

SPECIFICATION

Wire threading in wire-cut electroerosion machining processes

The present invention relates generally to wire-cutting electroerosion processes and, more specifically, to a method of and apparatus for wire-cutting a workpiece by electroerosion. The term "electroerosion" as used herein is intended to include electrical discharge machining (EDM), electrochemical machining (ECM) and electrochemical-discharge machining (ECDM). The invention particularly concerns a method of and arrangement for threading or passing a continuous wire electrode through a workpiece.

In the method of wire-cutting a workpiece by electroerosion, a continuous wire electrode is axially transported from a supply means to a collection means. In the path of wire travel, a pair of machining guide members is commonly disposed at opposite sides respectively of the workpiece to stretch the traveling wire electrode directly thereacross, thus traversing the workpiece and positioning the traveling wire electrode in a machining relationship with the workpiece. The apparatus includes a power supply for passing an electrical machining current, typically in the form of a succession of pulses, between the wire electrode and the workpiece across a machining gap flooded with a machining liquid, e.g. water, to electroerosively remove material from the workpiece. As the material removal proceeds, the workpiece is displaced transversely relative to the axis of the wire electrode along a prescribed feed path so that a desired cut is formed in the workpiece. The operation commonly requires, in advance, threading or passing the continuous wire electrode through the unmachined workpiece.

The present invention seeks to provide

(a) an improved method of wire-cutting a workpiece by electroerosion in which threading or passing the wire electrode through the workpiece is achieved easily and efficiently;

(b) a wire-cutting electroerosion method which is capable of easily and efficiently threading or passing the wire electrode through a workpiece whereby the operating efficiency of a given wire-cutting process is markedly improved;

(c) an improved method of operating a wire-cutting electroerosion machine in which threading or passing the wire electrode through a workpiece is achieved substantially automatically;

(d) an apparatus for wire-cutting a workpiece by electroerosion in which threading or passing a wire electrode through the workpiece is achieved easily and efficiently;

(e) a wire-cutting electroerosion apparatus which is capable of easily and efficiently threading or passing a wire electrode through a workpiece whereby the efficiency of a given wire-cutting operation is markedly improved; and

(f) an improved wire-cutting electroerosion machine for automatically threading a wire electrode through a workpiece.

According to a first aspect of the present

invention there is provided a method of wire-cutting a workpiece by electroerosion wherein a continuous wire electrode is axially transported from a supply means to a takeup means along a predetermined wire guiding path to traverse the workpiece linearly between a pair of wire guide members disposed at opposite sides of the workpiece in the path and adapted to position the wire electrode therebetween in a machining relationship with the workpiece; and an electrical machining current is passed between the wire electrode and the workpiece across a machining gap flooded with a machining medium to electroerosively remove material from the workpiece while the workpiece is displaced transversely and relative to the wire electrode along a prescribed feed path to form a desired cut in the workpiece, which method also includes the preliminary steps of:

(a) providing a straight through-hole in the workpiece at a preselected location thereon representing a start point of said prescribed feed path;

(b) providing a said wire electrode with a straightened broken, free end portion extending continuously from one of said supply means and said takeup means through a first of said wire guide members by:

(b1) holding a continuous electrode wire extending continuously and tightly under tension between said supply means and said takeup means through a previously machined cut,

(b2) heating said continuous electrode wire at least along a part thereof located at one of said opposite sides between the corresponding wire guide member at said one side and said previous cut to a temperature sufficient to thermally soften at least said part of the continuous electrode wire while drawing said continuous electrode wire axially, at least across said one side, under a tension sufficient to elongate and slenderize said softened part, and

(b3) applying a stress to said elongated part sufficient to sever there said continuous electrode wire to produce a first broken half having its broken, free end portion constituting said straightened broken, free end portion of the wire electrode and a second broken half extending continuously to the other of said supply means and said takeup means through the second of said wire guide members;

(c) displacing one of said first and second broken halves to withdraw it from said previous cut thereby to position the free end portion of the withdrawn broken half out of but adjacent said previous cut, the free end portions of both broken halves then lying out of said previous cut on opposite sides thereof;

(d) displacing said previous cut and positioning said workpiece to locate said through-hole therein coaxially with and ahead of said straightened broken, free end portion of said first broken half;

(e) axially advancing said first broken half to thread said straightened broken, free end portion into, through and out of said through-hole; and

(f) establishing a continuous stretch of said wire electrode between said supply means and said takeup means; whereafter wire-cutting of said workpiece is carried out.

5 In one arrangement for operating the method of the invention said part of the continuous electrode wire is located between said previous cut and said wire guide member which is located closer to said supply means in said wire guiding path.

10 Moreover, said first broken half may extend continuously from said supply means, in which case either of the two following operating modes may be adopted:—

(i) in step (c) said second broken half is withdrawn from said previous cut and continually displaced through said second wire guide member for collection into said takeup means, and in step (f) said continuous stretch is established by displacing the broken, free end portion of said first broken half threaded through said through-hole, continuously through said second guide member into said takeup means; or

(ii) in step (c) said second broken half is withdrawn from said previous cut to locate the broken, free end portion thereof ahead of said previous cut, and in step (f) said continuous stretch is established by connecting together at the other of said opposite sides the broken end portion of said second broken half and the broken end portion of said first broken half threaded through said through-hole.

