United States Patent [19]

Wada et al.

[11] **3,748,789**

[45] **July 31, 1973**

[54] **GRINDING MACHINE**

[75] Inventors: **Ryuji Wada; Kimio Kanou,** both of Aichi, Japan

[73] Assignee: **Toyoda Koki Kabushiki Kaisha,** Kariya-shi, Aichi-ken, Japan

[22] Filed: **Aug. 26, 1971**

[21] Appl. No.: **175,073**

[30] **Foreign Application Priority Data**

Aug. 28, 1970 Japan 45/74935

[52] **U.S. Cl.** **51/165.8,** 51/165.9

[51] **Int. Cl.** **B24b 49/16**

[58] **Field of Search** ..... 51/165.8, 165.9, 51/165 R

[56] **References Cited**

UNITED STATES PATENTS

3,601,930	8/1971	Robillard	51/165.8
3,503,158	3/1970	Robillard	51/165.8
3,555,741	1/1971	Hahn	51/165.9
2,984,952	5/1961	Gebel	51/165.9

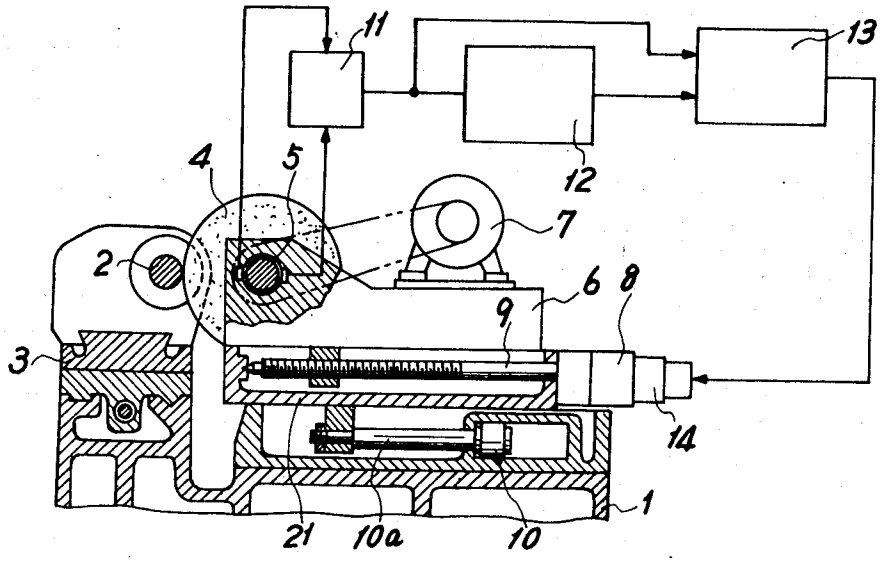
Primary Examiner—Harold D. Whitehead

Attorney—Norman F. Oblon et al.

