

SPECIFICATION

Supplying machining fluid to a machining zone

- 5 The present invention relates to a fluid pumping control method and apparatus for machine tools and, more particularly, to an improved method of and apparatus for controllably supplying a machining fluid from a reservoir therefor to a machining zone in a machine tool by means of a pump driven by an electric motor.

A machine tool for most applications commonly requires a supply system for feeding a machining fluid stored in a reservoir to a machining zone

- 15 constituted by a tool member and a workpiece. The machining fluid generally serves as a coolant and cutting medium as well as a flushing medium which carries away machined chips, particles and other machining products from the machining zone to keep the latter refreshed while allowing it to undergo continued machining or cutting actions under satisfactory conditions.

- In conventional fluid pumping systems used with a machine tool, it has been a common practice to utilize a pump driven at a constant speed by an electric motor with a constant input power and, when the quantity of the machining fluid delivered to the machining zone is to be regulated or modified, a check valve, return valve, relief valve and/or other similar valve arrangements have been employed to control the output pressure of the pump. Since the pump is driven at constant speed, it has had to be driven at its maximum speed to be sufficient to produce a maximum fluid pressure required in a given course of machining operation or among a plurality of desired machining operations to be carried out by the machine tool.

- One problem associated with conventional systems of this sort is that the machining fluid, while being circulated through a fluid conduit system, tends to rise in temperature due to its frictional contacts with the internal walls of the conduits. Such temperature rise is disadvantageous in that it produces alteration in machining quality and expansion of machine components with which the fluid comes directly or indirectly into contact, and thus leads to unsatisfactory and inaccurate machining results. In addition, with prior systems in which an excessive output delivery of the pump that is regulated by valve arrangements is almost always the case, considerable heat loss is brought about (derived from the pump driving power) through these additional fluid conduits.

- The present invention therefore seeks to provide an improved fluid pumping control method and apparatus whereby the temperature rise of the machining fluid is kept substantially to a minimum during a given machining operation.

- According to one aspect of the present invention there is provided a method of controllably supplying a machining fluid to a machining zone of a machine tool when such machine tool is in use carrying out a machining operation, which machine tool includes a reservoir for said machining fluid, a fluid feed conduit connecting said reservoir with said

machining zone, a pump for pumping when in operation fluid from said reservoir through said conduit to said machining zone, and a variable input, variable speed electric driving motor drivingly

- 70 connected to said pump, which method includes:-

(a) supplying an electrical input to said motor thereby to cause said pump to be driven and the output fluid of the pump to be delivered to said machining zone;

- 75 (b) sensing the rate of flow of said fluid through said conduit and producing in response thereto a rate signal dependent on said rate of flow; and

(c) modifying said input to said motor in response to said rate signal in a manner tending to maintain said rate of flow at a desired minimum, or other low, value necessary for the particular machining operation being carried out.

- Preferably, for switching said machining operation from one given mode to another, said input to said motor is modified to provide a new rate of flow suited to a new mode of machining operation.

- Where said machine tool is an electroerosion machine, said method may advantageously include sensing a machining current passing between a tool electrode and a workpiece electrode across a machining gap constituting said machining zone flushed with said machining fluid and producing in response thereto a machining current signal dependent on said current, and modifying said input to said motor in response to said machining current signal so as to modify said rate of flow in dependence upon said machining current. In such method said input to said motor is preferably modified in dependence upon said rate signal and said machining current signal in a manner tending to maintain the ratio of said signals substantially constant. In one convenient form of such method said rate signal is converted to a first voltage signal; said machining current signal is converted to a second voltage signal; said first voltage signal is divided by said second voltage signal to produce a third voltage signal; and said third voltage signal is supplied as said input to said motor.