Alternatively, said first broken half may extend continuously from said takeup means in step, in which case the following operating mode may be adopted:—

(c) said first broken half is withdrawn from said previous cut to locate said straightened broken, free end portion ahead of said previous cut, and in step (f) said continuous stretch is established by connecting together at said one of the opposite sides the broken end portion of said second broken half and the broken end portion of said first broken half threaded through said through-hole.

As an alternative to the foregoing arrangement for operating the method of the present invention, said part of the continuous electrode wire is located between said previous cut and said wire guide member which is located closer to said takeup means in said path, in which case either of the two following operating modes may be adopted:—

(i) said first broken half extends continuously from said supply means and, in step (c), is withdrawn from said previous cut to locate said straightened broken, free end portion ahead of said previous cut, and in step (f) said continuous stretch is established by connecting together at said one of the opposite sides the broken end portion of said second broken half and the broken end portion of said first broken half threaded through said through-hole; or

(ii) said first broken half extends continuously from said takeup means, and in step (c) said second broken half is withdrawn from said previous cut to locate the broken end portion

thereof ahead of said previous cut, and in step (f) said continuous stretch is established by connecting together at said other of said opposite sides the broken end portion of said second broken half and the broken end portion of said first broken half threaded through said through-hole.

In the step (b2) said heat is preferably applied in a manner such as to create a predetermined temperature gradient at least in the environment in which said part is located. Conveniently, said heat is applied in step (b2) to said electrode wire by surrounding said electrode wire with a heat-radiating surface disposed substantially coaxial therewith and tapered convergently in the direction of advance of said first broken half in step (e).

Said first and second broken halves may be connected together by fusion welding.

According to a second aspect of the present invention there is provided a machine for cutting a workpiece by electroerosion, in which machine a continuous wire electrode is axially transported from a supply means to a takeup means along a wire guiding path which includes a predetermined straight line path defined between a pair of wire guide members disposed at opposite sides of the workpiece for positioning the traveling wire electrode in a machining relationship with the workpiece; an electrical machining current is passed between the wire electrode and the workpiece across a machining gap flooded with a machining medium to electroerosively remove material from the workpiece; and the traveling wire electrode and the workpiece are relatively displaced transversely to said straight line path along a prescribed feed path to form a desired electroerosion cut in the workpiece, which machine includes an apparatus arranged for carrying out the preliminary steps of the method defined in claim 1, which apparatus includes:

(a) means for securing in a working position a workpiece having a straight through-hole formed therein at a preselected location which represents a start point of said prescribed feed path; and

(b) means for providing a said wire electrode with a straightened broken, free end portion extending continuously from the supply means through a first of said guide members, which means comprises:

(b1) means for holding a continuous electrode wire extending continuously between said supply means and said takeup means through a previously machined cut;

(b2) a heater means for heating said continuous electrode wire at least along a part thereof located at one of said opposite sides between said previous cut and the corresponding wire guide member to a temperature sufficient to thermally soften at least said part,

(b3) means operable in conjunction with means (b2) for drawing said electrode wire axially while being heated, at least at said one side, under a tension sufficient to elongate and slenderize said softened part,

(b4) means for applying a stress to said

elongated part sufficient to sever there said continuous electrode wire to produce a first broken half having its broken, free end portion constituting said straightened, broken free end portion of the wire electrode and a second broken half extending continuously to the other of said supply means and said takeup means through the second of said wire guide members;

(c) means for displacing one of said first and second broken halves to withdraw it from said previous cut thereby to position the free end portion of the withdrawn broken half out of but adjacent said previous cut, the free end portions of both broken halves then lying out of said previous cut on opposite sides thereof;

(d) means for displacing said previous cut and positioning said workpiece to locate said through-hole therein coaxially with and ahead of said straightened broken, free end portion of said first broken half; and

(e) means for axially advancing said first broken half to thread said straightened broken, free end portion into, through and out of said through-hole.

Preferably, said heater means has a heat-radiating surface arranged so as to create a predetermined temperature gradient at least in the vicinity of said part, said surface being convergently tapered in the direction of advance of said wire electrode effected by means (e).

Said machine may further comprise: (f) means for connecting together the broken end portions of said first and second broken halves one of which is threaded through said through-hole by means (e).

These and other objectives, features and advantages of the present invention will become apparent from a reading of the following description taken with reference to the accompanying drawings in which:

FIG. 1 is a schematic view diagrammatically illustrating a wire-cutting electroerosion machine or apparatus to which the present invention may if desired be applied;

FIGS. 2A, 2B and 2C are schematic views diagrammatically illustrating one method of using the arrangement of FIG. 1, to which the method the present invention may if desired be applied;

FIGS. 3A, 3B, 3C, 3D and 3E are schematic views diagrammatically illustrating another such method to which the present invention may if desired be applied, which method uses a modified form of said electroerosion machine or apparatus;

FIG. 4 is a schematic view diagrammatically illustrating a modified form of wire-cutting electroerosion machine or apparatus, in which the present invention is embodied and practised;

FIG. 5 is an enlarged schematic view diagrammatically illustrating a heater assembly incorporated in the arrangement of FIG. 4;

FIGS. 6A and 6B are enlarged views schematically illustrating a wire electrode elongated under heat and tension, and eventually broken, respectively, in the operation of the arrangement of FIG. 4;

FIG. 7 is an enlarged schematic view

diagrammatically illustrating a modified form of said heater assembly;

FIGS. 8A, 8B, 8C, 8D and 8E are schematic views diagrammatically illustrating a further method of using the arrangement of FIG. 4, which method embodies and practises the present invention; and

FIG. 9 is a schematic view diagrammatically illustrating a wire-cutting electroerosion machine or apparatus similar to that shown in FIG. 4 and including a further form of the wire-heating assembly.

