**New Process**

**PREPARING BLANK**

1. FORMING PILOT HOLE
2. DRILLING PILOT EXTENSION
3. THE BELL FINISHING THE BELL
4. DRILLING SECONDARY CONE BEARING STARTING FINISHING SECONDARY CONE
5. BACK OPENING BLENDING & POLISHING BACK OPENING
6. POLISHING & PIEVING

**Fig. 1a.**

- ABOUT 15 MM (0.060"
- CUT AND POLISH PRIMARY PILOT (DRI- ELECTRIC)
- DRILLING PRIMARY PILOT (DRI- ELECTRIC)
- MECHANICAL PILOT SINKING (DRI- ELECTRIC)
- MECHANICAL PILOT COUNTER SINKING (DRI- ELECTRIC)
- ELECTROLYTIC DRILLING (TRUE-
- ELECTRIC)
- ELECTROLYTIC DRILLING COURSE (TRUE-
- ELECTRIC)
- BLENDING AND POLISHING REDUCTION
- LAPPING TO OPEN (PREFERRED)
- DRILLING THRU (PREFERRED)
- REAMING AS WITH FINE WIRE WITHOUT FINE DIAMOND DUST
- COUNTER SINKING AS DRY DIAMOND DUST

- 2 HOURS
- 40 TO 60 MINUTES
- 59 MINUTES
- 20 MINUTES
- 1 MAN HR PER DIE IN QUANTITY

**Prior Art**

**PREPARING BLANK**

1. BRUTING FLAT
2. BRUTING STARTING HOLE
3. PECKING PRIMARY CONE
4. PECKING SECONDARY CONE
5. BRUTING & PECKING BACK OPENING
6. RELEIF AND SMOOTHING OF BEARING

**Fig. 1b.**

- 1/2 HRS
- 75 TO 175 HOURS
- 5 HOURS
- 1 MAN HR

**2,438,941 DAMOND DIE PRODUCTION**

April 6, 1948

C. G. PETERS ET AL.

DIAMOND DIE PRODUCTION AND THE LIKE

Filed Dec. 23, 1946
The invention herein described may be made and used by or for the Government of the United States without payment to us of any royalty therefor.

This invention relates to the production of wire drawing dies of hard crystalline material, such as diamond, and the like, and aims generally to improve the same. The present application relates to the new process as a whole, to novel combinations of steps therein, and to the novel products produced thereby.

In general, the production of diamond dies involves the following steps: (1) selection and preparation of die blanks, (2) spotting, or starting the hole, (3) drilling the bell or primary cone, (4) drilling the secondary cone, (5) back-opening, and (6) polishing of the die surface.

(1) In accordance with the prior art, for dies of .0015 inch diameter, or less, diamonds of 1/10 to 1/4 carat, allowing a thickness of 1.3 to 1.8 millimeters, have been selected. The selected diamond has then been formed into a flat plate having two parallel surfaces spaced apart by the thickness of the die, this being generally accomplished by bruting. This blank has then been mounted and centered in a metal die which is rotated in a bench lathe while a small conical hole is spotted or bruted in one of the flat surfaces of the stone with a diamond chip held in a pair of pliers, to act as a starting point for the drill. The blank is then ready for the drilling operation.

(3) The method and equipment developed in Europe for drilling diamond dies (see Paul Grodzinski, "Diamond and Gem Stone Industrial Production," Chap. II, page 169) essentially employ a star-drilling action. The drilling machine has a horizontal, single spindle which rotates at about 3500 revolutions per minute and carries a sewing needle for the drill. The diamond is mounted on a second spindle which oscillates the diamond against the sharpened end of the drill. Diamond dust of different grades mixed with alcohol or oil is used as the abrasive. Domestic machines as heretofore employed have operated on the same principle but usually employ ten vertical spindles to conserve space and facilitate inspection by the operator.

For drilling the primary cone, in the prior art the spotted blank is placed on the rough drilling machine, using a needle of about .040 inch diameter ground to a rather blunt point. Diamond dust of about 60 micron grade (our designation for dust having an average particle size of from 50 to 70 microns) is used for the first part of the operation, and of about 30 micron grade (25 to 28 microns) for the finish. In this way the bell is formed, preferably as a 60° cone of about 1 millimeter or .040 inch depth.