- According to a second aspect of the present invention there is provided an apparatus for controllably supplying, when in use, a machining fluid to a machine zone of a machine tool when said machine tool is in use carrying out a machining operation, which apparatus includes:-

- 115 (a) a reservoir for said fluid;
 (b) a fluid feed conduit connecting said reservoir with said machining zone;
 (c) a pump for pumping when in operation fluid from said reservoir through said conduit to said machining zone;
 (d) a variable input, variable speed electric driving motor drivingly connected to said pump;
 (e) means for connecting said motor with a source of electrical input thereby to cause said pump to be driven and the output of the pump to be delivered to said machining zone;
 (f) a sensor for sensing when in operation the rate of flow of fluid through said conduit and producing in response thereto a rate signal dependent upon said rate of flow; and

(g) means for modifying a said input to said motor in response to said rate signal in a manner tending to maintain said rate of flow at a desired minimum, or other low, value necessary for the particular machining operation being carried out.

Said input modifying means may include switching means effective for switching said machining operation from one mode to another, to modify a said input supplied to said motor so as to provide a new rate of flow suited to a new mode of machining operation.

Where said machine tool is an electroerosion machine, said input modifying means may include a sensor for sensing when in operation a machining current passing between a tool electrode and a workpiece electrode across a machining gap constituting said machining zone flushed with said machining fluid and producing in response thereto a machining current signal dependent on said current, and a control means responsive to said machining current signal for modifying said input supplied to said motor so as to modify said rate of flow in dependence upon said machining current.

Other features and advantages of the present invention will appear from the description that follows hereafter, and from the claims appended at the end of that description.

The sole accompanying drawing illustrates in a schematic manner and for illustrative purposes only, an electroerosion machine incorporating a machining fluid supply apparatus embodying, in a certain exemplary form, the present invention.

The electroerosion machine as shown includes a tool electrode 1 which is juxtaposed with a workpiece 2 across a machining gap G formed therebetween and constituting a machining zone in a work tank 3 receiving a machining fluid F , i.e. a liquid dielectric or electrolyte. A fluid flushing nozzle 4 is oriented toward the electroerosion gap G to inject the machining fluid F thereto.

A machining direct-current power supply 5 is connected to the tool electrode 1 and the workpiece 2 in series with a switching element 6 shown constituted by a power transistor which is controlled by a control pulsing circuit 7, e.g., an oscillator, to render the switch 6 alternately on and off so that a series of machining pulses are applied across the machining gap G filled with the machining fluid F to remove material from the workpiece 2.

As machining proceeds, the tool electrode 1 carried by a machining head (not shown) is advanced relatively toward the workpiece 2 by a servo-mechanism (not shown) to maintain the spacing of the machining gap G therebetween substantially constant.

Machining chips, tar and gases produced by the electroerosion process are carried away from the machining gap G by the machining fluid F supplied from the flushing nozzle 4 so that the region of the machining gap G may be kept rinsed and maintained at a substantially predetermined dielectric strength or conductivity when each individual machining pulse is applied thereto.

The machining fluid F is fed to the flushing nozzle 4 via a supply conduit 8 from a reservoir 9 by means

of a pump 10 with a rotor driven by a direct-current electric motor 11, and the fluid F in the work tank 3 is returned via a return conduit 12 to the reservoir 9 for recycling. A filter (not shown) is usually included in either line 8 or 12 to ensure that the machining fluid supplied to the machining zone is not contaminated by machining chips, tar, gases and other foreign matters.

In accordance with the principles of the present invention, the electric motor 11 is provided with a variable input means 13 designed to modify the speed of the rotor of the pump 10, thereby controlling the output pressure thereof and hence regulating the rate of delivery of the machining fluid F drawn from the reservoir 9 to the machining gap G without primary resort to a check valve, return valve, relief valve or any other pump pressure adjusting valve arrangement such as has conventionally been used in association with the fluid supply pumping unit in a machine tool.

The regulation and modification of the output pressure of the fluid delivery pump 10 is required when switching the machining operation from one given mode to another, and also when a change in machining conditions in the machining gap G arises in a given course of machining operation. For these purposes, since no primary resort is made to the use of any fluid checking or shunting valve arrangement, the power required for driving the pump 10 and hence the heat loss thereof is advantageously held to a minimum while allowing a required minimum quantity of the machining fluid F to be delivered to the machining zone G constantly and with assurance.