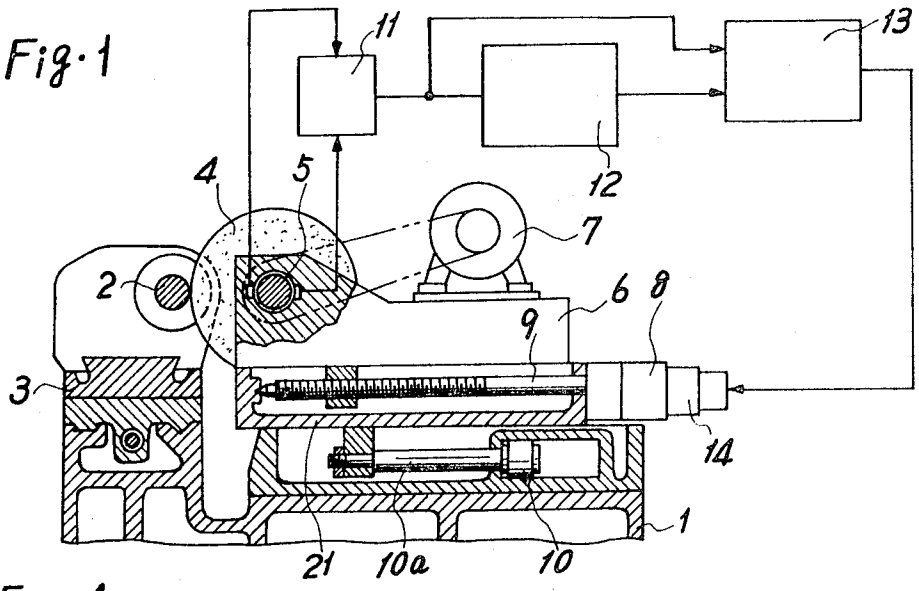
[57] **ABSTRACT**

A grinding machine capable of changing an infeed speed of a wheel slide during a grinding operation. When the grinding resistance is exceeded beyond a predetermined value, while the wheel slide is advanced toward a workpiece at a speed which is dominated by a selected predetermined optimum value for the grinding condition, the infeed speed thereof is changed from the selected predetermined optimum value to another optimum value or values for a predetermined period. As long as the grinding resistance is kept within the predetermined value, the infeed speed of the wheel slide is changed as a function of the grinding resistance and the selected predetermined optimum value.

