

WIRE-CUTTING ELECTROEROSION MACHINING METHOD

5 The present invention relates to electroerosion wire-cutting method and, more particularly, to a method of electro-erosively cutting a workpiece to form a desired contour therein with a continuous wire electrode axially advanced to linearly traverse the workpiece across a cutting zone while being displaced relative to the workpiece transversely to the axis thereof.

10

In electroerosion wire-cutting, a thin continuous wire or filamentary electrode, typically of a thickness of 0.05 to 0.5 mm, is continuously advanced from a supply side to a takeup side through a cutting zone in which a workpiece is positioned and into which a cutting liquid, typically distilled water or a liquid medium of dielectric and/or electrolytic nature, is supplied. The wire electrode is continuously advanced conveniently between a pair of guide members to define a linear or straight and continuously traveling wire stretch therebetween for positioning it precisely in a predetermined machining relationship with the workpiece traversed axially thereby. An electrical machining current, advantageously in the form of a succession of time-spaced and precisely ad-

15

20

justed electrical pulses, is applied across a machining gap formed between the workpiece and the traveling-wire stretch to effect electrical discharges and/or electrolytic action to electroerosively remove material from the workpiece. As
5 material removal proceeds, the workpiece is displaced relative to the linear traveling-wire stretch transversely to the axis thereof, typically under numerical control, along a predetermined path to generate a desired pattern of cut or contour in the workpiece. The continuous advancement or travel of
10 the wire electrode is effected typically by traction drive rollers disposed at a location between the guide member on the downstream side and the wire takeup means. A desired tension is established in the traveling wire bridged between the guide members typically by providing brake means at a
15 location between the guide member on the upstream side and the wire supply means.

The path along which the workpiece is displaced relative to the linear traveling-wire stretch transversely to the axis thereof is defined empirically so that the resulting machined
20 contour may precisely coincide both dimensionally and in shape with the desired pattern of cut. The tolerance or difference in size between the machined contour and the envelope line of the passage of the machining wire electrode (adjacent to the machined contour) is commonly called "overcut" and corre-
25 sponds to the size of the machining gap formed between the

wire electrode and the workpiece. There is therefore a deviation of size between the path of the center axis of the machining wire electrode and the resulting or desired contour in the workpiece which is equal to the radius of the wire electrode plus the machining gap or "overcut".

An attempt in the art to yield a machined contour with a due precision, surface finish and efficiency with respect to a desired contour makes common use of a double or multiple step wire-cutting process. In this process, the first step is used to rough-cut a workpiece by displacing the wire electrode relative to the workpiece along a path corresponding to the desired contour but sized to yield a rough-cut contour. The second step is used to remove the deviation between the rough-cut contour and the desired contour by displacing the wire electrode relative to the workpiece along a path shifted in the plane of displacement from the first-step path by a finish-cut distance. In the prior art, this latter distance together with the rough size path in the first step has been solely determined empirically. It has been the common practice in the art to choose the finish-step cut size roughly equal to the overcut in the first, rough-cutting step.

The present inventor has now discovered that in such a two- or multi-step wire-cutting operation a certain problem arises due to peculiar dynamic characteristics of the wire electrode in electroerosively cutting along the previously

rough-cut contour in the finish-cutting step. In the ordinary electroerosive operation or rough-cutting step in which the wire electrode is advancing transversely in the workpiece, the machining action takes place preferentially along the semi-circular surface of the wire electrode located in the direction of advance. The machining action is accompanied by machining pressure, e.g. discharge pressure and/or expansion pressure of gases produced, and accordingly tends to force the advancing wire electrode back or in the direction opposed to the direction of advance in the ordinary or rough-cutting operation. In the finish-cutting step, the wire electrode must be advancing semi-tangentially along the rough-cut contour and there develops an unbalance in the machining pressure on one and the other semi-circular surface sides on the wire electrode with respect to the direction of advance, which produces additionally a wire deflection force which tends to force the wire electrode in a direction away from the workpiece contour being finish-cut and may give rise to an undue finishing inaccuracy. It has been found that this additional wire deflection force develops in spite of a considerable external tension applied to the linear wire stretch bridged and traveling across the cutting zone and increases with the increase in the thickness of the workpiece. Thus, when the trajectory of displacement of the wire electrode in the finishing step is a path simply shifted from that in the roughing