The variable input means 13 to the electric motor 11 according to the present invention, as illustrated, advantageously makes use of a control circuit 14 responsive to the rate of flow of the machining fluid F through the supply line 8, and preferably to the machining current flow through the machining gap G . Thus, in the illustrated embodiment, the control circuit 14 is fed by a signal processing circuit 15 responsive to one or both of these variables. To this end, a resistor 16 is provided in series with the power supply 5 and the machining gap G to serve as a machining current sensor, and a capacitor 17 is connected across the resistor 16 via a charging resistor 18 and a unidirectional current conducting element 19, e.g. a diode, to develop a charging voltage E at an output resistor 20 connected across the capacitor. The resistor 20 has a much greater resistance than that of the sensing resistor 16 so that the output signal voltage E represents a mean machining current passing through the machining gap G , and undergoes changes in response and proportion to such current.

On the other hand, the rate of flow of the machining fluid F from the pump 10 is sensed by a rate signal generator 21 adapted to convert it to a signal voltage e which is fed to the signal processing circuit 15. The latter in this case is constituted by a dividing circuit to provide at its output a signal corresponding to the ratio $R = e/E$ which is fed to the control circuit 14. The control circuit 14 thus serves as a variable power supply for the electric motor 11 to

drive the latter at a variable speed, thereby controlling the output pressure of the pump 10 such that the signal voltage $R = e/E$ supplied thereto is held at a predetermined value R_0 .

- 5 Accordingly, when the machining current changes or fluctuates during a given machining operation or where the switching of the machining mode from one to another is desired in a sequence of machining operations, an automatic increase or decrease of the
10 machining fluid F supplied to the machining gap G or the region thereof in the work tank 3 is effected in proportion to the machining current passing through the gap G . The delivery of a required quantity of the machining fluid F to the machining zone is thereby
15 assured and, since this quantity is held at a required minimum value appropriate to the mode of machining at all times, the temperature rise of the machining fluid F resulting from its circulation is held at a minimum, thus permitting machine
20 components, the tool electrode 1 and the workpiece to suffer only a minimum temperature rise while preventing the quality (i.e. conductivity or dielectric strength) of the machining fluid F delivered to the machining zone from changing or fluctuating so that
25 a desired machining operation proceeds with an increased precision and accuracy.

Embodiments of the invention as designed to allow an automatic control are, of course, not limited to those as illustrated and described in the
30 foregoing. Instead of the feed-back control as described, a programmed feed-forward control may be provided. Also, the rate of rotation of the pump 10 may either be controlled stepwise or continually by a selector or dial switch and the closed-loop system as
35 described may be replaced by an open-loop system controllable responsive to one or more machining parameters to be employed variably.

There is thus provided in accordance with the present invention an improved machining fluid
40 pumping control method and apparatus for a machine tool, which assure an increased machining precision and eliminate disadvantages arising from an excessive heat loss in conventional machine tool fluid pumping systems.

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CLAIMS

1. A method of controllably supplying a machining fluid to a machining zone of a machine
50 tool when such machine tool is in use carrying out a machining operation, which machine tool includes a reservoir for said machining fluid, a fluid feed conduit connecting said reservoir with said machining zone, a pump for pumping when in
55 operation fluid from said reservoir through said conduit to said machining zone, and a variable input, variable speed electric driving motor drivingly connected to said pump, which method includes:-

- (a) supplying an electrical input to said motor
60 thereby to cause said pump to be driven and the output fluid of the pump to be delivered to said machining zone;
(b) sensing the rate of flow of said fluid through said conduit and producing in response thereto a
65 rate signal dependent on said rate of flow; and

(c) modifying said input to said motor in response to said rate signal in a manner tending to maintain said rate of flow at a desired minimum, or other low, value necessary for the particular
70 machining operation being carried out.

2. The method defined in Claim 1 wherein for switching said machining operation from one given mode to another, said input to said motor is modified to provide a new rate of flow suited to a
75 new mode of machining operation.