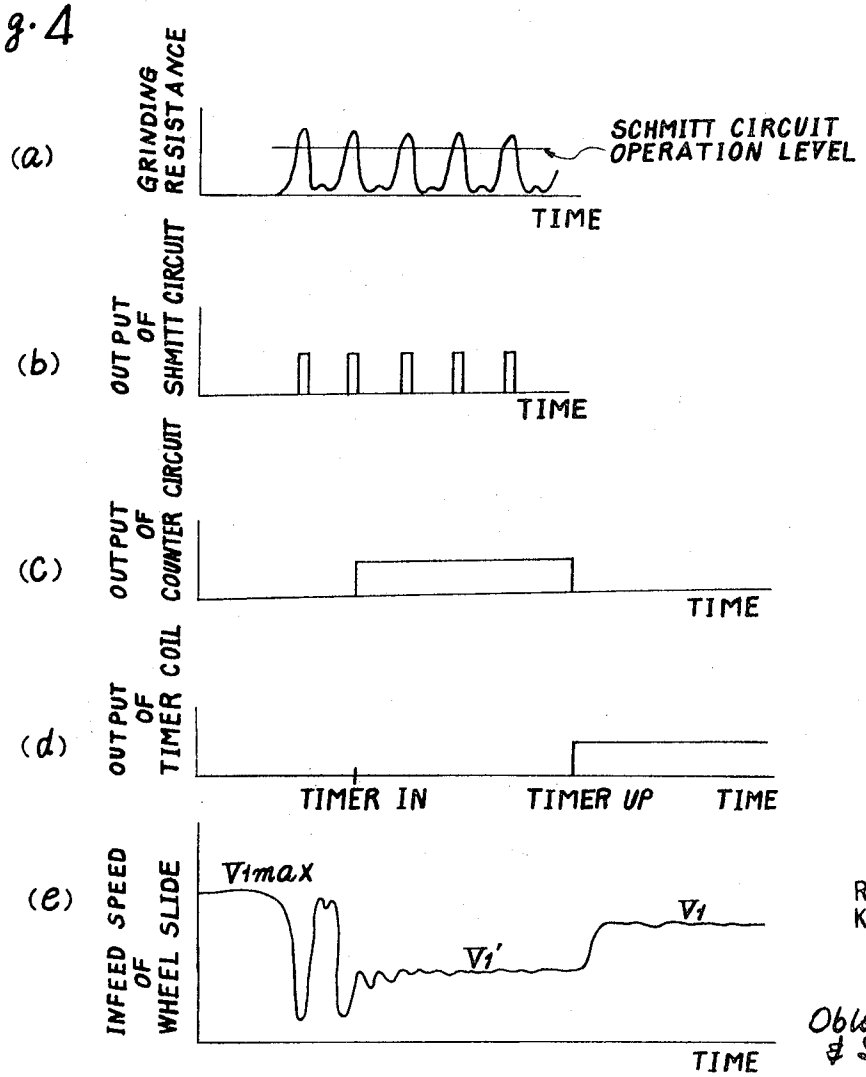
6 Claims, 4 Drawing Figures



Fig·1



Fig·4



INVENTORS
RYUJI WADA
KIMIO KANOU

Oblon, Fisher & Spivak
ATTORNEYS

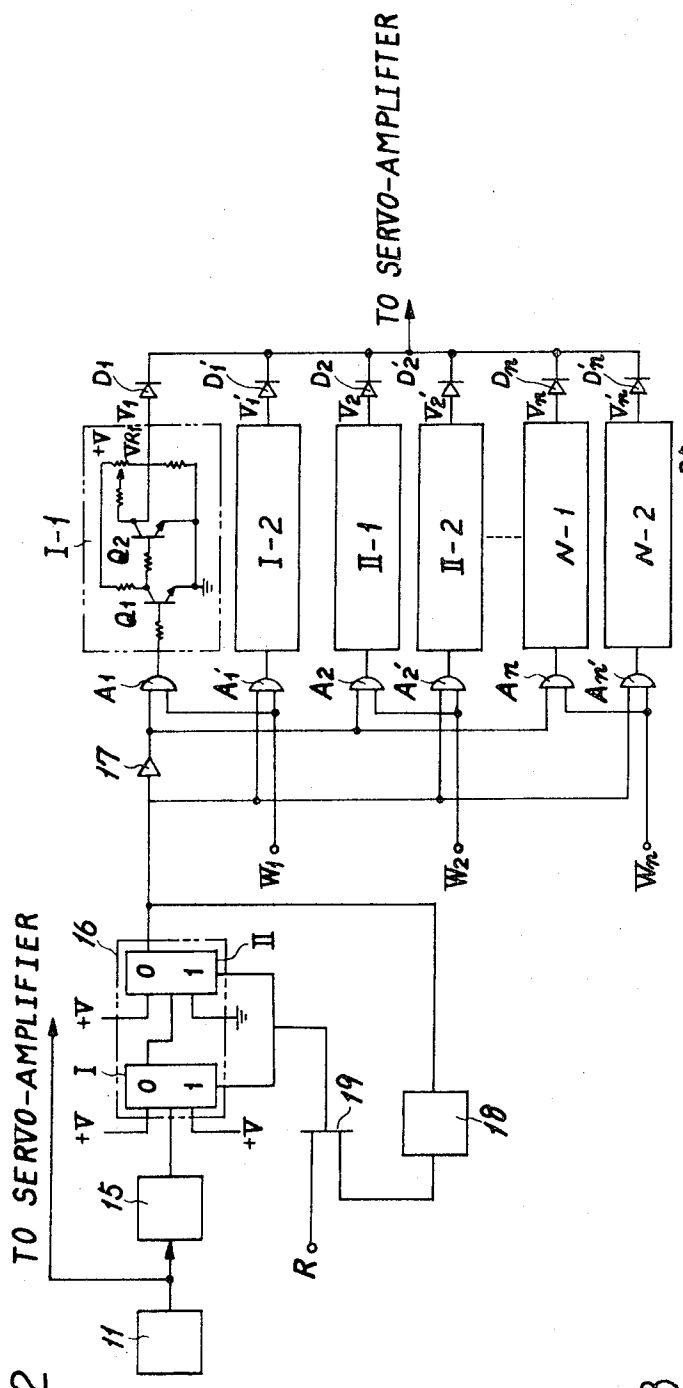

TO SERVO-AMPLIFIER
I-1
I-2
II-1
II-2
N-1
N-2
D1
D'1
D2
D'2
Dn
D'n
V1
V'1
V2
V'2
Vn
V'n
+V
VR1
Q2
Q1
A1
A'1
A2
A'2
An
A'n
17
W1
W2
Wn
16
0
1
II
I
19
18
15
11
R
TO SERVO-AMPLIFIER