Referring first to FIG. 1 a wire-cutting electroerosion machine is shown comprising a vertical column 1, an upper arm 2 and a lower arm 3 both of which extend horizontally from the column 1, and a machining head 4 which depends vertically movable, from the upper arm 2. The head 4 is carried on a lead screw 5 secured to the upper arm 2 and is driven by a motor 6 to adjust the vertical position of the head 4. A thin wire electrode 7 which is of a diameter, say, of 0.05 to 5 mm is stored in a supply reel 8 shown mounted on the column 1 and is continuously drawn into a cutting zone defined between a guide member 9 secured to the lower arm 3 and an upper guide member 10 secured to the machining head 4. A workpiece 11 is disposed in the cutting zone. The wire electrode is continuously drawn out from the supply reel 8 by the action of a capstan and pinch-roller arrangement 12 drivingly mounted on the lower arm 3, and is axially driven through the cutting zone while transversing the workpiece 11 by the action of another capstan and pinch-roller arrangement 13 drivingly mounted on the machining head 4, which serves to direct the wire electrode 7 from the cutting zone to a takeup side. In the supply side, brake rollers 14 are drivingly mounted on the lower arm 3 to apply a suitable tension to the wire electrode being driven, and a guide roller 15 is also arranged to change the direction of advance of the wire electrode 7. In the takeup side there are arranged guide rollers 16 and 17 on the upper arm 2 to guide the wire electrode 7 into or onto collection means such as a takeup reel not shown.

The guide members 9 and 10 serve to position the axis of the wire electrode 7 traveling stretched therebetween precisely machining relationship with the workpiece 11 securely mounted upon a workpiece support or worktable 19. An electroerosion power supply 18 is connected on one hand to the wire electrode 7 via a brush, and on the other hand to the workpiece 11 via the workpiece support 19 to supply a machining current, typically in the form of a succession of electrical pulses, between the traveling wire electrode 7 and the workpiece through a machining gap therebetween flooded with a machining medium, typically water, which may be supplied by one or more nozzles not shown, to electroerosively remove material from the workpiece 11.

During the course of machining operation, the worktable 19 is driven in a plane, shown by an

X—Y plane, by means of an X-axis motor 20 and a Y-axis motor 21 drivingly coupled via lead screws 22 and 23, respectively, to the worktable 19. The motors 20 and 21 are energized with X-axis and Y-axis drive signals furnished from a numerical-control (NC) unit 24 to displace the workpiece 11 relative to the axis of the traveling wire electrode 7 in a prescribed cutting path preprogrammed in the NC unit 24.

The apparatus of FIG. 1 is further provided with a vibration head 25 and a fusion or welding assembly 26, both of which are inoperative during a wire-cutting electroerosion operation but may be used if desired in the practice of a method embodying the present invention, as will appear later. The head 25 is attached to the machining head 4, while the fusion or welding assembly 26 is shown disposed on the lower arm 3 to act on the wire electrode 7 prior to entry into the workpiece 11.

With reference to FIGS. 2A, 2B and 2C in which, as well as in all subsequent FIGURES, the same reference numerals as are shown in FIG. 1 are used to designate the same components or parts of the apparatus, the aforesaid method which includes three steps will now be described.

The first step shown in FIG. 2A is designed to form a base hole shown at 11a in FIGS. 2B and 2C, the hole being for the purpose of receiving the wire electrode 7 for a wire-cutting electroerosion operation. To this end, the wire electrode 7 supplied from the source reel (8 in FIG. 1) is shown with a broken, free end portion 7a and is driven by means of the capstan and pinch-roller drive unit 12 to position the free end 7a just above the lower guide member 9 and below the lower surface of the workpiece 11; while a drilling electrode 27 in the form of a wire or a slender rod is mounted on the machining head 4. The drilling electrode 27 is supplied through the guide rollers 16 and 17 and is axially driven downwardly, while in contact with the machining positioning guide member 10, by means of the capstan and pinch-roller drive unit 13 until it is juxtaposed with the upper surface of the workpiece 11. The worktable 19 (FIG. 1) is displaced by means of the motors 20 and 21 (FIG. 1) under the instructions of the NC unit 24 (FIG. 1) to precisely fix the position of a desired base hole 11a (FIGS. 2B and 2C) immediately below and co-axial with the drilling electrode 27. The vibration head assembly 25 is brought into engagement with the drilling electrode 27 to impart a sonic or ultrasonic vibration to the electrode 27 longitudinally or transversely to the axis thereof. Under this state, the machining current is passed from the power supply 18 between the drilling electrode 27 and the workpiece 11 in the presence of the machining liquid, and the motor 6 (FIG. 1) is driven to downwardly move the machining head 4 thereby causing the drilling electrode to penetrate into the workpiece 11 at the rate of electroerosive material removal from the latter as that the hole 11a is completely formed through, or across the thickness of, the workpiece 11. By virtue of the

action of the sonic or ultrasonic vibration imparted to the electrode, the desired hole drilling is achieved with stability and in an extremely short period of time. The machining head 4 continues to be advanced until the lower end of the drilling electrode 27 passing through the hole 11a thus formed in the workpiece 11 comes in contact with the free end 7a of the wire electrode 7 projecting above the guide member 9 as shown in FIG. 2B. Upon completion of the hole forming operation, the vibration head assembly 25 is disengaged from the drilling electrode 27.

