerate the usual EDM oil. After using the coolant on the aluminum part, tests were made with a uranium workpiece and a brass electrode (see Table A-25), and with graphite and silver-tungsten alloy electrodes (see Table A-26).

The chemical content of the coolant, as stated by the producer, is:

Polyethylene Glycol	59%
Ethylene Glycol	3%
Water	35%
Rust Inhibitor	3%

Table 3
SMALL-HOLE CUTS

Workpiece Material	Electrode Conditions				Guide Diameter (inch)	Coolant Pressure (psi)	Finish Hole		Wear Ratio Tool: Depth	Time (minutes)	Tap	Verniers Up	Current (amps)	Capacitance (microfarads)	Frequency		Servo Set	Voltage		Number of Tests ⁽¹⁾
	Material	OD (inch)	ID (inch)	Rotation			Depth (inch)	Diameter (inch)							Set	Power Supply (kc)		Set	Meter	
Uranium	Copper	0.015	0.009	Yes	0.016	10	0.136	0.023	2.2:1	6	2	1	2	0.6	4	150	3	3 1/2	50	2
Uranium	Copper	0.050	0.020	Yes	0.052	15	0.535	0.056	1.2:1	10	3	3	3	2.5	2	103	4	2 1/2	44	2
Uranium	Copper	0.086	0.046	Yes	0.089	8	0.535	0.093	1.2:1	7	3	4	5	3.8	1/2	87	4	2 1/2	38	1
Uranium	Copper	0.050	0.020	Yes	0.052	20	0.300	0.556 0.552	1.2:1	8.8	2	4	4	1.5	2	120	4 1/2	3 1/2	44	1
Uranium	Copper	0.054	0.024	Yes	0.056	20	0.300	-	1.5:1	14.4	2	4	4	1.5	2	120	4 1/2	3 1/2	46	1
Uranium	Brass	0.054	0.024	Yes	0.056	20	0.300	-	1.2:1	4.4	2	5	4	1.5	2	120	4 1/2	3 1/2	44	1
Aluminum	Copper	0.086	0.046	Yes	None	40	11.75	0.100	1:3	25	5	6	33	11.5	2	19.6	8	1/2	30	2
Aluminum	Copper	0.062	0.032	Yes	None	35	6	0.066	1:1.7	120	1	5	2	0.6	3	168	4	3 1/2	40	1
Aluminum	Tungsten Carbide	0.063	0.027	Yes	None	30	6	-	1:2.4	-	1	3	2	0.6	4 1/2	201	3	1 1/2	30	1
Tungsten Carbide	Tungsten Carbide	0.063	0.027	Yes	None	30	1 3/4	0.066	2:1	45	1	2	2	0.5	5	212	3	3 1/2	37	1
Tungsten	Copper	0.010	0.004	Yes	0.014	25	0.155	0.016	5:1	75	1	1	1.5	0.3	5	212	1	3	25	1
Aluminum	Copper	0.074	0.034	Yes	None	25	2.85	0.080	1:10	20	1	3	2	0.5	3	168	3	4	44	2
Tungsten	Brass	0.234	0.124	Yes	None	4	0.556	0.244	3:1	20.3	5	4	20	14	5	25.2	5 1/2	3	31	1
Tungsten Alloy	Brass	0.494 x 0.119	0.063	No	None	20	1	0.500 0.125	Sharp Corner 10:1	-	2	4	3	0.8	4	150	5	6 1/2	42	1
Gold	Brass	0.0008 x 0.050	Solid	No	None	None	0.001	0.0025 Ragged	-	0.3	1	0	< 1(2)	0.1	0	RC	1 1/2	10	60	1
Tantalum	Brass	0.0012 x 0.050	Solid	No	None	None	0.001	0.002	-	0.3	1	0	< 1(2)	0.1	0	RC	2	3	60	2
Tantalum	Brass	0.003 x 0.050	Solid	No	None	None	0.001	0.004	-	0.3	1	0	< 1(2)	0.1	0	RC	2	3	60	2
Tantalum	Brass	0.1470 x 0.5	Solid	No	None	None	0.021	0.149 x 0.5	Sharp Corner 24:1	7.3	3	5	5	1	6 1/2	149	4 1/2	4 1/2	36	1
Tantalum	Brass	0.1470 x 0.5	Solid	No	None	None	0.021	0.1508 x 0.5	Sharp Corner 19:1	0.95	5	5	21	29	5	25.2	5	4 1/2	38	1

(1) Normal polarity was used on each test.

(2) Ex-Cell-O's Lectra-Lap (LL) Finishing Circuit Number 1.

The coolant has a relatively low flash point of 210° F and a fire point of 220° F. The pH is a relatively high 9.6. The viscosity is about 100 ssu as opposed to about 50 for the standard EDM oil.

Uranium Workpiece

Brass - Brass electrode material used in normal polarity performed very well with Cimjet-20 coolant (see Table A-25). Better results were obtained using brass with Cimjet-20 than with standard EDM oil. The metal-removal rate for a given surface finish was higher and corner wear was almost 100 percent better. End wear was about three to four times better. For a production setup designed to run continuously with a uranium workpiece, Cimjet-20 should be seriously considered as a coolant.

Graphite - Graphite (see Table A-26) was unstable with the Cimjet-20 coolant. The maximum cut which could be set up was only 12 amperes.

Silver-Tungsten Alloy - Silver-tungsten alloy (see Table A-26) worked well with the Cimjet-20 coolant. The cuts were stable and the wear ratio was very good. Metal-removal rates were not determined.

Aluminum Workpiece

None of the electrode materials worked well with Cimjet-20 coolant on aluminum. Good flushing was found to be more critical than with standard EDM oil.

Brass - Brass was very unstable in normal polarity (see Table A-27). Flushing conditions must be very good to get usable performance particularly at low amperage. End wear was good; corner wear was fair, but the metal-removal rate was very low. For practical purposes, normal polarity is not very useful because of the instability. In reverse polarity, brass is considerably more stable; however, the wear rates are very poor. The metal-removal rate is better in normal polarity, but still quite low. Of the combination of electrode materials tried, brass in reverse polarity has the greatest practical value for use on aluminum with Cimjet-20 coolant.

Graphite - Graphite will cut aluminum using Cimjet-20 coolant in reverse polarity, but the metal-removal rate is low (see Table A-28). It is only stable above three amperes and below 25 amperes. It will not stabilize in normal polarity.

Tellurium-Copper Alloy - Tellurium-copper alloy (see Table A-28) has the same EDM characteristics as copper, and it has good machining characteristics comparable to brass. However, it is not recommended as an electrode for aluminum with Cimjet-20. All normal polarity cuts are unstable and reverse polarity cuts are unstable below nine amperes.

Copper-Tungsten Alloy - Copper-tungsten alloy will not stabilize with aluminum using Cimjet-20 coolant.