Fig. 2

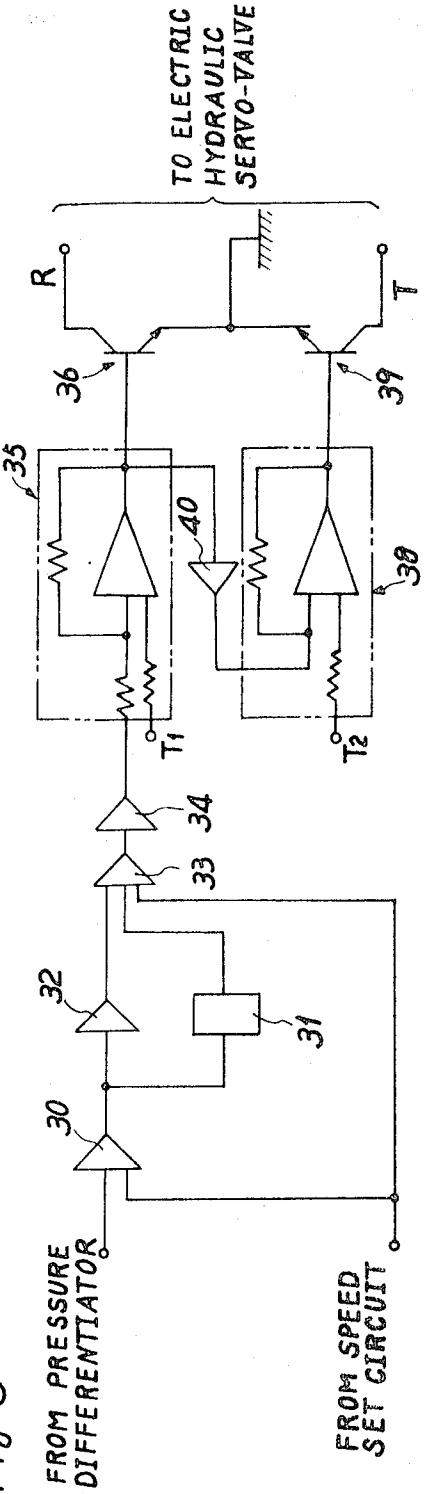

TO ELECTRIC HYDRAULIC SERVO-VALVE
R
T
36
39
35
40
38
T1
T2
34
33
32
31
30
FROM PRESSURE DIFFERENTIATOR
FROM SPEED SET CIRCUIT

Fig. 3

GRINDING MACHINE

BACKGROUND OF THE INVENTION

1. Field Of The Invention

The present invention generally relates to a grinding machine, and more particularly to an improved grinding machine which is capable of changing the infeed speed of a wheel slide from one optimum value into another optimum value or values in accordance with the condition of a grinding operation.

2. Description Of The Prior Art

Recently, a grinding resistance control, wherein an infeed speed of a wheel slide is changed according to the resistance applied on the grinding wheel so that the grinding resistance may be maintained at a required optimum value, has been developed for use in a cylindrical or other grinding machines. Such a grinding resistance control has proved to be very effective in improving machining efficiency. While generally satisfactory, with such a grinding resistance control it is difficult to obtain a high machining accuracy on a workpiece when the grinding resistance is large and periodically changed as shown in FIG. 4*a* due to a rough surface or the non-cylindrical shape of a workpiece which is roughly machined or which has not been previously machined.

SUMMARY OF THE INVENTION

It is, therefore, an object of the present invention to provide a new and improved unique grinding machine which is capable of changing the infeed speed of a wheel slide from one optimum value to another optimum value or values.

Another object of the subject invention is to provide a new and improved unique grinding machine which facilitates the grinding operation by allowing high machining efficiency and accuracy.

Still another object of this invention is to provide a new and improved unique grinding machine which is operable to change the infeed speed of the wheel slide as a function of the grinding resistance and a selected optimum value.

Briefly, in accordance with the present invention, the foregoing and other objects are, in one aspect, attained by initially selecting the infeed speed of a wheel slide to a predetermined optimum value. When the grinding resistance becomes large and periodically changes, while the wheel slide is moved at the selected optimum value due to the surface condition of a workpiece, the infeed speed is changed from the selected optimum value to another and smaller optimum value or values for a predetermined period of time.

As long as the grinding resistance is kept within the predetermined value, the infeed speed of the wheel slide is changed in accordance with the grinding resistance and the selected optimum value.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the invention and many of the attendant advantages thereof will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

FIG. 1 is a schematic view showing a grinding machine according to the present invention;

FIG. 2 is a block diagram showing a speed control system for a wheel slide in accordance with this invention;

FIG. 3 is a view showing a servo-amplifier for use with the present invention;and,

FIG. 4 is a chart showing the output signal of each of the components in the speed control system.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Referring now to the drawings, wherein like reference numerals designate identical, or corresponding parts throughout the several views, and more particularly to FIG. 1 thereof, wherein is shown a bed 1 on which a table 3 is slidably mounted. A grinding wheel 4 is mounted on a spindle which is rotatably supported by a wheel slide 6 through a hydraulic bearing 5 which is fixedly mounted thereon.

The grinding wheel 4 is connected to a motor 7 which is mounted on the wheel slide 6 and enables a grinding operation to be performed on a workpiece 2 supported on the table 3.

A slide base 21 is mounted on the base 1 and is slidable in a direction perpendicular to the table 3. The wheel slide 6 is, in turn, slidably mounted on the slide base 21 in a parallel relationship therewith.

A hydraulic feed motor 8 is secured on the slide base 21 and rotates a feed screw 9 which is threadedly engaged with the wheel slide 6 so that the wheel slide 6 may be moved toward and away from the workpiece 2. A piston rod 10a of a hydraulic actuator 10 is provided on the base 1 and is connected to the slide base 21, whereby the wheel slide 6 and the slide base 21 may be integrally moved back and forth at a high speed.