In the second step, the contacting free ends of the drilling electrode 27 and the wire electrode 7 are joined together. Thus, in FIG. 2B the welding assembly 26 is actuated to bring a pair of electrodes in to engagement with these contacting ends and to permit a welding current to be applied, thereby to join them together. The workpiece 11 is held stationary in position.

In the third step shown in FIG. 2C, the workpiece 11 continues to be held stationary in position while the welding assembly 26 is retracted and removed from the wire electrode 7 now joined with the drilling electrode 27, and the drive units 12 and 13 are actuated to draw the joined wire electrodes 27 and 7 upwardly through the hole 11a, thereby completing the mounting or threading of the wire electrode 7 through the base hole 11a. The drilling electrode 27 guided out from the rollers 17 may be cut and the wire electrode 7 led to the collection site to establish a setting condition preparatory to a given wire-cutting operation as described in connection with FIG. 1.

The fusion assembly 26 can also be used to divide (i.e. break) the continuous wire electrode 7 stretched between the guide members 9 and 10 across the wire-cut workpiece 11 into a lower part leading from the supply side 8 and an upper part leading to the collection side. By bringing the electrodes of the welding assembly 26 into engagement with a portion of the stretched wire 7 between the lower guide member 9 and the lower surface of the workpiece 11 and energizing the electrodes with the fusion current, the division can be achieved. When a subsequent wire-cutting operation is to follow, the lower part of wire electrode may remain in its position while the upper part of wire electrode is retracted to locate its end above the upper surface of the workpiece 11. The wire-cut workpiece may then be replaced by a subsequent workpiece or, when a plurality of areas of the workpiece are to be wire-cut, it may simply be displaced to present a new area to a subsequent wire-cutting operation. The worktable 19 is then driven under programmed instructions of the NC unit 24 to position a new base hole to be formed in the replaced workpiece or replaced area of workpiece, relative to the co-axial axes of the divided upper and lower parts of the wire electrode 7. The upper portion of wire electrode 7 may then be replaced by a drilling electrode. Then the hole-forming and wire-mounting operations in sequence as have been described may follow.

It is advantageous to use the retracted upper portion of wire electrode 7 as the drilling electrode 27. This is particularly convenient when the wire electrode 7 is relatively thick. Neither a separate drilling electrode nor a separate setting operation is then required.

It will be appreciated that the wire threading process described can be achieved on a fully automatic basis simply with the aid of the machining NC unit 24, and thus enables an extremely efficient wire-cutting operation.

FIGS. 3A—3E illustrate another method and apparatus to which the present invention may if desired be applied, in which a workpiece 11 is formed in advance with one or more base holes 11a, 11b, etc. at a preselected location or locations therein, and has a guide in the form of a wire or slender rod 28a, 28b, etc. threaded through each hole 11a, 11b, etc. and held there against dropping out. The wire threading through each hole is achieved by connecting the upper part of wire electrode 7 with the guide 28a, 28b, etc. In the apparatus shown, the machining head 4 is provided with an 'upward' roller unit 29 by means of which the guide 28a, 28b, etc. is caught at its upper end. The formation of each hole 11a, 11b, etc. may be done by any conventional drilling process, e.g. EDM, ECM, ECDM, mechanical machining or with a laser or electron beam. It is typical to mount on the machine the workpiece after formation of the hole or holes 11a, 11b, etc. and having the guide or guides 28a, 28b, etc. therein. To hold the guide 28a, 28b, etc. against dropping out, the top portion thereof may slightly be bent so that it hangs on the hole 11a, 11b, etc.

FIG. 3A shows a first step in the operation of the apparatus, in which by positioning the workpiece 11, the lower end portion of the guide 28a which passes through the hole 11a comes to meet with the end portion of the wire electrode 7 projecting from the lower wire guide member 9. The portions in mutual contact are held between the electrodes of the fusion assembly 26 and, energized with a fusion current, are welded together.

In a second step, as shown in FIG. 3B, the fusion assembly 26 is retracted and the machining head 4 is moved down to bring the top portion of the guide 28a into engagement with the roller unit 29. The unit is driven to catch the guide 28a between the rollers 29 and to continually draw it upwards to allow the wire electrode 7 to pass through the hole 11a and the rollers 29. The rollers 29 are made of a material having a large friction, such as rubber, and are thus capable of drawing the guide and the wire electrode in with ease.

A wire-cutting operation is conducted with the wire electrode 7 so drawn through the hole 11a. The capstan and pinch-roller units 12 and 13 are driven to continuously effect the take-up action of the wire electrode 7 from the supply reel 8 through the cutting zone (FIG. 1).

The desired contour having been formed in the workpiece 11 starting at the base hole 11a, the

cutting feed of the workpiece 11 is halted and the displacement of the wire electrode 7 by the capstan and pinch-roller 12 is brought to a stop. Then the continuous wire electrode 7 stretched between the supply and takeup sides is cut below the workpiece 11 by the fusion assembly 26 and the machining head 4 is retracted to draw the upper portion of wire electrode 7 out from the workpiece 11 as shown in FIG. 3C for removal.