CONCLUSIONS AND RECOMMENDATIONS

During the course of performing the tests and compiling the information included in this report, it became increasingly apparent that experience with electrical discharge machining equipment is necessary before the equipment can be used efficiently. Techniques used for EDM work, although not difficult, demand close attention to details, particularly in the machine setup. Only through continual use will machining personnel be able to operate the equipment at anywhere near its maximum efficiency. EDM also requires serious advance planning to be effective. Makeshift setups will usually provide poor results. The best way to accomplish these aims is with the organization of an EDM specialty shop. In addition to EDM equipment, the shop should be equipped with a few small tools that could handle most electrode fabrication needs. The shop's operating personnel should be stable so that the knowledge and experience gained would be concentrated in a few individuals, thus making the EDM effort as effective as the equipment is efficient.

In regard to the choice of electrode material, there is no single clear-cut choice for any given workpiece. For example, with a steel workpiece, graphite would appear to be the logical choice because of its high metal-removal characteristics. However, if the shape of the electrode is difficult to machine, an electrode material with a good wear ratio such as the copper-tungsten alloy might be better.

Some limited testing was done with coolants other than EDM oil. Distilled water, tap water, and ethyl alcohol were also tried, but without enough success to compile meaningful data. In an effort to increase the metal-removal rates, improve the electrode wear ratio, and improve the surface finish, tests should be performed to evaluate some of the new, but more expensive, fluids presently available on the market. Despite a high initial cost per gallon, when compared to standard EDM oil, these fluids may be more economical to use in relatively high-cost shops.

The EDM process is especially adaptable to small-hole work. Uranium and tungsten, which are particularly difficult to drill with conventional cutting methods, respond very well to the EDM process, provided that setup and operation are correct. Even aluminum, which machines readily by conventional methods, becomes difficult when the hole diameter is small and the depth great. For example, a 0.066-inch-diameter hole, 6 inches deep, was cut into an aluminum turbine blade in 120 minutes. Hole sizing to close tolerances and very good finishes are possible but difficult with EDM. Under these conditions, conventional reaming, boring, or lapping are recommended after making the original hole with EDM.

There are more expensive grades of EDM graphite available that may have better EDM characteristics than those tested. Tests should be performed to determine if this is true.

Electrode rotation proved to produce higher metal-removal rates and a higher current at the same power-supply settings in the three cases where comparisons were made. Electrode rotation should be used wherever possible.

The low-frequency, no-capacitance, reverse-polarity circuits could be of value since they practically eliminate wear on the electrode when machining a steel workpiece. However, a very rough surface finish and a decrease in the metal-removal rate result from using such circuits. Moreover, these circuits are limited to those workpiece materials, particularly steel, cut with a graphite electrode.

APPENDIX

PERFORMANCE CHARACTERISTICS OF VARIOUS WORKPIECES AND ELECTRODES

Table A-1
PERFORMANCE CHARACTERISTICS OF A URANIUM WORKPIECE
AND A BRASS ELECTRODE

Description	Performance			
	180	250	400	650
Finish (rms)				
Metal-Removal Rate (in ³ /hour)	0.060	0.132	0.216	0.364(1)
Metal-Removal Rate (in ³ /min-amp)	0.00020	0.00022	0.00024	0.00019
Overcut (inch)	0.0021	0.0029	0.0032	0.0048
Wear Ratio, Tool: Work (sharp corner)	4:1	3 1/2:1	3:1	4 1/2:1
Wear Ratio, Tool: Work (side)	-	2:1	2 1/2 : 1	2 1/2:1
Wear Ratio, Tool: Work (end)	1:2	1:2 1/2	1:2 1/2	1:2
Power Supply and Mechanical Setup				
Tap	3	5	5	6
Verniers Up	3	2	3	6
Current (amperes)	5	10	15	32
Capacitance (microfarads)	2.5	17	46	97 + 2R
Frequency Control Set	3	0	0	0
Power Supply Frequency (kc)	113	15.9	15.9	7.8
Servo Control Set	4	4	5 1/2	8 1/2
Voltage Control Set	3	4	4	3 1/4
Gap Voltage	32	37	37	32
Polarity	Normal	Normal	Normal	Normal
Flushing Arrangement	Reverse	Reverse	Reverse	Reverse
Electrode Size (inch square)	1/2	1/2	1/2	1/2
Number of Tests	3	4	2	3

(1) Maximum power due to capacitance requirements.

Table A-2
PERFORMANCE CHARACTERISTICS OF A URANIUM WORKPIECE
AND A GRAPHITE ELECTRODE

Description	Performance			
Finish (rms)	150	250	450	600
Metal-Removal Rate (in ³ /hour)	0.094	0.218	0.340	0.533(1)
Metal-Removal Rate (in ³ /min-amp)	0.00031	0.00033	0.00028	0.00034
Overcut (inch)	0.0022	0.0029	0.0036	0.0040
Wear Ratio, Tool:Work (sharp corner)	3 1/2:1	2 1/2:1	4:1	4 1/2:1
Wear Ratio, Tool:Work (side)	-	1:1	-	-
Wear Ratio, Tool:Work (end)	1:1 1/2	1:2 1/2	1:1/2	1:2
Power Supply and Mechanical Setup				
Tap	4	5	5	6
Verniers Up	0	1	3	4
Current (amperes)	5	11	20	26
Capacitance (microfarads)	4.3	32.2	65.1	97 + 2R
Frequency Control Set	0	6	1 1/2	0
Power Supply Frequency (kc)	64.5	27.1	8.7	7.8
Servo Control Set	4	6	7	9
Voltage Control Set	4 1/2	2	2	2 1/4
Gap Voltage	37	28	27	26
Polarity	Normal	Normal	Normal	Normal
Flushing Arrangement	Reverse	Reverse	Reverse	Reverse
Electrode Size (inch square)	1/2	1/2	1/2	1/2
Number of Tests	2	3	2	2

(1) Arcs readily; capacitance setup is critical.

Table A-3
PERFORMANCE CHARACTERISTICS OF A URANIUM WORKPIECE
AND A SILVER-TUNGSTEN ALLOY ELECTRODE

Description	Performance				
Finish (rms)	250	125	300	400	500
Metal-Removal Rate (in ³ /hour)	0.062	-	0.134	0.234	-
Metal-Removal Rate (in ³ /min-amp)	0.00009	-	0.00020	0.00021	-
Overcut (inch)	-	-	0.003	0.003	-
Wear Ratio, Tool:Work (sharp corner)	4:1	-	1:1	1:1	-
Wear Ratio, Tool:Work (side)	2:1	-	1:1	1:1	-
Wear Ratio, Tool:Work (end)	1:1 1/2	-	1:29	1:27	-
Power Supply ⁽¹⁾ and Mechanical Setup					
Tap	5	3	5	5	6
Verniers Up	2	6	2	4	6
Current (amperes)	11	5	11	19	36
Capacitance (microfarads)	19	1.5	19	41	89 + 2R
Frequency Control Set	6	4	5	3	0
Power Supply Frequency (kc)	27.1	123	21.5	25.2	7.8
Servo Control Set	6	4	4 1/2	4 1/2	6
Voltage Control Set	3 3/4	3 3/4	3 3/4	3 1/2	2 1/4
Gap Voltage	37	33	37	37	26
Polarity	Reverse	Normal	Normal	Normal	Normal
Flushing Arrangement	Reverse	Reverse	Reverse	Reverse	Reverse
Electrode Size	1/2	1/2	1/2	1/2	1/2
Number of Tests	2	1	2	2	1

(1) Power supply setup is critical and difficult to stabilize. Reverse polarity is impractical.