-5-

step by a distance defined roughly on the conventional empirical basis or without regard to the workpiece thickness, a desired finishing precision could not be obtained. The position of the wire electrode may even be shifted far away from the given wire trajectory in the finishing step so that the machined contour in the workpiece is deviated largely from the desired contour.

The present invention therefore seeks to provide an electroerosion method of wire-cutting whereby a contour as precisely as desired and with a requisite surface finish is formed in a workpiece.

The invention also seeks to provide a method of electroerosively wire-cutting a workpiece to form a desired contour therein with an increased precision and efficiency over the prior art.

Furthermore, the invention seeks to provide an improved two- or multiple-step electroerosive wire-cutting method wherein the dependency of the cutting accuracy in the finishing step on the thickness of a workpiece is effectively overcome.

These and other objectives are attained in accordance with the present invention by a method of cutting a workpiece to form a desired contour therein with a continuous wire electrode axially advanced to

linearly traverse the workpiece across a cutting zone
and also displaced relative to the workpiece
transversely to the axis of the wire electrode, which
method comprises the steps of: (a) electroerosively
5 rough-cutting the workpiece while effecting the
transverse relative displacement between the wire
electrode and the workpiece along a first
predetermined path corresponding to the desired
contour and defined to generate a rough-cut contour
10 with an overcut α in the workpiece; and (b)
electroerosively finish-cutting the workpiece while
effecting the transverse relative displacement
between the wire electrode and the workpiece along a
second predetermined path shifted by a distance
15 defined substantially by an expression: $n\alpha$ uniformly
from the first predetermined path where n is a value
essentially proportional to the thickness of the
workpiece, thereby generating a finish-cut contour
coinciding with the desired contour in the
20 workpiece.

These and other features and advantages of
the present invention will become more readily
apparent from the following description of certain
embodiments of the principles thereof, reference
25 being made to the accompanying drawing in which:

FIG. 1 is a schematic view essentially in
section diagram-

matically illustrating an apparatus for carrying out the method of the invention;

FIG. 2 is a planview diagrammatically illustrating a
workpiece preliminarily machined in a rough-cutting step and
5 to be secondarily machined in a finish-cutting step in accordance with the invention; and

FIG. 3 is an enlarged diagrammatic view of a portion of the arrangement of FIG. 2.

10 Referring to FIG. 1, an electrical-discharge wire-cutting arrangement includes a wire electrode 1 axially advanced from a supply reel 2 to a takeup reel 3 continuously through a cutting zone defined between a pair of guide means 4 and 5. A
workpiece 6 is disposed in the cutting zone and traversed
15 by a linear stretch of the wire electrode 1 tightly bridged and continuously traveling across the guide means 4 and 5. Further wire guide members 14 and 15 are provided in the wire travel path to change the direction of advance of the wire electrode 1
20 from the supply side 2 to the cutting zone and from the latter to the takeup side 3, respectively.

In the cutting zone, a machining liquid is supplied from nozzle means (not shown) to flood the machining gap formed between the wire electrode 1 and the workpiece 6. An EDM (electrical discharge machining) power supply 11 has a pair

of output terminals electrically connected to the wire electrode 1 and to the workpiece 6, respectively, to apply a succession of electrical machining pulses across the machining gap filled with the machining liquid to electroerosively remove material from the workpiece 6.