3. The method defined in Claim 1 or 2 wherein said machine tool is an electroerosion machine, which method includes sensing a machining current passing between a tool electrode and a workpiece
80 electrode across a machining gap constituting said machining zone flushed with said machining fluid and producing in response thereto a machining current signal dependent on said current, and modifying said input to said motor in response to
85 said machining current signal so as to modify said rate of flow in dependence upon said machining current.

4. The method defined in Claim 3 wherein said input to said motor is modified in dependence upon
90 said rate signal and said machining current signal in a manner tending to maintain the ratio of said signals substantially constant.

5. The method defined in Claim 4 wherein said rate signal is converted to a first voltage signal; said
95 machining current signal is converted to a second voltage signal; said first voltage signal is divided by said second voltage signal to produce a third voltage signal; and said third voltage signal is supplied as said input to said motor.

100 6. An apparatus for controllably supplying, when in use, a machining fluid to a machining zone of a machine tool when said machine tool is in use carrying out a machining operation, which apparatus includes:-

- 105 (a) a reservoir for said fluid;
(b) a fluid feed conduit connecting said reservoir with said machining zone;
(c) a pump for pumping when in operation fluid from said reservoir through said conduit to said
110 machining zone;
(d) a variable input, variable speed electric driving motor drivingly connected to said pump;
(e) means for connecting said motor with a source of electrical input thereby to cause said pump
115 to be driven and the output of the pump to be delivered to said machining zone;
(f) a sensor for sensing when in operation the rate of flow of fluid through said conduit and producing in response thereto a rate signal dependent upon said rate of flow; and
120 (g) means for modifying a said input to said motor in response to said rate signal in a manner tending to maintain said rate of flow at a desired minimum, or other low, value necessary for the particular machining operation being carried out.

7. The apparatus defined in the Claim 6 wherein said input modifying means includes switching means effective, for switching said machining operation from one mode to another, to modify a
130 said input supplied to said motor so as to provide a



drive the latter at a variable speed, thereby controlling the output pressure of the pump 10 such that the signal voltage $R = e/E$ supplied thereto is held at a predetermined value R_0 .

- 5 Accordingly, when the machining current changes or fluctuates during a given machining operation or where the switching of the machining mode from one to another is desired in a sequence of machining operations, an automatic increase or decrease of the
- 10 machining fluid F supplied to the machining gap G or the region thereof in the work tank 3 is effected in proportion to the machining current passing through the gap G . The delivery of a required quantity of the machining fluid F to the machining zone is thereby
- 15 assured and, since this quantity is held at a required minimum value appropriate to the mode of machining at all times, the temperature rise of the machining fluid F resulting from its circulation is held at a minimum, thus permitting machine
- 20 components, the tool electrode 1 and the workpiece to suffer only a minimum temperature rise while preventing the quality (i.e. conductivity or dielectric strength) of the machining fluid F delivered to the machining zone from changing or fluctuating so that
- 25 a desired machining operation proceeds with an increased precision and accuracy.

- Embodiments of the invention as designed to allow an automatic control are, of course, not limited to those as illustrated and described in the
- 30 foregoing. Instead of the feed-back control as described, a programmed feed-forward control may be provided. Also, the rate of rotation of the pump 10 may either be controlled stepwise or continually by a selector or dial switch and the closed-loop system as
- 35 described may be replaced by an open-loop system controllable responsive to one or more machining parameters to be employed variably.

- There is thus provided in accordance with the present invention an improved machining fluid
- 40 pumping control method and apparatus for a machine tool, which assure an increased machining precision and eliminate disadvantages arising from an excessive heat loss in conventional machine tool fluid pumping systems.

45 CLAIMS

1. A method of controllably supplying a machining fluid to a machining zone of a machine
- 50 tool when such machine tool is in use carrying out a machining operation, which machine tool includes a reservoir for said machining fluid, a fluid feed conduit connecting said reservoir with said machining zone, a pump for pumping when in
- 55 operation fluid from said reservoir through said conduit to said machining zone, and a variable input, variable speed electric driving motor drivingly connected to said pump, which method includes:-

- (a) supplying an electrical input to said motor
- 60 thereby to cause said pump to be driven and the output fluid of the pump to be delivered to said machining zone;
- (b) sensing the rate of flow of said fluid through said conduit and producing in response thereto a
- 65 rate signal dependent on said rate of flow; and

- (c) modifying said input to said motor in response to said rate signal in a manner tending to maintain said rate of flow at a desired minimum, or other low, value necessary for the particular
- 70 machining operation being carried out.