Table A-4
PERFORMANCE CHARACTERISTICS OF A URANIUM WORKPIECE
AND A COPPER ELECTRODE

Description	Performance				
	110	160	275	350	600
Finish (rms)					
Metal-Removal Rate (in ³ /hour)	0.024	0.064	0.120	0.180	0.233(1)
Metal-Removal Rate (in ³ /min-amp)	0.00014	0.00019	0.00020	0.00018	0.00015
Overcut (inch)	0.0016	0.0023	0.0029	0.0032	0.0042
Wear Ratio, Tool:Work (sharp corner)	2:1	3:1	2 1/2:1	4:1	6:1
Wear Ratio, Tool:Work (side)	-	-	1:1	-	-
Wear Ratio, Tool:Work (end)	-	-	1:5	-	-
Power Supply and Mechanical Setup					
Tap	3	3	5	5	6
Verniers Up	1	4	2	3	4
Current (amperes)	2.8	5.5	10	17	26
Capacitance (microfarads)	1	2.5	16.5	31	97 + 2R
Frequency Control Set	7	0	5	4	0
Power Supply Frequency (kc)	154	82	25.2	23.3	7.8
Servo Control Set	3	5	5 1/4	4	6
Voltage Control Set	3 1/4	5 1/4	4 1/2	3 1/2	2 1/2
Gap Voltage	33	40	39	34	27
Polarity	Normal	Normal	Normal	Normal	Normal
Flushing Arrangement	Reverse	Reverse	Reverse	Reverse	Reverse
Electrode Size (inch square)	1/2	1/2	1/2	1/2	1/2
Number of Tests	2	2	2	2	2

(1) Maximum power due to capacitance requirements.

Table A-5
PERFORMANCE CHARACTERISTICS OF A URANIUM WORKPIECE
AND A COPPER GRAPHITE ELECTRODE

Description	Performance			
	110	190	280	500
Finish (rms)				
Metal-Removal Rate (in ³ /hour)	-	0.045	0.104	0.195(1)
Metal-Removal Rate (in ³ /min-amp)	-	0.00015	0.00016	0.00016
Overcut (inch)	-	0.0023	0.0024	0.0028
Wear Ratio, Tool:Work (sharp corner)	-	-	-	-
Wear Ratio, Tool:Work (side)	-	1 1/2:1	1 1/2:1	1 1/2:1
Wear Ratio, Tool:Work (end)	-	1:3	1:3 1/2	1:2 1/2
Power Supply and Mechanical Setup				
Tap	2	3	5	6
Verniers Up	1	6	2	4
Current (amperes)	2	5	11	20
Capacitance (microfarads)	0.5	3.5	19	97 + 2R
Frequency Control Set	6	1	4	0
Power Supply Frequency (kc)	179	92	23.3	7.8
Servo Control Set	4	3	5	6
Voltage Control Set	5	4 1/2	4 1/2	3 1/4
Gap Voltage	39	41	39	32
Polarity	Normal	Normal	Normal	Normal
Flushing Arrangement	Reverse	Reverse	Reverse	Reverse
Electrode Size (inch round)	1/2	1/2	1/2	1/2
Number of Tests	1	2	2	2

(1) Maximum power due to capacitance requirements.

Table A-6
PERFORMANCE CHARACTERISTICS OF A URANIUM WORKPIECE AND COPPER-TUNGSTEN
ALLOY, NICKEL-TUNGSTEN ALLOY, ALUMINUM, AND ZINC ELECTRODES

Description	Performance(1)								
	Copper-Tungsten Alloy		Nickel-Tungsten Alloy				Aluminum	Zinc	
Finish (rms)	-	-	-	-	-	-	600	300	200
Metal-Removal Rate (in ³ /hour)	0.053	0.093	-	-	-	-	0.150(2)	0.035	-
Metal-Removal Rate (in ³ /min-amp)	0.00009	0.00015	-	-	-	-	0.00007	0.00008	-
Overcut (inch)	0.0023	0.0023	-	-	-	-	0.003	-	-
Wear Ratio, Tool: Work (sharp corner)	-	1 1/2:1	-	-	-	-	6:1	-	-
Wear Ratio, Tool: Work (side)	2 1/2:1	1:1	-	-	-	-	2 1/2:1	-	-
Wear Ratio, Tool: Work (end)	1:2	1:1	-	-	-	-	1:1	3:1	3:1
Power Supply and Mechanical Setup									
Tap	5	5	5	6	6	6	Dual 6	5	4
Verniers Up	1	2	0	2	4	6	5:4	1	0
Current (amperes)	10	10	5	12	20	30	38	7	5
Capacitance (microfarads)	3.1	20	18.5	53	80	96	97 + 2R	95	14
Frequency Control Set	0	4	9 1/2	4 1/2	0	0	0	0	0
Power Supply Frequency (kc)	15.9	23.3	33.6	11.7	7.8	7.8	7.8	15.9	64.5
Servo Control Set	3 1/2	5	5	7	7	8	8 1/2	5	5
Voltage Control Set	3 1/2	3 3/4	4	4	3 3/4	3 3/4	3 1/2	3 1/2	3
Gap Voltage	34	36	35	35	33	33	32	37	32
Polarity	Reverse	Normal	Reverse	Reverse	Reverse	Reverse	Reverse	Normal	Normal
Flushing Arrangement	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse
Electrode Size (inch square)(3)	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2
Number of Tests	2	2	1	1	1	1	2	2	1

(1) Copper-tungsten alloy is difficult to start in normal polarity and the cut is unstable. Reverse polarity is impractical. Nickel-tungsten alloy cuts are unstable and will not cut with normal polarity.

(2) Maximum power due to capacitance requirements.

(3) Inch diameter in case of aluminum and zinc.

Table A-7
PERFORMANCE CHARACTERISTICS OF AN ALUMINUM WORKPIECE
AND A BRASS ELECTRODE

Description								
		Performance						
Finish (rms)	40	100	110	160	200	400	500	
Metal Removal Rate (in ³ /hour)	-	-	0.124	0.255	0.518	0.177	-	
Metal Removal Rate (in ³ /min-amp)	-	-	0.00069	0.00085	0.00096	0.00147	-	
Overcut (inch)	-	-	0.0021	0.0024	0.0027	0.0055	-	
Wear Ratio, Tool:Work (sharp corner)	-	-	-	-	1:1	1:1	-	
Wear Ratio, Tool:Work (side)	-	-	-	-	-	-	-	
Wear Ratio, Tool:Work (end)	-	-	-	-	1:8 1/2	1:8 1/2	-	
		Power Supply and Mechanical Setup						
Tap	1	1	2	3	4	5	5	
Verniers Up	0	5	2	5	2	4	6	
Current (amperes)	1	2 1/2	3	5	9	20	30	
Capacitance (microfarads)	0.1	0.5	0.6	0.7	2.5	22	39	
Frequency Control Set	6	6	2 1/2	4	2	7 1/2	4	
Power Supply Frequency (kc)	233	233	128	93.5	79.0	29.8	23.3	
Servo Control Set	4	3	2	2 1/2	4 1/2	6 1/2	5	
Voltage Control Set	2 1/2	4	1	1 1/2	3 3/4	3 1/2	3	
Gap Voltage	30	36	30	31	33	33	30	
Polarity	Normal	Normal	Normal	Normal	Normal	Normal	Normal	
Flushing Arrangement	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse	
Electrode Size (inch square)	1/2	1/2	1/2	1/2	1/2	1/2	1/2	
Number of Tests	1	1	2	2	5	2	1	