The next step may, as shown in FIG. 3D, displace the workpiece 11 to a next cutting start position under instructions from the NC unit 24 to bring hole 11b in alignment with the axis of the wire electrode 7 projecting from the guide member 9. The fusion assembly 26 is again actuated to weld together the lower end of the guide wire 28b previously passed through the hole 11b and the upper end portion of the lower part of wire electrode 7. The fusion-joining of the guide wire 28b with the wire electrode 7 is followed by the step of FIG. 3E to pass the wire electrode 7 through the hole 11b, thus bringing it ready for the subsequent wire-cutting operation starting at the hole 11b. In this manner, a number of preselected areas in a workpiece are machined in sequence starting successively at preformed holes 11a, 11b, etc. The threading of the wire electrode 7 through each starting hole in each stage is extremely accurate and yet simple as will be apparent from the foregoing and permits each individual and sequential wire-cutting operation to be performed with a markedly improved efficiency.

It will be appreciated that any means other than fusion welding, such as soldering, adhesive-bonding or manual knotting, may be used to join the wire-like guide 28a, 28b with the wire electrode 7. Further, the guide 28a, 28b may be held against dropping out by any known means. For example, when the workpiece 11 is a magnetically susceptible material, the wire-like guide 28a, 28b may be composed of a magnetized material and may be held in the hole 11a, 11b in position by magnetic attraction to the workpiece. The guide 28a, 28b may also be held by electrostatic attraction. The guide 28a, 28b may also have a fishhook-like end may thereby be suspended. The continuous wire electrode may be divided into upper and lower portions by cutting with a knife.

In FIG. 4 there is shown a modified wire-cutting machine or apparatus for the explanation of a method and apparatus embodying and practising the present invention. In this machine, a supply reel 108 for the wire electrode 7 is mounted on the machining head 4, the capstan and pinch-roller unit 13 mounted on the machining head 4 is used for drawing the wire electrode 7 from the supply reel 108, and the capstan and pinch roller unit 12 mounted on the lower arm 3 is used to draw the wire electrode 7 travelling between a wire-guide member 110 at the inlet side and a wire-guide member 109 at the outlet side across the region of the workpiece 11 in the direction of arrow. Downstream of the traction capstan and pinch-roller unit 12, there are provided a pair of

guide roller units 114 and 115 around which two endless belts 116 and 117 pass in mutual engagement so that the wire electrode 7 fed out from the unit 12 is drawn in between the belts 116 and 117 passing in engagement therewith, and is fed to collection means not shown.

Beneath the workpiece 11 at the outlet side of the cutting region there is provided a heater unit 31 on the lower arm 3 in this embodiment to apply heat to the wire electrode 7 coming out from the workpiece 11. A preferred example of this unit may, as diagrammatically shown in FIG. 5, have a body 31a with a trapezoidal or frustoconical inner heating surface 31b tapered convergently in the direction of displacement of the wire electrode 7 and with a heating coil 31c embedded therein and energized by a power supply 31d. Because the heating surface 31b is so tapered, a temperature gradient develops in the heated wire electrode 7 as diagrammatically shown by broken lines in FIG. 5. The wire electrode 7 in the machining head 4 is held by a magnetic grip 32 and the machining head 4 is moved upwardly to apply a tension to the wire electrode. The wire electrode heated in the heater unit 31 is then drawn and elongated with a taper as shown in FIG. 6A and is eventually broken as shown in FIG. 6B. In this manner, any deflection in the heated wire electrode 7 is eliminated and a sharp, straight needle-like tip is formed in the broken wire electrode 7 as shown in FIG. 6B. For example, a copper wire electrode has a tensile strength of 45 kg/mm² in a room temperature. When heated to 150 to 230°C, the wire electrode has the tensile strength reduced to about 15 kg/mm². When loaded with a suitable tension, the wire of 1 m long is capable of being elongated to a length of 3.5 m. The thermally controlled elongation eliminates any deflection with the wire 7 has and makes it linearly straightened. The wire electrode 7 is broken at the most heated portion and, since the broken wire electrode is sharply pointed as shown in FIG. 6B, it can quite easily be passed into the base hole 11a formed in the workpiece 11.

FIG. 7 shows another embodiment of the heater unit 31. This embodiment makes use of a coil 31c wound tapering convergently in the direction of travel of the wire 7 and energized with a heating current furnished by a power supply 31f. The heater may be disposed at the inlet side of or above the workpiece 11.

With reference to FIGS. 8A, 8B, 8C, 8D and 8E, a wire threading or mounting operation with the apparatus of FIG. 4 will be described.

FIG. 8A shows a first step in which the wire electrode 7 is broken and the machining head 4 is retracted. The workpiece 11 has been formed in advance with base holes 11a and 11b by mechanical drilling, EDM, ECM etc. The hole 11a has been positioned properly under control of the NC unit 24 as described previously.