The workpiece 6 is securely mounted on a worktable 7 and the drive system for displacing the workpiece 6 relative to the wire electrode 1 transversely to the axis thereof or in an X-Y plane includes a first motor 8 for feeding the worktable 7 along the X-axis and a second motor 9 for feeding the worktable 7 along the Y-axis, the motors 8 and 9 being driven by electrical signals furnished by a numerical controller 10.

In addition or optionally, a pair of vibrator units 12 and 13 are provided in contact with or in close proximity to the wire electrode 1 between the machining guide means 4 and 5 and at opposite sides of the workpiece 6, respectively. The vibrators 12 and 13 are energized by high-frequency power supply means (not shown) of a frequency or frequencies not lower than 100 Hz and, preferably between 1 and 50 kHz to impart to the traveling wire 1 stretch between the guide means 4 and 5, vibrations of an amplitude between 1 and 50 microns and, preferably between 1 and 10 microns. By virtue of the vibrator arrangement, any arc discharge or short-circuiting condition can, immediately upon development, be extinguished

mechanically and the contact friction over the guide means 4 and 5 can markedly be reduced. Further, the removal of machining products and gases produced in the machining gap which tend to disturb the machining stability is facilitated with the result that steady machining is continued with a stability, without breakage of the wire electrode 1, and with an increased removal rate.

The vibrations are imparted at one or both of the locations shown to the wire electrode 1 in a direction transverse to the axis thereof so that an undulating oscillatory motion with more than two nodes and antinodes or loops is provided in the wire 1 traveling between the two guide members 4 and 5 positioned at opposite sides with respect to the workpiece 6.

The vibrations are preferably imparted at the two locations shown, which are opposite with respect to the workpiece 6, to the wire electrode 1 each in a direction transverse to the axis thereof so that they are superimposed upon one another to create a composite undulating oscillatory motion with more than two nodes and antinodes or loops in the wire 1 traveling between the two guide members 4 and 5 positioned at opposite sides with respect to the workpiece and each outside of each location at which the vibration is applied.

By imparting a vibration to the traveling wire electrode 1 at one or preferably both sides of the workpiece 6 through

which it is passed in a traveling-wire electroerosion system, it has been found that an improvement in the removal rate is attained, this being especially noticeable when workpieces of a greater thickness are machined. Thus, an intensified
5 pumping action appears to be generated in the cutting zone to facilitate removal of machined products therefrom, i.e. chips and gases and, of even more importance, a highly effective dispersive production of successive discharges in the cutting zone over the entire workpiece thickness is assured,
10 thus favorably restraining the discharges from being concentrated on a single point or region of the wire electrode 1 traversing or traveling through the workpiece 6.

The vibrations imparted at the two opposite locations with respect to the workpiece 6 are preferably of different
15 frequencies such that a beat or the periodic variation in amplitude of a wave that is the superimposition of the corresponding two simple harmonic waves of the different frequencies is produced in the traveling wire electrode 1. This arrangement is advantageous to facilitate and enhance the removal
20 of machining chips and other gap products while suppressing the temperature rise of the workpiece 6 being cut.

The two vibration means 12 and 13 are preferably in some cases positioned at their respective locations so as to provide the respective vibrations in directions transverse
25 to each other, viz., for example, one in the direction of

X-axis and the other in the direction of Y-axis, the axes along which the workpiece 6 is displaced relative to the traveling wire electrode 1 by the aforementioned drive means e.g. a numerically controlled drive means.

5 Each of the vibrator means 12, 13 is preferably in contact with a guide member 4, 5 for the electrode 1 and may be an electromagnetic, or a sonic or ultrasonic vibrator. Each vibrator means may be a magnetostrictive or piezoelectric vibrator. The vibrators 12 and 13 may be connected for energization with respective resonant circuits (not shown) each
10 connected across the machining gap.

A control system (not shown) is preferably provided, in operation of the apparatus, to respond to the machining gap condition to cause a parameter of the vibrations to be
15 modified in response to the gap state. The vibrator means 12 and 13 are preferably arranged to be cooled by a coolant fluid.