Table A-8
PERFORMANCE CHARACTERISTICS OF AN ALUMINUM WORKPIECE
AND A GRAPHITE ELECTRODE

Description	Performance				
Finish (rms)	60	140	250	350	500
Metal-Removal Rate (in ³ /hour)	0.409	0.531	1.18	2.22	-
Metal-Removal Rate (in ³ /min-amp)	0.00228	0.00178	0.00207	0.00185	-
Overcut (inch)	0.001	0.0020	0.0026	0.0048	-
Wear Ratio, Tool:Work (sharp corner)	-	1:1	1:1 1/2	1:1 1/2	-
Wear Ratio, Tool:Work (side)	-	-	-	-	-
Wear Ratio, Tool:Work (end)	1:10	1:8 1/2	1:8 1/2	1:10	-
Power Supply and Mechanical Setup					
Tap	2	3	4	5	5
Verniers Up	3	6	2	4	6
Current (amperes)	3	5	9 1/2	20	30
Capacitance (microfarads)	0.3	0.6	1.5	22	44
Frequency Control Set	2 1/2	3	5	1	0
Power Supply Frequency (kc)	128	113	100.8	17.8	15.9
Servo Control Set	3 3/4	4	3 1/2	7	5
Voltage Control Set	1 1/2	1 1/2	2 1/2	3 1/2	3
Gap Voltage	27	27	31	33	32
Polarity	Normal	Normal	Normal	Normal	Normal
Flushing Arrangement	Reverse	Reverse	Reverse	Reverse	Reverse
Electrode Size (inch square)	1/2	1/2	1/2	1/2	1/2
Number of Tests	2	3	3	2	1

Table A-9
PERFORMANCE CHARACTERISTICS OF AN ALUMINUM WORKPIECE
AND A COPPER GRAPHITE ELECTRODE

Description	Performance				
Finish (rms)	95	125	200	300	400
Metal-Removal Rate (in ³ /hour)	-	0.271	0.750	-	-
Metal-Removal Rate (in ³ /min-amp)	-	0.00090	0.00114	-	-
Overcut (inch)	-	0.0023	0.0037	-	-
Wear Ratio, Tool:Work (sharp corner)	-	-	-	-	-
Wear Ratio, Tool:Work (side)	-	1:1	1:1	-	-
Wear Ratio, Tool:Work (end)	-	1:6 1/2	1:6 1/2	-	-
Power Supply and Mechanical Setup					
Tap	1	3	4	5	6
Verniers Up	3	5	3	4	6
Current (amperes)	2	5	11	20	33
Capacitance (microfarads)	0.5	1	2.5	28	58
Frequency Control Set	6	5	4	2	4
Power Supply Frequency (kc)	233	134	86.3	19.2	11.2
Servo Control Set	4	5 1/2	5	4 1/2	7 1/2
Voltage Control Set	5	4	4	3	3
Gap Voltage	38	34	35	32	32
Polarity	Normal	Normal	Normal	Normal	Normal
Flushing Arrangement	Reverse	Reverse	Reverse	Reverse	Reverse
Electrode Size (inch diameter)	1/2	1/2	1/2	1/2	1/2
Number of Tests	1	2	2	1	1

Table A-10
PERFORMANCE CHARACTERISTICS OF AN ALUMINUM WORKPIECE
AND A COPPER-TUNGSTEN ALLOY ELECTRODE

Description						
Performance						
Finish (rms)	120	300	400	-	-	-
Metal-Removal Rate (in ³ /hour)	-	-	1.600	-	-	0.785
Metal-Removal Rate (in ³ /min-amp)	-	-	0.00083	-	-	0.00069
Overcut (inch)	-	-	0.004	0.0019	-	0.004
Wear Ratio, Tool:Work (sharp corner)	-	-	1:1	-	-	1:1
Wear Ratio, Tool:Work (side)	-	-	-	-	-	-
Wear Ratio, Tool:Work (end)	-	-	1:83	-	-	1:33
Power Supply and Mechanical Setup						
Tap	4	5	6	3	4	5
Verniers Up	2	4	6	5	2	4
Current (amperes)	10	20	32	5	10	19
Capacitance (microfarads)	4	16	21	1.5	3	36
Frequency Control Set	2	6	8	5	3 1/2	3
Power Supply Frequency (kc)	79.0	27.1	14.7	134	89.9	21.5
Servo Control Set	4	4	5 1/2	4	4	4
Voltage Control Set	3	3 1/4	2 1/2	3 1/2	3	3 1/2
Gap Voltage	31	32	29	33	32	33
Polarity (I)	Reverse	Reverse	Reverse	Normal	Normal	Normal
Flushing Arrangement	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse
Electrode Size (inch square)	1/2	1/2	1/2	1/2	1/2	1/2
Number of Tests	1	1	2	2	1	1

(1) Reverse polarity is usable to a minimum of 10 amperes. Normal polarity is unstable, but usable to a minimum of 5 amperes.

Table A-11
PERFORMANCE CHARACTERISTICS OF A TUNGSTEN WORKPIECE
AND SILVER AND COPPER-TUNGSTEN ALLOY ELECTRODES

Description		
Performance		
	Silver-Tungsten Alloy	Copper-Tungsten Alloy
Finish (rms)	200	0.250
Metal-Removal Rate (in ³ /hour)	0.255	0.213
Metal-Removal Rate (in ³ /min-amp)	0.00013	0.00011
Overcut (inch)	0.0025	0.0026
Wear Ratio, Tool:Work (sharp corner)	1 1/2:1	1 1/2:1
Wear Ratio, Tool:Work (side)	1 1/2:1	1 1/2:1
Wear Ratio, Tool:Work (end)	1:3 1/2	1:2 1/2
Power Supply and Mechanical Setup		
Tap	5	5
Verniers Up	6	6
Current (amperes)	32	32
Capacitance (microfarads)	29.5	29.5
Frequency Control Set	0	0
Power Supply Frequency (kc)	15.9	15.9
Servo Control Set	7	6 1/2
Voltage Control Set	2 3/4	2 3/4
Gap Voltage	30	28
Polarity	Normal	Normal
Flushing Arrangement	Normal	Reverse
Electrode Size (inch square)	1/2	1/2
Number of Tests	2	2