In the second step shown in FIG. 8B, the machining head 4 is moved down to insert the lower end of the broken wire 7 into the hole 11a

and the electromagnetic grip 32 is deactuated to release the wire 7. Then the capstan and pinch-roller drive units 12 and 13 and the belt drive units 114, 116; 115, 117 are actuated to cause the inserted wire electrode 7 to be further driven and its lower end to pass through the hole 11a, the lower wire guide member 109 and the capstan and pinch rollers 12 and to be rolled between the take-up belts 116 and 117. The belts 116 and 117 are made of a material having a large friction, such as rubber, and are thus capable of drawing the wire electrode in with ease. The mounting or threading of the wire electrode 7 through the base hole 11a has been completed.

A wire-cutting operation is conducted with the wire electrode 7 so threaded through the hole 11a. The capstan and pinch-roller units 12 and 13 and the belt assembly 114 to 117 continue to be driven to continuously effect the take-up action of the wire electrode 7 from the supply reel 108 (FIG. 4) through the cutting region.

The desired contour having been formed in the workpiece 11 starting at the base hole 11a under controlled drive signals for the motors 20 and 21 furnished from the NC unit 24, the displacement of the workpiece 11 comes to stop, and the capstan and pinch-roller units 12 and 13 and the belt assembly 114 to 117 also deactuate to bring the wire electrode 7 to a halt.

Then the heater unit 31 is energized while the electromagnetic grip 32 is actuated to hold the wire 7. The machining head 4 is then moved upwards to give a tension to the heated wire 7. This causes the wire 7 to be thermally controlledly elongated and broken as described previously to develop a straight, sharply pointed, broken, free end portion. With the continued upward displacement of the machining head 4, the broken, free end portion of wire electrode is withdrawn from the hole 11a and retracted above the workpiece 11 as shown in FIG. 8C. The lower broken half of wire 7 is fed out through the belt assembly 114 to 117 to the collection site.

In the subsequent step shown in FIG. 8D, the workpiece 11 is repositioned under drive signals furnished from the NC unit 24 so that the next operation—starting hole 11b comes into coincidence with the traveling axis of the wire electrode 7.

In the following step of FIG. 8E, the machining head 4 is again moved down to insert the broken free end portion of wire 7 into the hole 11b and the electromagnetic grip 32 is deactuated to release the wire 7. The capstan and pinch-roller units 12 and 13 and the take-up belt assembly 114 to 117 are actuated to cause the inserted wire electrode 7 to be further driven and its lower end to pass through the hole 11b, the lower wire guide member 109 and the capstan and pinch rollers 12 and to be rolled into the take-up belt assembly 114 to 117. The wire-cutting operation starting at the base hole 11b follows.

FIG. 9 shows the wire-cutting electroerosion machine including a further embodiment of the invention in which the continuous wire electrode 7

24

after completing a given wire-cutting operation is straightened by thermal elongation and cutting in a zone between the machining wire-positioning guide members 109 and 110. In this embodiment, a heating current supply 35 is connected via an operating switch 36 to a pair of current conducting rollers 37a and 37b disposed in contact with the wire electrode 7 across the workpiece 11 between the upper and lower guide members 109 and 110. In the path of the wire electrode between the workpiece 11 and the lower current-conducting roller 37a there is disposed a cutter unit 38.

Closing the switch 36 causes a heating current from the supply 35 to be passed directly through the wire electrode 7 stretched between the guide members 109 and 110. The electromagnetic grip is actuated to hold the wire 7 and the machining head 4 is moved upwards to give a tension to the heated wire 7. The wire stretch elongates and is broken by the cutter 38 into an upper half leading from the supply 108 and a lower half leading to the take-up belt assembly 114 to 117. Thereafter, steps corresponding to the steps shown in FIGS. 8D and 8E follow in sequence.

CLAIMS

1. A method of wire-cutting a workpiece by electroerosion wherein a continuous wire electrode is axially transported from a supply means to a takeup means along a predetermined wire guiding path to traverse the workpiece linearly between a pair of wire guide members disposed at opposite sides of the workpiece in the path and adapted to position the wire electrode therebetween in a machining relationship with the workpiece; and an electrical machining current is passed between the wire electrode and the workpiece across a machining gap flooded with a machining medium to electroerosively remove material from the workpiece while the workpiece is displaced transversely and relative to the wire electrode along a prescribed feed path to form a desired cut in the workpiece, which method also includes the preliminary steps of:

(a) providing a straight through-hole in the workpiece at a preselected location thereon representing a start point of said prescribed feed path;

(b) providing a said wire electrode with a straightened broken, free end portion extending continuously from one of said supply means and said takeup means through a first of said wire guide members by:

(b1) holding a continuous electrode wire extending continuously and tightly under tension between said supply means and said takeup means through a previously machined cut,

(b2) heating said continuous electrode wire at least along a part thereof located at one of said opposite sides between the corresponding wire guide member at said one side and said previous cut to a temperature sufficient to thermally soften at least said part of the continuous electrode wire while drawing said continuous electrode wire

axially, at least across said one side, under a tension sufficient to elongate and slenderize said softened part, and

(b3) applying a stress to said elongated part sufficient to sever there said continuous electrode wire to produce a first broken half having its broken, free end portion constituting said straightened broken, free end portion of the wire electrode and a second broken half extending continuously to the other of said supply means and said takeup means through the second of said wire guide members;

(c) displacing one of said first and second broken halves to withdraw it from said previous cut thereby to position the free end portion of the withdrawn broken half out of but adjacent said previous cut, the free end portions of both broken halves then lying out of said previous cut on opposite sides thereof;

(d) displacing said previous cut and positioning said workpiece to locate said through-hole therein coaxially with and ahead of said straightened broken, free end portion of said first broken half;

(e) axially advancing said first broken half to thread said straightened broken, free end portion into, through and out of said through-hole; and

(f) establishing a continuous stretch of said wire electrode between said supply means and said takeup means; whereafter wire-cutting of said workpiece is carried out.