(4) For drilling the secondary cone, a lighter drilling machine is used with a fine needle ground to approximately the shape of the desired cone. Diamond dust of about 30 micron grade is used at the start followed by grades 12 (8 to 15 micron) and 6 (4 to 8 micron) as the drilling progresses.

Frequent regrinding of the needle is required as the pecking action soon blunts the sharp tip. If after many tedious hours the apex of the cone is found to be .001 inch or less in diameter the drilling is considered complete.

(5) For back-opening according to the prior art, the die in its casing, is then returned to the chuck of the bench lathe for counter drilling. In this operation a spherical hole, in line with the die axis, is bruted into the back surface of the die with diamond splints held in sharp-nosed pliers until it reaches the point of the secondary cone. In some shops the bruting is discontinued when the sphere comes within .003 inch of the cone. The final opening is then made on the drilling machine using a needle sharpened to a hemisphere .010 inch in diameter with 6 micron grade powder to obtain a polish.

(6) The final polish of the cone and bearing is then performed on a light drilling machine or oscillating polishing machine. The needle is sharpened to a long taper and the diamond dust in oil is the abrasive.

The time required to complete a die of about .0007 to .0010 inch diameter according to this prior practice, even when cutting on the easier planes, runs from about 115 to about 170 hours, roughly divided as follows:

<table>
<thead>
<tr>
<th>Operation</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blank preparation</td>
<td>1½ to 2</td>
</tr>
<tr>
<td>Bruting the spot</td>
<td>about ½</td>
</tr>
<tr>
<td>Drilling primary cone</td>
<td>15 to 50</td>
</tr>
<tr>
<td>Drilling secondary cone</td>
<td>75 to 120</td>
</tr>
<tr>
<td>Back-opening</td>
<td>6 to 8</td>
</tr>
<tr>
<td>Polishing</td>
<td>15 to 20</td>
</tr>
<tr>
<td><strong>Average total</strong></td>
<td>157</td>
</tr>
</tbody>
</table>

**UNITED STATES PATENT OFFICE**

**2,438,941**

**DIAMOND DIE PRODUCTION AND THE LIKE**


Application December 23, 1946, Serial No. 718,094

6 Claims. (Cl. 125—30)

(Granted under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)
Furthermore, where attempts were made to use stones more difficult to cut, additional time was required. To cut near parallel to a flat face of a 3 point capes, for example, required 1 1/2 days as against roughly two hours for cutting on the easier planes. Such stones were accordingly not used for die-making.

Our present research has been directed toward improving the method of forming diamond dies, and toward producing a die of improved structure. A particular object of the invention is to reduce the time required in the production of such dies, and in the several combinations of steps incident to such production. A further object is to facilitate formation of dies from 3-point capes and the like, which heretofore could not be economically used for the purpose.

Briefly, by our new procedure, as a whole, we (1) prepare the parallel flats and window on the blank by a new lapping method, (2a) spot drill a pilot hole in the diamond surface electrically by a new dry drilling method, (2b) shape it to the form of a wide angle, say a 90° cone, preferably by a new countersinking method eliminating the star-drilling principle, (3a) extend a second pilot hole from the bottom of the wide angle cone by the electrical dry drilling method, (3b) shape the resulting funnel shape hole into a final primary cone which may be a 40° to 70° cone, preferably by the new countersinking method, (4a) extend the initial section of a secondary cone from the bottom of the primary cone, preferably by a new electrolytic drilling method, (4b) extend the secondary cone through the final bearing portion, preferably by a modified new electrolytic drilling method, (4c) where desired, blend this die stage, or later, the secondary and primary cones, by polishing on the drilling machine using grade 3 micron powder, (5) back-open the die, preferably by the new method of lapping off the flat back face until opening is achieved, or, in different circumstances, by the new method of drilling the cone bearing surface clear through to the back face by the new electrolytic method, (6) carefully polish the lower part of the secondary cone (the reduction portion), the bearing therein, and the relief thereof, as by polishing with a short piece of 0.004 inch tungsten wire and grade 3 micron diamond dust and then inverting the die and countersinking the relief to a depth of about 0.004 inch with a 90° drill and grade 3 micron dust. As a result of this procedure as a whole we can reduce the time of manufacture per die from approximately 137 hours by the prior art methods to approximately 4 hours by our new method, and at the same time obtain a more perfect die, better polished in its reduction, bearing and relief portions, and having a correspondingly longer life, moreover, by our new process as a whole we can make such dies with the expenditure of but little more time, from 3 point capes and like stones heretofore considered so hard to cut as to be economically useless for die manufacture. Obviously, when desired, all of the steps of our new process, and all of the features of our new die need not be employed, and where desired, some of the operations may be performed by prior art methods, or other methods which may be developed, while still retaining the advantages of novel features and subcombinations of our invention in other respects. Our invention accordingly contemplates the provision of these novel features and combinations individually and in subcombination, as well as collectively, and since some of these features and subcombinations disclosed herein have been developed by less than the total number of the present applicants, claims for them, of necessity, will be patented in separate or divisional applications made by the inventors thereof.