In the use of the apparatus, the machining liquid is advantageously supplied to the wire electrode 1 by flowing
20 through the location where the vibrator end of each vibrator arrangement comes in contact with the wire 1 or by flowing in contact with the body of each vibrator so that the heat generated at the vibrating body is sufficiently dissipated to avoid a detrimental heating of the wire electrode 1.

25 It is generally desirable to keep the plane of the wire

vibration in coincidence with the direction of advance in the relative transverse displacement of the workpiece 6 to the axially traveling wire electrode 1.

5 The wire-vibration arrangement described can, as described below, be advantageously employed in a double- or multi-step electrical machining operation including a finish-cutting, reforming or secondary-cutting step to which a workpiece 6 rough-cut in the preliminary cutting step is subjected to finish the machined surface contour with due precision and surface finish. The problem inherent to this operation is the fact that it is extremely difficult to maintain a desired cutting depth precisely constant. In the finish-cutting operation, a force tending to force the wire electrode 1 away from the previously rough-cut contour in the workpiece 6 being finish-cut develops at all times due to a pressure caused by the machining discharges and the decomposed gases expanding in the machining liquid in the gap region. This force causes the wire 1 to be bent and to move away from the directed position so that the cutting depth may variably be deviated.

20 Referring now to FIGS. 1 and 2, a traveling-wire EDM operation comprising roughing and finishing steps in accordance with the present invention is described. A workpiece 6 having a starting bore 6a formed therethrough at a predetermined location by mechanical or EDM drilling is first set on the worktable 7. The wire electrode 1 is threaded through the

25

bore 6a and the wire drive mechanism (not shown) is actuated to axially advance the wire electrode 1 in the direction of arrow and to transport it from the supply reel 2 onto the takeup reel 3 via guides 14 and 4, the bore 6a and guides 5 and 15 under a predetermined tension. A machining-liquid circulation unit (not shown) is operated to supply the machining liquid through the nozzles into the region of the workpiece 6 so that the machining gap is flooded uniformly therewith. The EDM power supply 11 is turned on to apply a succession of electrical pulses across the gap between the traveling wire electrode 1 and the workpiece 6, thereby effecting successive machining discharges between them through the liquid medium to remove material from the workpiece 6. In the course of cutting operation, the vibrators 12 and 13 may be operated to function in the manner already described.

A predetermined cutting path corresponding to a desired contour is programmed in advance in the numerical controller 10 whose output signals are applied to the drive motors 8 and 9 to displace the worktable 7 so that the workpiece 6 carried thereby moves along the programmed path relative to the traveling wire electrode 1. In the course of the rough-cutting feed displacement, as seen from FIG. 2, the wire electrode 1 moves relative to the workpiece 6, first advancing from the position of the preformed starting bore 6a in the workpiece 6 rectilinearly along the shortest distance to

a point on the programmed rough-cutting contour, then following the latter path as indicated by the arrows back to that point. The cutting width L formed during this rough-contouring operation is, as better
5 seen from FIG. 3, defined by $2(r+g)$ where r is the radius of the wire electrode and g is the machining gap spacing which may be equivalent to overcut α . When the wire 1 returns to the initial point, the core portion 61 of the machined or rough-cut
10 workpiece 6 surrounded by the inner edge of the path is separated from the remainder thereof 62 surrounding the outer edge of the path and constituting the rough-contoured workpiece.