Table A-12
PERFORMANCE CHARACTERISTICS OF A TUNGSTEN WORKPIECE
AND A BRASS ELECTRODE

Description						
Performance						
Finish (rms)	40	75	125	200	230	300
Metal-Removal Rate (in ³ /hour)	-	-	0.030	0.061	-	-
Metal-Removal Rate (in ³ /min-amp)	-	-	0.00005	0.00005	-	-
Overcut (inch)	-	-	-	0.0034	-	-
Wear Ratio, Tool: Work (sharp corner)	-	-	-	10:1	-	-
Wear Ratio, Tool: Work (side)	-	-	-	-	-	-
Wear Ratio, Tool: Work (end)	-	-	-	-	-	-
Power Supply and Mechanical Setup						
Tap	1	3	4	5	5	6
Verniers Up	0	6	2	4	5	6
Current (amperes)	1	5	10	20	25	27
Capacitance (microfarads)	0.3	1	5.5	14.5	22.5	53
Frequency Control Set	4	9 1/2	0	9	0	3
Power Supply Frequency (kc)	190	180	64.5	32.6	15.9	10.4
Servo Control Set	3 1/2	4	4 1/2	6 1/2	7	6 1/2
Voltage Control Set	2 1/2	2 1/2	3	3 1/2	4 1/2	4
Gap Voltage	31	31	32	34	38	24
Polarity	Normal	Normal	Normal	Normal	Normal	Normal
Flushing Arrangement	Normal	Normal	Normal	Normal	Normal	Normal
Electrode Size (inch diameter)	1/4	1/4	1/4	1/2(1)	1/4	1/4
Number of Tests	1	1	2	2	1	1

(1) Inch square.

Table A-13
PERFORMANCE CHARACTERISTICS OF A TUNGSTEN WORKPIECE
AND A GRAPHITE ELECTRODE

Description					
Performance					
Finish (rms)	45	65	90	160	350
Metal-Removal Rate (in ³ /hour)	-	-	-	0.107	-
Metal-Removal Rate (in ³ /min-amp)	-	-	-	0.00019	-
Overcut (inch)	-	-	-	0.003	-
Wear Ratio, Tool: Work (sharp corner)	-	-	-	-	-
Wear Ratio, Tool: Work (side)	-	-	-	-	-
Wear Ratio, Tool: Work (end)	-	-	-	1:1	-
Power Supply and Mechanical Setup					
Tap	2	2	3	5	6
Verniers Up	1	6	6	2	4
Current (amperes)	2	4	6	9 1/2	18
Capacitance (microfarads)	0.5	1	1.5	9.5	26 + R
Frequency Control Set	6	3	4	5	0
Power Supply Frequency (kc)	179	135	123	25.2	7.8
Servo Control Set	4	4	4	5	8
Voltage Control Set	5	5	4	5	5
Gap Voltage	38	37	36	38	37
Polarity	Normal	Normal	Normal	Normal	Normal
Flushing Arrangement(1)	Reverse	Reverse	Reverse	Normal	Reverse
Electrode Size (inch square)	1/2	1/2	1/2	1/2	1/2
Number of Tests	1	1	1	2	1

(1) Coolant pressure adjustment is very critical above 9 amperes to avoid arcing.

Table A-14
PERFORMANCE CHARACTERISTICS OF A STEEL WORKPIECE
AND A KOSTKUTTER 10 GRAPHITE ELECTRODE

Description		Performance						
		65	90	140	200	290	350 ⁽¹⁾	350
Finish (rms)	-	0.060	-	0.447	1.09	1.31	1.91	0.674
Metal-Removal Rate (in ³ /hour)	-	0.00036	-	0.00078	0.00091	0.0087	0.00088	0.00034
Metal-Removal Rate (in ³ /min-amp)	-	0.0007	-	0.0018	0.0024	-	-	0.0033
Overcut (inch)	-	2 1/2:1	-	1 1/2:1	1 1/2:1	-	-	1:1
Wear Ratio, Tool: Work (sharp corner)	-	-	-	-	-	-	-	-
Wear Ratio, Tool: Work (side)	-	1:2 1/2	-	1:4 1/2	1:5 1/2	1:4	-	1:60
Wear Ratio, Tool: Work (end)	-	-	-	-	-	-	-	-
		Power Supply and Mechanical Setup						
Tap	1	1	3	4	5	5	Dual 6	6
Verniers Up	3	6	6	4	5	6	4-4	5
Current (amperes)	2	2.8	5	9.5	20	30	36	33
Capacitance (microfarads)	0.5	0.5	1	2.5	27	27	50 + R	0
Frequency Control Set	6 1/2	4	5	3 1/2	5	1/2	0	0
Power Supply Frequency (kc)	244	190	134	89.9	25.2	16.8	7.8	7.8
Servo Control Set	4	4 1/2	3 1/2	4	6	6 1/2	9	4 1/2
Voltage Control Set	4	4 1/2	4	4 1/2	2 1/2	2 1/2	3 1/2	1/2
Gap Voltage	40	40	38	40	32	31	33	22
Polarity	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Reverse
Flushing Arrangement	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse
Electrode Size (inch square)	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2
Number of Tests	1	2	2	4	2	2	1	2

(1) Maximum stable cut.

Table A-15
PERFORMANCE CHARACTERISTICS OF A STEEL WORKPIECE
AND A GRADE C-18 GRAPHITE ELECTRODE

Description	Performance					
	90	125	180	300	450(1)	500
Finish (rms)	0.141	-	0.399	-	1.312	0.513
Metal-Removal Rate (in ³ /hour)	0.00079	-	0.00063	-	0.00088	0.00025
Metal-Removal Rate (in ³ /min-amp)	0.0010	-	0.0012	-	0.0042	0.0045
Overcut (inch)	3:1	-	-	-	-	1:1
Wear Ratio, Tool:Work (sharp corner)	-	-	-	-	-	-
Wear Ratio, Tool:Work (side)	-	-	-	-	-	-
Wear Ratio, Tool:Work (end)	1:3	-	1:3 1/2	-	1:5 1/2	1:73
Power Supply and Mechanical Setup						
Tap	1	3	4	5	6	6
Verniers Up	6	5	3	4	6	5
Current (amperes)	3	5	10	20	25	34
Capacitance (microfarads)	1	1.5	3.5	19	29 + R	0
Frequency Control Set	4 1/2	4	1	2	0	0
Power Supply Frequency (kc)	201	123	71.8	19.6	7.8	7.8
Servo Control Set	4 1/2	4 1/2	5 1/2	5	5 1/2	4
Voltage Control Set	3 1/2	4	4 1/2	2 1/2	4	1/2
Gap Voltage	36	37	38	32	37	22
Polarity	Normal	Normal	Normal	Normal	Normal	Reverse
Flushing Arrangement	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse
Electrode Size (inch square)	1/2	1/2	1/2	1/2	1/2	1/2
Number of Tests	2	1	2	1	2	2

(1) Maximum stable cut.