In the accompanying drawings of embodiments illustrative of the several features of this invention:

Fig. 1a is a flow diagram of the steps in a complete process performed in accordance with the invention.

Fig. 1b is a similar diagram of the conventional prior art. A further object is to facilitate formation of dies from 3-point capes and the like, which heretofore could not be economically used for the purpose.

Fig. 1c is a perspective view of one embodiment of the new die.

Fig. 4 is a diagram of countersinking apparatus, partly in section.

Fig. 5 is a diagram of the electrolytic drilling step and means shown connected for coarse electromechanical drilling, also showing in dotted lines the connections employed for fine electrolytic drilling.

Referring to Figs. 1a and 1b of the accompanying drawings, Fig. 1a illustrates diagrammatically the several operations performed on the die blank. Fig. 1b shows in similar diagram, for reference and comparison, the six prior art steps, numbered to correspond to the numbered paragraphs of description thereof, above. In Fig. 1a, for ease of reference the several steps of the method are numbered, identified by name above the diagram, described as to the preferred manner of performance below the diagram, and accompanied by a time schedule showing the approximate time required to perform the several groups of steps in one illustrative practice of the invention hereinafter more fully described. Similarly, in Fig. 1b the six prior art steps are not only numbered, but identified by legends and accompanied by a comparable time schedule based on averages of data such as that set forth under numbered paragraphs 6, above.

As indicated in the diagrams, Fig. 1a, by our new procedure the facial surfaces of the die are cut and polished and not simply bruted, a pilot hole is bored and a diamond by means of an electric spark, and the operation is completed by a modified light commercial drilling machine. In this latter operation the rotating drill follows the pilot hole without being dulled by apexal contact with the diamond, and the conical surface of the drill, which is rotated with considerable peripheral speed, acts as a countersink or reamer for shaping the contour of the cones and applying the polish to the cone and bearing surfaces. Thus the tedious and time consuming star-drilling operation which is the basis of prior methods is eliminated, and the strains, flaws, and fractures, and other damage to the bearing surface frequently resulting from preparing the blank and opening the die by bruting is avoided.

(1) Preparation of die-blank

To exemplify the invention, the preparation of a diamond die having an orifice diameter of from 0.004 inch to .0015 inch, is diagrammed in Fig. 1a and herein described. As shown in Fig. 1a, step 1, the blank is first prepared by cutting
on a lap to form a blank having two parallel polished faces and a third polished face perpendicular to the first two, through which the progress of drilling and polishing of the die can be observed. Through their polished faces any deleterious natural imperfections in the diamond can be easily seen, and bad stones can be discarded before drilling operations are begun. For the size of die selected for illustration, the blank may be prepared with a thickness of about 0.060 inch (1.5 mm). In accordance with the present invention this step is preferably accomplished by the new and rapid method of electrical cutting and polishing illustrated in Fig. 2, and hereinafter described.

In the prior art cutting method universally employed by lapi-daries since the earliest records of the art a flat cast iron lap about one foot in diameter is rotated at approximately 2000 R. P. M. Diamond powder mixed with olive oil or some other viscous material is fed onto the surface of the lap. The diamond is embedded in a wiping solder contained in a copper cup or dop which in turn is supported by a wooden arm. The diamond is then brought into contact with the surface of the specimen or lap and allowed to be cut until the desired surface or facet is produced.