2. The method defined in claim 1 wherein in step (b) said part of the continuous electrode wire is located between said previous cut and said wire guide member which is located closer to said supply means in said wire guiding path.

3. The method defined in Claim 2 wherein said first broken half extends continuously from said supply means.

4. The method defined in Claim 3 wherein step (c) said second broken half is withdrawn from said previous cut and continually displaced through said second wire guide member for collection into said takeup means and in step (f) said continuous stretch is established by displacing the broken, free end portion of said first broken half threaded through said through-hole, continually through said second guide member into said takeup means.

5. The method defined in Claim 3 wherein in step (c) said second broken half is withdrawn from said previous cut to locate the broken, free end portion thereof ahead of said previous cut and in step (f) said continuous stretch is established by connecting together at the other of said opposite sides the broken end portion of said second broken half and the broken end portion of said first broken half threaded through said through-hole.

6. The method defined in Claim 2 wherein said first broken half extends continuously from said takeup means and, in step (c), is withdrawn from said previous cut to locate said straightened broken, free end portion ahead of said previous cut, and in step (f) said continuous stretch is established by connecting together at said one of the opposite sides the broken end portion of said



after completing a given wire-cutting operation is straightened by thermal elongation and cutting in a zone between the machining wire-positioning guide members 109 and 110. In this embodiment, a heating current supply 35 is connected via an operating switch 36 to a pair of current conducting rollers 37a and 37b disposed in contact with the wire electrode 7 across the workpiece 11 between the upper and lower guide members 109 and 110. In the path of the wire electrode between the workpiece 11 and the lower current-conducting roller 37a there is disposed a cutter unit 38.

Closing the switch 36 causes a heating current from the supply 35 to be passed directly through the wire electrode 7 stretched between the guide members 109 and 110. The electromagnetic grip is actuated to hold the wire 7 and the machining head 4 is moved upwards to give a tension to the heated wire 7. The wire stretch elongates and is broken by the cutter 38 into an upper half leading from the supply 108 and a lower half leading to the take-up belt assembly 114 to 117. Thereafter, steps corresponding to the steps shown in FIGS. 8D and 8E follow in sequence.

CLAIMS

1. A method of wire-cutting a workpiece by electroerosion wherein a continuous wire electrode is axially transported from a supply means to a takeup means along a predetermined wire guiding path to traverse the workpiece linearly between a pair of wire guide members disposed at opposite sides of the workpiece in the path and adapted to position the wire electrode therebetween in a machining relationship with the workpiece; and an electrical machining current is passed between the wire electrode and the workpiece across a machining gap flooded with a machining medium to electroerosively remove material from the workpiece while the workpiece is displaced transversely and relative to the wire electrode along a prescribed feed path to form a desired cut in the workpiece, which method also includes the preliminary steps of:

(a) providing a straight through-hole in the workpiece at a preselected location thereon representing a start point of said prescribed feed path;

(b) providing a said wire electrode with a straightened broken, free end portion extending continuously from one of said supply means and said takeup means through a first of said wire guide members by:

(b1) holding a continuous electrode wire extending continuously and tightly under tension between said supply means and said takeup means through a previously machined cut;

(b2) heating said continuous electrode wire at least along a part thereof located at one of said opposite sides between the corresponding wire guide member at said one side and said previous cut to a temperature sufficient to thermally soften at least said part of the continuous electrode wire while drawing said continuous electrode wire

axially, at least across said one side, under a tension sufficient to elongate and slenderize said softened part, and

(b3) applying a stress to said elongated part sufficient to sever there said continuous electrode wire to produce a first broken half having its broken, free end portion constituting said straightened broken, free end portion of the wire electrode and a second broken half extending continuously to the other of said supply means and said takeup means through the second of said wire guide members;

(c) displacing one of said first and second broken halves to withdraw it from said previous cut thereby to position the free end portion of the withdrawn broken half out of but adjacent said previous cut, the free end portions of both broken halves then lying out of said previous cut on opposite sides thereof;

(d) displacing said previous cut and positioning said workpiece to locate said through-hole therein coaxially with and ahead of said straightened broken, free end portion of said first broken half;

(e) axially advancing said first broken half to thread said straightened broken, free end portion into, through and out of said through-hole; and

(f) establishing a continuous stretch of said wire electrode between said supply means and said takeup means; whereafter wire-cutting of said workpiece is carried out.

2. The method defined in claim 1 wherein in step (b) said part of the continuous electrode wire is located between said previous cut and said wire guide member which is located closer to said supply means in said wire guiding path.

3. The method defined in Claim 2 wherein said first broken half extends continuously from said supply means.

4. The method defined in Claim 3 wherein step (c) said second broken half is withdrawn from said previous cut and continually displaced through said second wire guide member for collection into said takeup means and in step (f) said continuous stretch is established by displacing the broken, free end portion of said first broken half threaded through said through-hole, continually through said second guide member into said takeup means.