Table A-16
PERFORMANCE CHARACTERISTICS OF A STEEL WORKPIECE
AND A GRADE ATJ GRAPHITE ELECTRODE

Description	Performance					
	80	100	190	300	400(1)	650
Finish (rms)	0.0623	-	0.376	0.848	1.145	0.615
Metal-Removal Rate (in ³ /hour)	0.00037	-	0.00063	0.00071	0.00077	0.00030
Metal-Removal Rate (in ³ /min-amp)	0.0007	-	0.0022	0.0035	0.0044	0.0044
Overcut (inch)	2:1	-	2:1	1 1/2:1	1 1/2:1	1:1
Wear Ratio, Tool:Work (sharp corner)	-	-	-	-	-	-
Wear Ratio, Tool:Work (side)	-	-	-	-	-	-
Wear Ratio, Tool:Work (end)	1:3	-	1:5	1:6	1:6	1:44
Power Supply and Mechanical Setup						
Tap	1	3	4	5	6	6
Verniers Up	6	6	3	4	5	5
Current (amperes)	2.8	5	10	20	25	34
Capacitance (microfarads)	0.5	1	2.5	21	16 + R	0
Frequency Control Set	5	5 1/2	1	0	0	0
Power Supply Frequency (kc)	212	139	71.8	15.9	7.8	7.8
Servo Control Set	4	4 1/2	2	4	6	5
Voltage Control Set	4	4	4	3	2 1/2	1/2
Gap Voltage	37	37	37	34	32	32
Polarity	Normal	Normal	Normal	Normal	Normal	Reverse
Flushing Arrangement	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse
Electrode Size (inch square)	1/2	1/2	1/2	1/2	1/2	1/2
Number of Tests	2	1	2	2	2	2

(1) Maximum stable cut.

Table A-17
PERFORMANCE CHARACTERISTICS OF A STEEL WORKPIECE
AND AN EXTRUDED GRAPHITE ELECTRODE

Description	Performance					
Finish (rms)	90	125	200	300	400(1)	450
Metal-Removal Rate (in ³ /hour)	-	0.120	0.393	-	1.432	0.791
Metal-Removal Rate (in ³ /min-amp)	-	0.0004	0.00067	-	0.0008	0.0004
Overcut (inch)	-	0.0025	0.003	-	0.005	0.004
Wear Ratio, Tool: Work (sharp corner)	-	2 1/2:1	2:1	-	2:1	1:1
Wear Ratio, Tool: Work (side)	-	-	-	-	-	-
Wear Ratio, Tool: Work (end)	-	1:3	1:4	-	1:5	1:60
Power Supply and Mechanical Setup						
Tap	1	3	4	5	6	6
Verniers Up	6	6	2	4	6	5
Current (amperes)	3	5	10	21	30	33
Capacitance (microfarads)	0.6	0.6	2.5	15	10 + R	0
Frequency Control Set	4	6	1 1/2	6	0	0
Power Supply Frequency (kc)	190	144	75.4	27.1	7.8	7.8
Servo Control Set	4	4 1/2	4 1/2	4	6	4 1/2
Voltage Control Set	4 1/2	4	2 1/2	2 1/2	2 1/2	1/2
Gap Voltage	40	36	31	32	32	22
Polarity	Normal	Normal	Normal	Normal	Normal	Reverse
Flushing Arrangement	Normal	Normal	Normal	Normal	Normal	Normal
Electrode Size (inch hex)	3/4	3/4	3/4	3/4	3/4	3/4
Number of Tests	1	2	2	1	2	3

(1) Maximum stable cut.

Table A-18
PERFORMANCE CHARACTERISTICS OF A STEEL WORKPIECE
AND A GRAPHITE ELECTRODE FOR SPECIAL
LOW-WEAR APPLICATION

Description	Performance	
	Elox No Wear Power Supply(1)	Ex-Cell-O 221-40S Standard Power Supply(2)
Finish (rms)	~ 1000	350
Metal-Removal Rate (in ³ /hour)	1.39	0.674
Metal-Removal Rate (in ³ /min-amp)	0.00046	0.00034
Overcut (inch)	0.010	0.0033
Wear Ratio, Tool: Work (sharp corner)	1:100	1:1
Wear Ratio, Tool: Work (side)	1:100	-
Wear Ratio, Tool: Work (end)	1:100	1:60
Power Supply and Mechanical Setup		
Tap	NW	6
Verniers Up	-	5
Current (amperes)	50	33
Capacitance (microfarads)	0	0
Frequency Control Set	-	0
Power Supply Frequency (kc)	2	7.8
Servo Control Set	-	4 1/2
Voltage Control Set	-	1/2
Gap Voltage	~ 25	22
Polarity	Reverse	Reverse
Flushing Arrangement	Reverse	Reverse
Electrode Size (inch square)	1 1/2	1/2
Number of Tests	1	2

(1) Test performed at Elox Corporation's Demonstration Laboratory.

(2) Test performed at Y-12.

Table A-19
PERFORMANCE CHARACTERISTICS OF A STEEL WORKPIECE
AND A BRASS ELECTRODE

Description	Performance					
Finish (rms)	50	75	115	150	190	300
Metal-Removal Rate (in ³ /hour)	0.015	0.060	0.150	0.235	0.450	0.720
Metal-Removal Rate (in ³ /min-amp)	0.00013	0.00020	0.00025	0.00025	0.00035	0.0003
Overcut (inch)	0.0007	0.0011	0.0017	-	0.0036	0.0045
Wear Ratio, Tool:Work (sharp corner)	-	-	-	3:1	-	-
Wear Ratio, Tool:Work (side)	-	-	-	2:1	-	-
Wear Ratio, Tool:Work (end)	-	-	-	1:2	-	-
Power Supply and Mechanical Setup						
Tap	1	3	4	4	5	6
Verniers Up	2	5	1	3	4	6
Current (amperes)	2	5	10	16	25	40
Capacitance (microfarads)	0.2	0.6	1.2	2.3	13	40
Frequency Control Set	10	7	7	0	10	5
Power Supply Frequency (kc)	320	154	71.8	64.5	34.5	12.1
Servo Control Set	-	-	-	-	-	-
Voltage Control Set	2	2	2	2	2	1
Gap Voltage	30	30	30	30	30	25
Polarity	Normal	Normal	Normal	Normal	Normal	Normal
Flushing Arrangement	-	-	-	Reverse	-	-
Electrode Size (inch square)	-	-	-	1/2	-	-
Number of Tests	(1)	(1)	(1)	2	(1)	(1)

(1) Data furnished by the Ex-Cell-O Corporation, Lectra-Form Division from a 221-40S power supply.

Table A-20
PERFORMANCE CHARACTERISTICS OF A STEEL WORKPIECE
AND A COPPER-TUNGSTEN ALLOY ELECTRODE

Description	Performance					
Finish (rms)	40	50	65	220	300	350
Metal-Removal Rate (in ³ /hour)	-	-	0.073	0.251	-	-
Metal-Removal Rate (in ³ /min-amp)	-	-	0.00040	0.00040	-	-
Overcut (inch)	-	0.0008	-	-	-	-
Wear Ratio, Tool: Work (sharp corner)	-	-	-	1:1	-	-
Wear Ratio, Tool: Work (side)	-	-	-	1:1	-	-
Wear Ratio, Tool: Work (end)	-	-	-	1:21	-	-
Power Supply and Mechanical Setup						
Tap	1	1	3	4	5	6
Verniers Up	2	6	6	4	5	6
Current (amperes)	2	3	5	10.6	22	34
Capacitance (microfarads)	0.5	0.6	1	5.5	30.5	39 + R
Frequency Control Set	6	3	7	2	5	0
Power Supply Frequency (kc)	233	168	154	79.0	25.2	7.8
Servo Control Set	4	4	4 1/2	6	7	9
Voltage Control Set	3 1/2	3	4	3 1/2	4	2 1/4
Gap Voltage	38	31	36	34	38	26
Polarity	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse
Flushing Arrangement	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse
Electrode Size (inch square)	1/2	1/2	1/2	1/2	1/2	1/2
Number of Tests	1	2	2	2	1	1