After the above roughing step is
15 accomplished, the workpiece 62 is to be formed with a further cut of a width or depth l , indicated by the broken line, by the succeeding finish-cutting step. The width l is generally smaller than the previous cut width L and the finishing step is generally
20 performed at a faster cutting rate and desirably with a minimum amount of material removal to finish the previously machined contour and surface. In accordance with the present invention, the cutting path in the finishing step is shifted by a distance
25 $n\alpha$ from the cutting path in the roughing step where α is the overcut in the roughing step and n is a value, preferably, an integer, essentially proportional to the thickness t of the workpiece 6 (FIG. 1) so that the depth l is removed in the finishing step. In
30 other words, it is essential in accordance with the principles of the present invention that the trajectory of the wire electrode 1 displaced transversely relative to the workpiece 6 in the finishing step be shifted by the distance $n\alpha$ from the
35 trajectory of the wire electrode displaced in the

roughing step. The values α and n are defined in conjunction with the radius of the wire electrode r to achieve the widths $\frac{L}{2}$ and l , hence $\frac{L}{2} + l$ in defining the first programmed cutting path to be traveled by the center axis of the wire electrode 1 in the roughing step. Then the contouring feed applied during the finishing step by the numerical controller 10 is, as indicated by the broken line, an enlarged feed defined by the addition of the width l , which is equal to n , to the previous rough-cutting path.

The overcut α which results from the roughing step is a well-accepted term in electrical machining and is here defined by the minimum distance between the rough-cut contour at any point thereon and the path of displacement of the center axis of the wire electrode less the radius of the wire electrode. As will readily be seen, it is basically dependent on the size of the machining gap g , but further on the other gap parameters such as the nature of machining products in the gap during wire-cutting and, when vibrations as described before are imparted to the wire electrode, still further on the amplitude of the vibrations. At any event, the overcut α can be determined in setting, and preparatory to, the roughing

step.

Example

5 In determining the trajectory of a wire electrode 1 (e.g. a copper wire of a diameter of 0.2mm) and hence the programmable path of a workpiece (e.g. carbon steel) previously rough-cut with an overcut α and displaced relative to the center axis of the wire electrode 1 in the finishing step, the values n and $l=n\alpha$ are set, for example, as follows:

Workpiece thickness	n	l
20 ^{mm}	1	α
40 ^{mm}	2	2α
80 ^{mm}	4	4α

It has been found that for the varying values of the workpiece thickness, the thickness of the finish-cut layer is uniformly constant, hence the finish-cutting precision extremely high. The ratio of removal rate in roughing and finishing is then 1:4. The value α is determined by parameters of machining pulses, and wire and workpiece materials and, to this extent only, the value $\underline{l}$ may depend on these parameters and materials.

The trajectory of the wire electrode 1 in the finishing step may be shifted by $\underline{l} = n\alpha$ from the trajectory of the wire electrode in the roughing step by using the vibrator means 12 and 13 hereinbefore described. In this case, no change in the programmed cutting path from the roughing step to the finishing step may be required when the amplitude of the vibrations which then defines the shift $\underline{l} = n\alpha$ does not exceed preferably 1 to 5 microns and at most 10 microns.

The vibrators 12 and 13 are preferably coupled together and oriented so that the direction of the plane of the composite vibrations which result is maintained to be essentially perpendicular to the direction of advance of the wire electrode 1 in the finishing step.

There is thus provided an improved electroerosion method of wire-cutting a desired contour in a workpiece, which overcomes the problems encountered in the prior art.



-18-

CLAIMS

1. A method of cutting a workpiece to form a desired final contour therein with a continuous wire electrode which has a predetermined thickness and is arranged to be axially advanced to linearly traverse the workpiece across a cutting zone and also displaced relative to the workpiece transversely to the axis of the wire electrode, said method comprising the steps of: (a) electroerosively rough-cutting said workpiece while effecting the transverse relative displacement between said wire electrode and said workpiece along a first predetermined path corresponding to said desired final contour and prescribed to generate a desired rough-cut contour with an overcut α in said workpiece; and (b) electroerosively finish-cutting said rough-cut workpiece while effecting the transverse relative displacement between said wire electrode and said workpiece along a second predetermined path shifted from said first predetermined path substantially uniformly by a distance defined by the product $n\alpha$ where n is a value substantially proportional to the thickness of the workpiece traversed by the wire electrode, thereby generating a finish-cut contour coinciding with said desired contour in said workpiece.
2. The method defined in Claim 1 wherein n is an integer.