In practice, with this prior method great difficulty has been experienced in effecting cutting in certain orientations of the diamond. Diamonds crystallize in the cubic system, which has three equal axes at right angles, usually in the form of octahedrons, dodecahedrons, and cubes. It is known that as a general rule cutting is most rapid when the facet is parallel to one or two of the axes and the direction of motion of the lap surface is parallel to one of the axes. It is well established that cutting on an octahedron face, which is approximately at 35 degrees to all three axes, is almost impossible.

The fact that under certain orientations the diamond is more resistant to abrasion than under others no doubt accounts for the possibility of cutting a diamond with its own powder. A part of the myriad of fine particles in the powder is always in the most resistant position and will thus abrade a surface oriented in a less resistant plane. In addition, microhardness tests of diamonds have disclosed the ability to make as many as 50 indentations, 30 microns long, in a flat diamond surface without injury to the point of a diamond indenter cut in the form of a four-sided pyramid. From this it may be concluded that the indenter point under compression has greater resistance to fracture than the diamond surface under tension. This may be a contributing factor in the ability of powder particles to fracture or abrade the diamond facet.

In the present invention, an improved cutting method is employed, which not only accelerates the rate of cutting on the less resistant planes, but also enables cutting to be effected with adequate rapidity on the octahedron face, and thus enables preparation of dies from diamonds heretofore regarded as unsuitable for this purpose.

A preferred arrangement for the practice of this improvement is shown in Fig. 2 in which the lap L of cast iron, copper or other material, supported by the base B in a suitable bearing W, is suitably driven by the belt and pulley P at speeds ranging from 30 to 2500 R. P. M. An arm B of insulating material such as a one inch square fiber bar supports the diamond in its dop D and the weight P. The leads from a 110 volt, 60 cycle A. C. outlet are connected to the primary terminals of a 5000 volt, 50 to 1, 300 volt-ampere power transformer T. A variable resistance such as rheostat R which may have a value of 400 ohms is placed in one of the primary leads of transformer T and A. C. ammeter A, which may have a two ampere range is placed in the other. A capacitor C of about .001 to .008 microfarad is connected across the secondary leads of the transformer. The rheostat R may be dispensed with if a constant limiting transformer such as a 12,000 volt, 20 millionmure neon sign lighting transformer is used instead of the power transformer T and if a zero to 120 volt output adjustable ratio autotransformer such as a "Variac" is placed between the A. C. outlet and the current limiting transformer, generally described hereinafter in connection with Fig. 3c.

Still referring to Fig. 2, as there shown one of the secondary leads of the transformer is electrically connected to the diamond dop D and the other to a brush B which makes electrical contact with the bottom of the lap L. The diamond in this instance is mounted in a copper dop using high melting point solder such as SAE No. E06, tin, lead, silver, or an alloy of equal weights of silver and aluminum, and protrudes about ½ to 1 millimeter from the surface of the surrounding solder. The heat conductivity of the compound reduces the chance of solder being melted by the frictional heat of the lap. The lap L, if of cast iron may have a high carbon and graphite content and contain numerous small pits or pockets in its metallurgical structure, and is turned in a lathe on both sides and on the edge and carefully balanced. We have found that cross scoring of the top surface of the lap by hand or with a cupped wheel is not necessary and that the final cut should be a light one producing a smooth surface. A small quantity of diamond powder and a few drops of oil are applied to the lap, mixed well and rubbed into the surface using a flat hardened steel block. A mixture of oil and powder can be applied while the lap is in motion.

In the arrangement just described a maximum cutting rate has been attained with an applied voltage of 110 volts, a current of about ½ ampere in the primary of transformer T and a capacity across the secondary leads of from .005 to .008 microfarad. To obtain that current in the primary circuit the rheostat R was adjusted to about 200 ohms. To decrease the cutting rate the primary current and the capacity C are reduced. The cutting may be practiced with diamond powder of any suitable size, number 40 as above defined cutting slightly faster than number 25, but the latter producing a better finish. Vegetable oils and asphalt and paraffine based mineral oils may be employed as the mixing oil, the best results being obtained with paraffine base high flash point Pennsylvania oils of 3 to 50 SAE viscosity. Undue increase of the current during cutting of the stone augments the arc and produces increased burning of the mixing oil and a slower cutting rate.