Table A-21

PERFORMANCE CHARACTERISTICS OF A STEEL WORKPIECE
AND A SILVER-TUNGSTEN ALLOY ELECTRODE

Description		Performance					
Finish (rms)	-	230	-	-	-	210	-
Metal-Removal Rate (in ³ /hour)	-	0.165	-	-	-	0.205	-
Metal-Removal Rate (in ³ /min-amp)	-	0.00026	-	-	-	0.00033	-
Overcut (inch)	-	0.0018	-	-	-	0.0019	-
Wear Ratio, Tool: Work (sharp corner)	-	1:1	-	-	-	1:1	-
Wear Ratio, Tool: Work (side)	-	1:1	-	-	-	1:1	-
Wear Ratio, Tool: Work (end)	-	1:18	-	-	-	1:6	-
Power Supply and Mechanical Setup							
Tap	3	4	5	2	3	4	5
Verniers Up	6	3	5	6	6	4	6
Current (amperes)	4	10.5	25	2	5	10.3	25
Capacitance (microfarads)	1	3.5	27	0.5	1	2.5	24.5
Frequency Control Set	6	1	6	10	4	6	6
Power Supply Frequency (kc)	144	71.8	27.1	238	123	108	27.1
Servo Control Set	4	3	4	4	4	4	4 1/2
Voltage Control Set	4 1/2	3 1/2	2 1/2	4	4	4	4
Gap Voltage	40	38	32	39	39	39	38
Polarity ⁽¹⁾	Normal	Normal	Normal	Reverse	Reverse	Reverse	Reverse
Flushing Arrangement	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Electrode Size (inch square)	1/2	1/2	1/2	1/2	1/2	1/2	1/2
Number of Tests	1	2	1	1	1	2	1

(1) Normal polarity is difficult to start and is somewhat unstable.

Table A-22

PERFORMANCE CHARACTERISTICS OF A TYPE 304L STAINLESS STEEL
WORKPIECE AND GRAPHITE AND COPPER-
TUNGSTEN ALLOY ELECTRODES

Description	Performance		
	Graphite		Copper-Tungsten Alloy
	450	600	150
Finish (rms)	0.433	-	0.078
Metal-Removal Rate (in ³ /hour)	0.00045	-	0.00026
Metal-Removal Rate (in ³ /min-amp)	0.0040	-	0.0011
Overcut (inch)	-	-	2 1/2:1
Wear Ratio, Tool:Work (sharp corner)	-	-	2 1/2:1
Wear Ratio, Tool:Work (side)	-	-	1:6 1/2
Wear Ratio, Tool:Work (end)	-	-	
Power Supply and Mechanical Setup			
Tap	5	6	3
Verniers Up	3	6	6
Current (amperes)	16	38	5
Capacitance (microfarads)	23	0	3.5
Frequency Control Set	2	0	3 1/2
Power Supply Frequency (kc)	19.6	7.8	118
Servo Control Set	6	9	4 1/2
Voltage Control Set	3 1/2	3/4	4
Gap Voltage	32	21	34
Polarity(1)	Normal	Reverse	Reverse
Flushing Arrangement	Reverse	Reverse	Reverse
Electrode Size (inch square)	1/2	1/2	1/2
Number of Tests	6	1	6

(1) Graphite in reverse polarity arcs readily and should be used with caution.

Table A-23

PERFORMANCE CHARACTERISTICS OF A MAGNESIUM
WORKPIECE AND A GRAPHITE ELECTRODE

Description	Performance		
	80	190	500
Finish (rms)	0.252	0.787	4.67
Metal-Removal Rate (in ³ /hour)	0.00140	0.00151	0.00236
Metal-Removal Rate (in ³ /min-amp)	0.0011	0.0014	0.0055
Overcut (inch)	-	-	-
Wear Ratio, Tool:Work (sharp corner)	-	-	-
Wear Ratio, Tool:Work (side)	-	-	-
Wear Ratio, Tool:Work (end)	1:14	1:24	-
Power Supply and Mechanical Setup			
Tap	1	4	5
Verniers Up	4	1	6
Current (amperes)	3	8.7	33
Capacitance (microfarads)	0.6	1.6	35
Frequency Control Set	2 1/2	5	2 1/2
Power Supply Frequency (kc)	157	100.8	20.5
Servo Control Set	3 1/2	4	3 1/2
Voltage Control Set	1 1/2	1 1/2	1 1/2
Gap Voltage	26	28	30
Polarity	Normal	Normal	Normal
Flushing Arrangement	Normal	Normal	Normal
Electrode Size (inch square)	1/2	1/2	1/2
Number of Tests	2	2	2

Table A-24
PERFORMANCE CHARACTERISTICS OF TITANIUM AND TUNGSTEN
CARBIDE WORKPIECES AND A BRASS ELECTRODE

Description	Performance				
	Titanium Carbide			Tungsten Carbide	
	1	2	3	5	5
Finish (rms)	-	-	-	-	-
Metal-Removal Rate (in ³ /hour)	-	-	-	-	0.238
Metal-Removal Rate (in ³ /min-amp)	-	-	-	-	0.00020
Overcut (inch)	-	0.002	0.003	-	0.003
Wear Ratio, Tool: Work (sharp corner)	-	-	-	-	-
Wear Ratio, Tool: Work (sharp corner)	-	-	-	-	-
Wear Ratio, Tool: Work (end)	-	-	-	-	-
Power Supply and Mechanical Setup					
Tap	1	2	3	5	5
Verniers Up	4	6	6	3	4
Current (amperes)	3	6	8	16	20
Capacitance (microfarads)	0.8	2	3.5	9.5	29.5
Frequency Control Set	4	1/2	0	5	2
Power Supply Frequency (kc)	190	98	82	25.2	19.6
Servo Control Set	3	4 1/2	5	6	4 1/2
Voltage Control Set	2	1/2	1/2	3	3 1/2
Gap Voltage	30	20	20	32	32
Polarity	Normal	Normal	Normal	Normal	Normal
Flushing Arrangement	Normal	Normal	Normal	Normal	Normal
Electrode Size (inch diameter)	3/4	3/4	3/4	3	3
Number of Tests	1	1	1	1	1

Table A-25
PERFORMANCE CHARACTERISTICS OF A URANIUM WORKPIECE
AND A BRASS ELECTRODE WITH CIMJET-20 COOLANT

Description	Performance					
	90(1)	180	300	600	-	-
	1	2	3	4	5	6
Finish (rms)	-	-	-	-	-	-
Metal-Removal Rate (in ³ /hour)	-	0.089	0.141	0.418	-	-
Metal-Removal Rate (in ³ /min-amp)	-	0.00030	0.00024	0.00024	-	-
Overcut (inch)	-	0.0026	0.0033	0.005	-	-
Wear Ratio, Tool: Work (sharp corner)	-	2:1	3 1/2:1	2 1/2:1	-	-
Wear Ratio, Tool: Work (side)	-	-	-	-	-	-
Wear Ratio, Tool: Work (end)	-	1:9 1/2	1:11 1/2	1:6	10:1	10:1
Power Supply and Mechanical Setup						
Tap	2	3	4	6	2	4
Verniers Up	1	3	2	5	3	2
Current (amperes)	2	5	10	29	3	10
Capacitance (microfarads)	1	3	7	40 + 2R	0.8	5.0
Frequency Control Set	3	2	0	0	2	2
Power Supply Frequency (kc)	135	103	64.5	7.8	120	79
Servo Control Set	5	5	5	5 1/2	4	6
Voltage Control Set	3 1/2	3 1/2	3 1/2	2 1/2	3	3 1/4
Gap Voltage	36	32	32	31	35	33
Polarity	Normal	Normal	Normal	Normal	Reverse	Reverse
Flushing Arrangement(2)	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse
Electrode Size (inch square)	1/2(3)	1/2	1/2	1/2	1/2	1/2
Number of Tests	1	3	3	2	1	1

(1) Rotation required for stability.