2. The method defined in Claim 1 wherein for switching said machining operation from one given mode to another, said input to said motor is modified to provide a new rate of flow suited to a
- 75 new mode of machining operation.

3. The method defined in Claim 1 or 2 wherein said machine tool is an electroerosion machine, which method includes sensing a machining current passing between a tool electrode and a workpiece
- 80 electrode across a machining gap constituting said machining zone flushed with said machining fluid and producing in response thereto a machining current signal dependent on said current, and modifying said input to said motor in response to
- 85 said machining current signal so as to modify said rate of flow in dependence upon said machining current.

4. The method defined in Claim 3 wherein said input to said motor is modified in dependence upon
- 90 said rate signal and said machining current signal in a manner tending to maintain the ratio of said signals substantially constant.

5. The method defined in Claim 4 wherein said rate signal is converted to a first voltage signal; said machining current signal is converted to a second
- 95 voltage signal; said first voltage signal is divided by said second voltage signal to produce a third voltage signal; and said third voltage signal is supplied as said input to said motor.

6. An apparatus for controllably supplying, when in use, a machining fluid to a machining zone of a machine tool when said machine tool is in use carrying out a machining operation, which apparatus includes:-

- 100 (a) a reservoir for said fluid;
- (b) a fluid feed conduit connecting said reservoir with said machining zone;
- (c) a pump for pumping when in operation fluid from said reservoir through said conduit to said
- 110 machining zone;
- (d) a variable input, variable speed electric driving motor drivingly connected to said pump;
- (e) means for connecting said motor with a source of electrical input thereby to cause said pump
- 115 to be driven and the output of the pump to be delivered to said machining zone;
- (f) a sensor for sensing when in operation the rate of flow of fluid through said conduit and producing in response thereto a rate signal dependent upon said rate of flow; and
- 120 (g) means for modifying a said input to said motor in response to said rate signal in a manner tending to maintain said rate of flow at a desired minimum, or other low, value necessary for the particular machining operation being carried out.

7. The apparatus defined in the Claim 6 wherein said input modifying means includes switching means effective, for switching said machining operation from one mode to another, to modify a
- 130 said input supplied to said motor so as to provide a

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new rate of flow suited to a new mode of machining operation.

8. The apparatus defined in the Claim 6 or 7 wherein said machine tool is an electroerosion machine, and said input modifying means includes a sensor for sensing when in operation a machining current passing between a tool electrode and a workpiece electrode across a machining gap constituting said machining zone flushed with said machining fluid and producing in response thereto a machining current signal dependent on said current, and a control means responsive to said machining current signal for modifying said input supplied to said motor so as to modify said rate of flow in dependence upon said machining current.

9. The apparatus defined in the Claim 8 wherein said input to said motor is modified in dependence upon said rate signal and said machining current signal in a manner tending to maintain the ratio of said signals substantially constant.

10. The apparatus defining in the Claim 9 wherein said rate signal is converted to a first voltage signal; said machining current signal is converted into a second voltage signal; said first voltage signal is divided by said second voltage signal to produce a third voltage signal; and said third voltage signal is supplied as said input to said motor.

11. An apparatus as defined in any one of the Claims 6 to 10 for controllably supplying a machining fluid to a machining zone of a machine tool, said apparatus being constructed, arranged and adapted to operate substantially as hereinbefore described with reference to the accompanying diagrammatic drawing.

12. A method as defined in any one of the Claims 1 to 5 of controllably supplying a machining fluid to a machining zone of a machine tool, said method being substantially as hereinbefore described with reference to the accompanying drawing.

13. A machine tool having an apparatus as defined in any one of the Claims 6 to 11.

14. A workpiece which has been machined by a machine tool as defined in Claim 13, or by a machining method as defined in any one of Claims 1 to 5 and 12.

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