5. The method defined in Claim 3 wherein in step (c) said second broken half is withdrawn from said previous cut to locate the broken, free end portion thereof ahead of said previous cut and in step (f) said continuous stretch is established by connecting together at the other of said opposite sides the broken end portion of said second broken half and the broken end portion of said first broken half threaded through said through-hole.

6. The method defined in Claim 2 wherein said first broken half extends continuously from said takeup means and, in step (c), is withdrawn from said previous cut to locate said straightened broken, free end portion ahead of said previous cut, and in step (f) said continuous stretch is established by connecting together at said one of the opposite sides the broken end portion of said



25
second broken half and the broken end portion of said first broken half threaded through said through-hole.

7. The method defined in claim 1 wherein in step (b) said part of the continuous electrode wire is located between said previous cut and said wire guide member which is located closer to said takeup means in said path.

8. The method defined in claim 7 wherein said first broken half extends continuously from said supply means and, in step (c), is withdrawn from said previous cut to locate said straightened broken, free end portion ahead of said previous cut, and in step (f) said continuous stretch is established by connecting together at said one of the opposite sides the broken end portion of said second broken half and the broken end portion of said first broken half threaded through said through-hole.

9. The method defined in Claim 7 wherein said first broken half extends continuously from said takeup means and in step (c) said second broken half is withdrawn from said previous cut to locate the broken end portion thereof ahead of said previous cut and in step (f) said continuous stretch is established by connecting together at said other of said opposite sides the broken end portion of said second broken half and the broken end portion of said first broken half threaded through said through-hole.

10. The method defined in any one of the preceding claims wherein said heat is applied in step (b2) in a manner such as to create a predetermined temperature gradient at least in the environment in which said part is located.

11. The method defined in any one of claims 1 to 9 wherein said heat is applied in step (b2) to said electrode wire by surrounding said electrode wire with a heat-radiating surface disposed substantially coaxial therewith and tapered convergently in the direction of advance of said first broken half in step (e).

12. The method defined in any one of claims 5, 6, 8 and 9 wherein said first and second broken halves are connected together by fusion welding.

13. A machine for cutting a workpiece by electroerosion, in which machine a continuous wire electrode is axially transported from a supply means to a takeup means along a wire guiding path which includes a predetermined straight line path defined between a pair of wire guide members disposed at opposite sides of the workpiece for positioning the traveling wire electrode in a machining relationship with the workpiece; an electrical machining current is passed between the wire electrode and the workpiece across a machining gap flooded with a machining medium to electroerosively remove material from the workpiece; and the traveling wire electrode and the workpiece are relatively displaced transversely to said straight line path along a prescribed feed path to form a desired electroerosion cut in the workpiece, which machine includes an apparatus arranged for carrying out the preliminary steps of the method

defined in claim 1, which apparatus includes:

(a) means for securing in a working position a workpiece having a straight through-hole formed therein as a preselected location which represents a start point of said prescribed feed path; and

(b) means for providing a said wire electrode with a straightened broken, free end portion extending continuously from the supply means through a first of said guide members, which means comprises:

(b1) means for holding a continuous electrode wire extending continuously between said supply means and said takeup means through a previously machined cut;

(b2) a heater means for heating said continuous electrode wire at least along a part thereof located at one of said opposite sides between said previous cut and the corresponding wire guide member to a temperature sufficient to thermally soften at least said part,

(b3) means operable in conjunction with means (b2) for drawing said electrode wire axially while being heated, at least at said one side, under a tension sufficient to elongate and slenderize said softened part,

(b4) means for applying a stress into said elongated part sufficient to sever there said continuous wire to produce a first broken half having its broken, free end portion constituting said straightened, broken free end portion of the wire electrode and a second broken half extending continuously to the other of said supply means and said takeup means through the second of said wire guide members;

(c) means for displacing one of said first and second broken halves to withdraw it from said previous cut thereby to position the free end portion of the withdrawn broken half out of but adjacent said previous cut, the free end portions of both broken halves then lying out of said previous cut on opposite sides thereof;

(d) means for displacing said previous cut and positioning said workpiece to locate said through-hole therein coaxially with and ahead of said straightened broken, free end portion of said first broken half; and

(e) means for axially advancing said first broken half to thread said straightened broken, free end portion into, through and out of said through-hole.

14. A machine as defined in claim 13 wherein said heater means has a heat-radiating surface arranged so as to create a predetermined temperature gradient at least in the vicinity of said part, said surface being convergently tapered in the direction of advance of said wire electrode effected by means (e).

15. A machine as defined in claim 13 or 14, further comprising: (f) means for connecting together the broken end portions of said first and second broken halves one of which is threaded through said through-hole by means (e).

16. A machine as defined in any one of the claims 13 to 15 for wire-cutting a workpiece by electroerosion, substantially as hereinbefore described with reference to, and as illustrated in,



26

any single figure or group of associated figures of the accompanying drawings.

17. A method as defined in any one of the claims 1 to 12 of wire-cutting a workpiece by electroerosion, substantially as hereinbefore described with reference to, and as illustrated by, any single figure or group of associated figures of

the accompanying drawing.

18. A workpiece machined by a wire-cut electroerosion method according to any one of the claims 1 to 12 and 17, or by means of a wire-cut electroerosion machine according to any one of the claims 13 to 16.