From experimental data it has been determined that when cutting on the dodecahedron face with the lap motion parallel to the crystal axis (which appears to be the best condition for cutting diamonds), the diamond cuts fairly rapidly with or without the arc, the arc increasing the rate of cutting approximately 10 percent. However, when the direction of lap motion is at right angles to the axis the arc increases the cutting rate about four times com-
pared with the speed of cutting without the arc. On the cube face, when the direction of the lap motion is parallel to one axis and at right angles to the others the arc doubles the rate of cutting, and at 45 degrees to the two axes it nearly triples this rate of cutting as compared to cutting without the arc.

For the octahedron faces, without the arc no cutting resulted in any direction of the lap motion, that is not as much as .0001 inch layer could be removed in a full day's cutting time. This agrees with the experience of expert lapidaries as recorded in the literature (see Paul Grodzinski, Diamonds and Gem Stones, Industrial Production, first edition, 1942; Kraus and Slawson, The American Mineralogist, vol. 24, p. 661, November 1939). With the arc, however, the cutting rate on the octahedron face equals the rates found for the unfavorable directions on the cube and dodecahedron faces which in turn have been augmented about four times by the use of the arc. The fact that the arc facilitates such rapid cutting directly on the octahedron face is the most striking and unexpected result of this invention and should make it possible, in designing industrial diamond tools, to take full advantage of the orientational of the crystallographic directions of the diamond with respect to the cutting surfaces of the tool. As indicated in Fig. 1a, step 1, on the average the parallel faces and window of the die selected for illustration may be prepared by our new method in approximately two hours with complete absence of the strains and fractures resulting from the prior art bruting method.

(2) Foredrilling of pilot hole

For forming the pilot hole, step 2, Fig. 1a, apparatus is preferably used corresponding to that illustrated in Figs. 3a and 3b. As shown in Fig. 3a the leads from the 110 volt, 60 cycle A. C. outlet are connected to the primary terminals of a zero to 120 volt output variac V and the secondary of the variac is connected to the primary of a power transformer T which may be a 5000 volt, 300 volt-amper power transformer or a 20 milliamper neon sign lighting transformer as above described. When employing the 5000 volt, 300 watt power transformer a resistance R' which may have a value of about 70 ohms, is placed in the primary lead of the transformer and an A. C. ammeter A of approximately two amperes range in the other. A capacitor C of about .001 to .008 microfarads is connected across the secondary leads of the transformer. The rheostat R can be dispensed with if a current limiting transformer such as a 12,000 volt, 20 milliamper neon sign lighting transformer is used instead of the power transformer.

Control and speed of drilling is improved by inserting a quenched spark gap G in the secondary lead between the transformer T and the capacitor C. When this is done, however, the apparatus must be enclosed in a metallic shield S to avoid radio interference.

As shown in Fig. 3b, the drill stand for dry drilling of the pilot hole provides a metallic support for the diamond and an aligning support for the drilling needle together with electrical connections, for connecting these two elements on the condenser C, Fig. 3a. In the simple form of stand shown in Fig. 3b for purposes of illustration, two 5-inch brass angle pieces 10, 11 are fastened to a wooden pillar 12 which is supported by the base 13. A small brass rod 14 weighing approximately 5 to 10 grams, slides closely but with minimum friction through two aligned guide holes drilled in the brass angle pieces. Into the lower end of the rod 14 is fastened the drilling needle 15 of brick for the purpose of step 2 in Fig. 1a is preferably a 70% platinum, 30% iridium wire approximately .020 inch in diameter. A brass block 16 provided with an upstanding brass table 17 supports the diamond die blank 18.

With the arrangement shown in Figs. 3a and 3b it is not necessary to secure the unmounted diamond D to the pedestal 17 at all, but if desired, we contemplate effecting such securement in any suitable way, for example, by the use of a drop of cellulose acetate cement, such as that currently sold under the trade-name "Duco" cement, between the diamond and the top of the pedestal 17 to prevent shifting of the diamond relative to the electrode 18, particularly during the initial spotting operation.

In this operation the end of the drill needle 15 is ground to a cone of about 20 degrees, and the point is brought into contact with the center of the flat surface of the die blank D. The current is then applied and adjusted by means of the variac V until a white spark extends from the needle 15 to the brass pillar 17. This should occur in about 20 minutes time.