-19-

3. The method defined in Claim 1 or Claim 2 wherein said first predetermined path is preprogrammed in a numerical controller associated with a drive system for effecting said transverse
5 relative displacement between said wire electrode and said workpiece for executing the step (a) on the basis of said desired contour and said desired overcut α , and said second predetermined path is preprogrammed in said numerical controller on the
10 basis of said first predetermined path and adding thereto information representing the expression $n\alpha$ for executing the step (b).

4. The method defined in Claim 1 or Claim 2, further comprising the step of imparting vibrations
15 to said wire electrode transversely to the axis thereof in said cutting zone in step (b), the vibration being of an amplitude essentially equal to $n\alpha$, thereby in effect shifting said first predetermined path of the step (a) by the distance
20 essentially $n\alpha$ to produce in effect said second predetermined path of the step (b).

5. The method defined in Claim 4, wherein said amplitude of vibrations is at most 10 microns.

6. The method defined in Claim 4 or Claim 5
25 wherein said vibrations are imparted to said wire electrode in a plane which is oriented so as to be maintained essentially perpendicular to the direction of advance of the wire electrode relative to said workpiece.



-20-

7. A method of electroerosively cutting a
workpiece to form a desired final contour therein
with an axially continuously renewed electrode wire
having a predetermined thickness wherein the
electrode wire is axially advanced continuously from
supply means on to takeup means through the workpiece
in a cutting zone while the workpiece is displaced
relative to the advancing electrode wire transversely
to the axis thereof, which method comprises the steps
of: (a) electroerosively rough-cutting the workpiece
while effecting the transverse relative displacement
so that the trajectory of the electrode wire closer
to said desired final contour follows a first
predetermined path spaced by an overcut
substantially uniformly from a rough-cut contour
desired in the workpiece; (b) prior to step (a),
determining said overcut from machining conditions to
be employed in step (a) and determining said rough-
cut contour so as to be spaced substantially
uniformly from said desired final contour by a
distance defined by an expression $(n+1)\alpha$ where n is
an integer; and (c) subsequent to step (a),
electroerosively finish-cutting said rough-cut
workpiece while effecting the transverse relative
displacement so that the trajectory of the electrode
wire closer to said desired final contour follows a
second predetermined path corresponding thereto and
substantially uniformly spaced by a distance $n\alpha$ from
said first predetermined path.

8. The method defined in Claim 7 wherein in
steps (a) and (c), the axis of the electrode wire is
displaced relative to the workpiece along respective
paths which are substantially uniformly spaced from
one another by said distance $n\alpha$.



-20A-

9. The method defined in Claim 7 wherein in steps (a) and (c), the axis of the electrode wire is displaced relative to the workpiece along respective paths which are substantially coincident with one another and in step (c) a vibration is imparted to said electrode wire transversely to the axis thereof at least in said cutting zone, said vibration being of an amplitude substantially equal to said distance $n\alpha$, thereby permitting said trajectory of the electrode wire to follow said second predetermined path in step (b).
10. The method defined in Claim 9 wherein said amplitude of vibration ranges between 1 and 50 microns.
11. The method defined in Claim 7 wherein in steps (a) and (c) the axis of the electrode wire is displaced relative to the workpiece along respective paths which are substantially coincident with one another and in steps (a) and (c) vibrations are imparted to said electrode wire transversely to the axis thereof at least in said cutting zone, the vibration in step (c) being greater in amplitude than the vibration in step (a) by a difference which is substantially equal to said distance $n\alpha$, thereby permitting said trajectory of the electrode wire to follow said second predetermined path in step (c) which is spaced substantially uniformly by said distance $n\alpha$ from said first predetermined path in step (a).
12. A method of cutting a workpiece to form a desired contour therein with a continuous wire electrode, the method being substantially as hereinbefore described with reference to the accompanying diagrammatic drawings.