(2) Coolant pressure is critical on all setups.

(3) Inch diameter.

Table A-26
PERFORMANCE CHARACTERISTICS OF A URANIUM WORKPIECE AND GRAPHITE
AND SILVER-TUNGSTEN ALLOY ELECTRODES WITH CIMJET-20 COOLANT

Description	Performance						
	Graphite			Silver-Tungsten Alloy			
Finish (rms)	-	-	-	-	-	-	-
Metal Removal Rate (in ³ /hour)	-	C. 1485	-	-	-	-	-
Metal Removal Rate (in ³ /min-amp)	-	C. 00025	-	-	-	-	-
Overcut (inch)	-	0.0045	-	-	-	-	-
Wear Ratio, Tool:Work (sharp corner)	-	3 1/2:1	-	-	-	1:1 1/2	1:1 1/2
Wear Ratio, Tool:Work (side)	-	-	-	-	-	-	-
Wear Ratio, Tool:Work (end)	-	1:1 1/2	-	-	-	1:28	1:28
Power Supply and Mechanical Setup							
Tap	3	4	5	3	4	4	5
Verniers Up	3	2	2	0	0	2	4
Current (amperes)	5	10	12	3	5	10	20
Capacitance (microfarads)	4.5	10	22	1	4	6.5	32.5
Frequency Control Set	0	0	7	0	0	0	1
Power Supply Frequency (kc)	32	64.5	28.9	82	64.5	64.5	17.8
Servo Control Set	4	5 1/2	7	5	5	5	5
Voltage Control Set	3 1/2	3 1/2	4	4 1/2	4 1/2	4	4 1/2
Gap Voltage	33	32	36	37	37	37	37
Polarity(1)	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Flushing Arrangement	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse
Electrode Size (inch square)	1/2	1/2	1/2	1/2	1/2	1/2	1/2
Number of Tests	1	2	1	1	1	1	1

(1) Maximum stable cut with graphite is 12 amperes.

Table A-27
PERFORMANCE CHARACTERISTICS OF AN ALUMINUM WORKPIECE
AND A BRASS ELECTRODE WITH CIMJET-20 COOLANT

Description	Performance										
	32	63	100	130	160	250	350	200	230	270	400
Finish (rms)	32	63	100	130	160	250	350	200	230	270	400
Metal-Removal Rate (in ³ /hour)	-	-	0.105	0.350	-	-	-	-	-	0.600	-
Metal-Removal Rate (in ³ /min-amp)	-	-	0.00035	0.00060	-	-	-	-	-	0.00010	-
Overcut (inch)	-	-	0.0017	0.0024	-	-	-	-	-	0.0030	-
Wear Ratio, Tool: Work (sharp corner)	-	-	2 1/2:1	2 1/2:1	-	-	-	-	-	1 1/2:1	-
Wear Ratio, Tool: Work (side)	-	-	-	-	-	-	-	-	-	-	-
Wear Ratio, Tool: Work (end)	-	-	1:1 1/2	1:2 1/2	-	-	-	-	-	1:10	-
Description	Power Supply and Mechanical Setup										
	32	63	100	130	160	250	350	200	230	270	400
Tap	1	2	3	4	5	5	6	4	4	4	5
Verniers Up	1	2	3	3	3	4	5	0	1	2	6
Current (amperes)	1 1/2	3	5	10	20	29	35	5	7	10	30
Capacitance (microfarads)	0.3	0.8	1.5	2.5	15	35	40 + R	5	7	10.5	39.5
Frequency Control Set	3	5	7	5	10	0	4	2	2	2	2
Power Supply Frequency (kc)	168	164	154	100.8	34.8	15.9	11.2	79.0	79.0	79.0	19.6
Servo Control Set	6	7	6	5	6	8	8	4	5	5	5
Voltage Control Set	3	2 1/2	1 1/2	4 1/2	1 1/2	1/2	1/2	4	4	2 1/2	3
Gap Voltage	32	31	28	38	28	23	23	38	37	32	32
Polarity (1)	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse	Normal	Normal	Normal	Normal
Flushing Arrangement	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse
Electrode Size (inch square)	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2
Number of Tests	1	1	2	4	1	1	1	1	1	2	1

(1) Normal polarity is unstable and difficult to set up and very good coolant conditions are required. A five-ampere cut is usable only with extreme care.

Table A-28
PERFORMANCE CHARACTERISTICS OF AN ALUMINUM WORKPIECE AND GRAPHITE AND
TELLURIUM-COPPER ALLOY ELECTRODES WITH CIMJET-20 COOLANT

Description	Performance							
	Graphite				Tellurium-Copper Alloy			
Finish (rms)	-	-	180	-	-	-	-	-
Metal-Removal Rate (in ³ /hour)	-	-	0.124	-	-	-	-	-
Metal-Removal Rate (in ³ /min.-amp)	-	-	0.0002	-	-	-	-	-
Overcut (inch)	-	-	0.004	-	-	-	-	-
Wear Ratio, Tool: Work (sharp corner)	-	-	-	-	-	-	-	-
Wear Ratio, Tool: Work (side)	-	-	-	-	-	-	-	-
Wear Ratio, Tool: Work (end)	-	-	-	-	-	-	-	-
Power Supply and Mechanical Setup								
Tap	1	3	4	5	6	4	5	6
Verniers Up	6	4	2	3	4	2	4	5
Current (amperes)	3	4 1/2	10	20	25	9	20	30
Capacitance (microfarads)	0.5	1.5	3	22	30 + R	3	28	64 + 2R
Frequency Control Set	6	7	4	6	6	4	4	0
Power Supply Frequency (kc)	233	154	93.5	27.1	7.8	93.5	23.3	7.8
Servo Control Set	5	4	3 1/2	8	9	4	4	6
Voltage Control Set	3 1/2	3	2	2	1 1/2	2 1/2	2 1/2	1/2
Gap Voltage	35	33	31	27	25	32	32	26
Polarity ⁽¹⁾	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse
Flushing Arrangement	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse
Electrode Size (inch square)	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2
Number of Tests	1	1	2	1		1	1	1

(1) Three and twenty-five ampere cuts are unstable with graphite. Normal polarity will not stabilize with graphite. Normal polarity is unstable with the tellurium-copper alloy. Low-amperage cuts in reverse polarity will not stabilize with the tellurium-copper alloy.