If the end of the drill 15 becomes red the current should be reduced by adjusting the variac V until the color disappears. The current should, however, be sufficient to maintain the white spark between the drill 15 and the pillar 17. In about 20 minutes time a roughly cylindrical hole, Fig. 1a, step 2, about 0.6 mm. (0.020 inch) deep and 2 mm. (0.008 inch) in diameter, is drilled in the diamond and the end of the drill 15 is disintegrated. Very little progress is made at this point by repeating the dry drilling operation with a sharpened needle.

(3) Countersinking

According to our invention, therefore, the foredrilled blank 18 is next mounted on the foredrilling machine using a suitable drill needle, for example, a No. 1 drill needle, sharpened to a 90 degree cone and rotated at a relatively high speed, for example 3200 R. P. M. Using grade 45 micron powder in alcohol or any other suitable vehicle, and reciprocating the diamond axially of the needle at a slow rate, say 20 times per minute, so that the powder may enter between the needle point and diamond surface, the bell cone is then countersunk to the bottom of the foredrilling as indicated in Fig. 1a, step 3, in about 45 minutes. During this operation the die is applied against the countersinking point about .01 inch in the time with a very light pressure, of the order of a few grams, and the distance of reciprocation of the diamond away from the needle point may be of the order of a half millimeter.

Suitable apparatus for the performance of this step is diagrammatically illustrated in Fig. 4 in which the drill needle 20 is carried by a vehicle shaft 21 rotated in a bearing 22 by any suitable means as the cord and pulley drive 23. The diamond 18 is mounted on a support 24, which is shown as provided with a height adjusting means 25, and carried by a shaft 26 together with the center of the condenser C, Fig. 3a. The simple form of stand shown in Fig. 3b for purposes of illustration, two 5-inch brass angle pieces 10, 11 are fastened to a wooden pillar 12 which is supported by the
ably driven, effects the displacement of the blank 18 from contact with the drill point.

For convenience in the machine drilling, the blank 18 is mounted in a newly developed small window-nib illustrated in Fig. 4. This nib, in the form shown, comprises a cylindrical cup 30 provided with two diametrically aligned viewing openings 31 and with a close fitting cylindrical plug 32 having a conical reservoir 33 to hold the dust-and-vehicle mixture. The reservoir 33, as shown, narrows to an axial center opening, and the diamond blank is sealed to the plug 32 by a thin layer of wax on the bottom of the plug in the space 34 surrounding this center opening. This layer of wax prevents leakage of the cutting mix and also enables the blank 18 to be lifted from the cup 30 by lifting out the plug 32, which may be provided with a flange around its upper end to facilitate its removal, if desired. Beeswax, dental wax, or the like, makes a good seal from which the diamond is easily disengaged. The window on the diamond, when it is secured in the nib, is aligned with the openings 31, so that the progress of the drilling may be seen through one of these openings, the blank being illuminated by a light shining through the other. With this unit the blank 18 can be mounted or unmounted in a few moments.

(4) Pilot extension

In the next step, Fig. 1a, step 4, by repeating the dry drilling operation of step 2 (see Figs. 3a-3b) the fordrilling is extended an additional 0.5 mm. (0.020 inch) in about 20 minutes.

(5) Finishing the bell

Following the pilot extension the blank is again returned to the drilling machine, and further countersunk with a needle ground to a 60 degree cone as shown in Fig. 1a, step 5. Using grade 2 micron powder at the start and grade 6 micron powder to finish, a smooth 60 degree cone about 1.0 mm. (0.040 inch) deep in about an hour. The set-up is generally like that employed in step 3 (see Fig. 4). At this point about 0.2 mm. (.008 inch) of the blank thickness should be left for the secondary cone. If the finished blank is to be more than 1.2 mm. thick, say 1.6 mm., a third fordrilling and countersinking of the bell may be practiced.

(6) Starting secondary cone

The primary cone or bell of the die now being finished, the next step (step 6, Fig. 1a) consists in starting the secondary cone or reduction portion of the die. This step is most readily performed by an electrolytic drilling operation and preferably by the improved electrolytic drilling method exemplified in Fig. 5. In this illustrated arrangement a 110 volt, 60 cycle source is connected to the input terminals of a zero to 270 volt output variac V. The secondary of the variac is connected to a capacitor C of about 20 microfarads and an A.C. ammeter A” of about 1 ampere range. A wooden base 49 and pillar 41 forms the support for the diamond and electrolytic drilling apparatus. The pillar 49 is provided with suitable means for raising and lowering the drill, preferably in the form of a 5 inch rack 42 which carries a bar 43 provided with a flexure strip 44 and an adjusting screw 45 for fine adjustment. A glass plate or block 46 is placed in a shallow evaporating dish 47 supported on the base 46 which may be provided with suitable centering elements, as three or more angle members 48, for correctly positioning dish 47. A small, flat plate of glass or the like 49 is preferably cemented to the corner of block 46 to form the supporting pillar for the die blank 18. The drilling needle 50 is fastened into the lower end of a pendulous rod 51 preferably weighted at its lower end as indicated by collar 51a. In the illustrated embodiment, the needle 50 is made from .020 inch diameter, 70 percent platinum, 30 percent iridium wire. The pendulous rod 51 is connected to the flexure strip 44 by a light coiled spring 52. The end of the drill needle 50 is ground to a cone of 10 degrees having a .002 inch to .003 inch spherical tip. The drill is lowered by means of the rack 42 and screw 45 until the tip comes into contact with the apex of the bell cone previously formed in the diamond. The spring is then lowered an additional two or three millimeters until the load on the needle tip is approximately 1 gram or less. An electrolyte such as a 5% aqueous solution of commercial KNO₃ (salmeter) is poured into the evaporating dish 47 until the liquid level is about 1 mm. above the top surface of the diamond. The leads from the variac-ammeter-capacitor circuit are connected to the flexure strip 44 and to a platinum electrode 53 which dips into the solution in the dish 47. With the variac set for 210 volts the current is applied. Under the existing conditions the ammeter should record about 0.5 ampere. If the current is greater than that the liquid level is lowered. If less, the level is raised. Under these conditions a secondary 16 degree cone .003 inch deep, .0015 inch diameter at the bottom is drilled in eight minutes as indicated in step 6, Fig. 1a.

(7) Finishing secondary cone

For the final drilling of the secondary cone the capacitor is by-passed and the variac is set at 80 volts, as indicated in dotted lines in Fig. 5 and the drill is resharpened. Under these conditions the drilling is extended an additional .005 inch in about 45 minutes, as indicated in step 7, Fig. 1a.

As the result of steps 6 and 7 a 16-degree secondary cone .008 inch deep, .003 inch diameter at the top and .0003 inch to .0005 inch diameter at the bottom is usually produced in less than one hour.

(8) Blending and polishing

If the original distance from the apex of the bell cone to the back face of the die blank exceeds .010” the bell and secondary cones are blended and polished on the drilling machine using grade 3 micron powder as shown in Fig. 1a, step 8. The die is then back opened on the flat diamond lap (Fig. 1a, step 9a) or on the drilling machine using a needle ground to a hemisphere (Fig. 1a, step 9b). If the distance from the bell apex to the back face of the die blank is from .007” to .010” the die is drilled through electrically, as shown in Fig. 1a, step 9c. A final polish is then applied to the secondary cone and bearing of the die.

Since it is evident that the life of a die, free from flaws, will be proportional to the perfection of the finish of the bearing, relief and reduction portion of the secondary cone, a considerable amount of time should be devoted to these last procedures. Inspection and tests in the laboratory of more than one thousand foreign and domestic commercial dies showed that little or no attention was given to this vital part of the work. This probably resulted from the fact that a finan-
cial premium was placed on smallness of the die size regardless of finish. We believe that about 20 hours should be devoted to the polishing operation. However, by using fine diamond dust in oil for the abrasive, and a light multiple head drilling machine, operating continuously 24 hours per day and requiring attention only twice during that period, the cost per die is very small.

For blending the ball and secondary cones the die is mounted on the light drilling machine and the needle ground to a long taper. Grade 6 micron powder is used for fast cutting and grade 3 micron powder to produce the final polish. Polishing the lower part of the secondary cone and the bearing is performed with a short piece of .003" tungsten wire and grade 3 micron powder. In the polishing operation a method which may be called neck-reaming is preferably used. For this purpose the polishing needle is rotated, but no pecking action is employed. In other words, the apparatus may be similar to that shown in Fig. 4, with the cam 29 disconnected. This usually occurs by the time the diameter of the orifice has increased by .0002". The die is then inverted and a relief about .0004" deep is countersunk with a 90° drill and grade 3 micron powder, if this relieving operation was not performed prior to the polishing step.

Conclusion and summary

By the foregoing procedure we have made finished dies to various contour specifications, such as the following:

<table>
<thead>
<tr>
<th>Example</th>
<th>Bell Cone</th>
<th>Secondary Cone Length</th>
<th>Orifice Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Degrees</td>
<td>Inches</td>
<td>Inches</td>
</tr>
<tr>
<td>1</td>
<td>70</td>
<td>0.004</td>
<td>0.006</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>0.014</td>
<td>0.007</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>0.012</td>
<td>0.006</td>
</tr>
</tbody>
</table>

With careful control of the electrical drilling and mechanical reaming and polishing steps, the following preferred contour specifications can be held within very close limits:

<table>
<thead>
<tr>
<th>Angle</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree</td>
<td></td>
</tr>
<tr>
<td>Bell cone</td>
<td>60</td>
</tr>
<tr>
<td>Secondary</td>
<td>0.07&quot;</td>
</tr>
<tr>
<td>Bearing</td>
<td>4</td>
</tr>
</tbody>
</table>

The majority of dies should polish out with an orifice diameter between .006" and .001" and a maximum range of from .008" to .015".

With the die drilling method herein disclosed, two parallel facets and a window perpendicular to these are cut on the diamond with a cast iron lap. This operation requires about 2 hours per blank and at least 2 units can be run simultaneously.

To form the bell cone a pilot hole is foredrilled electrically followed by countersinking on a drilling machine. This operation repeated until the desired depth is attained requires about 3 hours per die. One operator can care for 2 to 3 times its entrance diameter; mechanically countersinking said hole to a generally conical shape having an entrance diameter greater than its depth; electrically dry-drilling a further pilot hole from the apex of said countersunk hole again of relatively narrow entrance diameter compared to its depth; again mechanically countersinking said hole to a generally conical shape conforming to the entrance diameter of said first countersinking operation; electrolytically drilling a reduction and bearing portion extending from the apex of said countersunk hole; effecting a junction of said extension with a smoothly lapped back-opening surface; and relieving said bearing portion at its junction with said smoothly lapped surface.

2. The method of producing a diamond die for the drawing of fine wire, which comprises forming a die-blank by cutting on the diamond two parallel facets and a window perpendicular thereto; forming a bell in the blank by dry electro pneumatic drilling followed by countersinking to approximately the depth of the foredrilling; forming a secondary cone extending from the apex of the bell by electrolytic-electronic drilling; back opening and relieving the die; and blending and polishing the reduction, bearing and relief portions of the die.

3. A method according to claim 2, in which the die-blank facets and window are formed by lapping the diamond while subjecting it to a high frequency electrical discharge.

4. A method according to claim 2, in which the back opening of the die is effected by lapping away the back facet of the die.

5. A method according to claim 2, in which the back opening of the die is effected by drilling the secondary cone through to the back facet of the die.

6. An electromechanical method of forming diamond dies which consists in (a) forming a die-blank by lapping on a diamond, while subjecting it to a high frequency electric arc, two parallel facets and a window generally perpendicular thereto, (b) mounting said blank in a circuit between a mass contact and a point contact, applying pressure to said contacts and creating a high frequency electrical discharge across said contacts to effect an electronic dry-drilling of a pilot-hole in said diamond, (c) mechan-
cally countersinking the pilot hole to substantially its full depth (d) continuing steps (b) and (c) until the countersunk hole attains the dimensions of the bell of the die, (e) immersing the so-formed blank with its bell-opening uppermost in an electrolyte such as a 5% aqueous solution of potassium nitrate to a depth of approximately 1 mm. above the top surface of the diamond, (f) suspending a needle-like electrode in contacting relation to the apex of the bell-opening of the die and effecting an electrical discharge from said electrode to the electrolyte until the apex of the bell-opening is extended as a fine secondary cone, (g) repeating step (f) with a re-sharpened needle and a reduced discharge current until the apex of the secondary cone is extended as a still finer reduction and bearing portion, and (h) back opening, relieving and blending and polishing the bearing and reduction portions of the die.

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