A pressure differentiator 11 is provided and is responsive to the pressure differential which is produced by the grinding resistance on the grinding wheel 4 between the front and rear pressure pockets of the hydraulic bearing 5. It should be appreciated that the pressure differentiator 11 is conventional and may be of the type which changes the pressure differential into an electric signal. The output of the pressure differentiator 11 is applied to an infeed control circuit 12 and a differential servo-amplifier 13. The amplifier 13 is responsive to the outputs of the differentiator 11 and the infeed control circuit 12 and provides an output corresponding to the differential therebetween. In accordance with any output differential from the servo-amplifier 13, an electric hydraulic servo-value 14, which is connected to the hydraulic feed motor 8, is controlled so that the amount of rotation of the hydraulic feed motor 8, and in turn, the infeed speed of the wheel slide 6 may be controlled to a speed which is most suitable to the present grinding resistance on the grinding wheel 4.

Referring now to FIG. 2, the details of a preferred embodiment of the infeed control circuit 12 are described. The infeed speed control circuit 12 generally includes a schmitt circuit 15, the output of which changes only when the input from the differentiator 11 exceeds a predetermined value, a counter circuit 16 which consists of flip-flop circuits I and II and pairs of speed set circuits (I-1, I-2), (II-1, II-2), - - -, (N-1, N-2) which set up optimum infeed speeds for the wheel slide 6. The speed set circuits I-1, II-1, - - -, N-1 are provided to enable the infeed speeds V1, V2, - - -, V*n*, and the speed set circuits I-2, II-2, - - -, N-2 are provided to en-

able the infeed speeds V1', V2', - - -, Vn' which are respectively slower than the infeed speeds V1, V2, - - -, Vn by a predetermined amount. A particular optimum pair of speed set circuits is selected from the pairs (I-1, I-2), (II-1, II-2), - - -, (N-1, N-2) in accordance with the material of the workpiece 2 and the accuracy required therefor. Each of the speed set circuits (I-1, I-2), - - -, (N-1, N-2) consists of transistors Q1 and Q2 and a variable resistor VR1 for controlling an electric voltage supplied to the servo-amplifier 13 through a respective one of diodes D1, D1', D2, - - -, Dn and Dn'. Additionally, pairs of AND circuits (A1, A1'), - - -, (An , An') are provided and the output terminals thereof are connected to the base of a respective transistor Q1. One input terminal of each pair of the AND circuits (A1, A1'), (A2, A2'), - - -, (An, An') are respectively connected to terminals W1, W2, - - -, W n, to which are applied input information in accordance with the material of the workpiece, the accuracy required on the workpiece and the like. The input information may be conventionally transmitted from a control command tape or by manual selection.

The output of the counter circuit 16 is applied through an inverter 17 (NOT circuit) to the other input terminal of the AND circuits A1, A2, - - -, An and is directly connected to the other input terminal of the AND circuits A1', A2', - - -, An'. The counter circuit 16 according to the preferred embodiment is arranged to produce an output signal when the schmitt circuit 15 generates a signal two times. A timer coil 18, which is energized by means of the output signal of the counter circuit 16, is connected to an OR circuit 19 which operates to reset the flip-flop circuits I and II of the counter circuit 16 when the time determined by the timer coil 18 has lapsed. The OR circuit 19 is further provided with a reset terminal R for enabling resetting of the flip-flops I and II in the counter circuit 16.

Reference is now made to FIG. 3 for a detailed description of the servo-amplifier 13. The outputs of the pressure differentiator 11 and the infeed control circuit 12 are supplied to a subtracter 30 which serves to subtract the output of the differentiator 11 from that of the control circuit 12. The resultant output of the subtracter 30 is supplied to an adder 33 through an integrator 31 and an amplifier 32 which are dispoed in parallel with each other. The output of the infeed control circuit 12 is individually supplied to the adder 33 for summing with the outputs of the amplifer 32 and of the intergrator 31. The output of the adder 33 is applied through an amplifier 34 to one input of an adder 35 whose output terminal is connected to a base of a transistor 36.

The adder 35 is provided with another input terminal T1 through which a reference input voltage is supplied. The output of the adder 35 is supplied through a sign converter 40 to another adder 38 which is identical in function with the adder 35 and whose output terminal is connected with a base of a transistor 39. It should be understood that the sign converter 40 can change from a plus voltage to a minus voltage or vice versa, but that the absolute value of the voltage applied thereto will not change. The adder 38 is also provided with a reference voltage input terminal T2. The reference input voltages to the input terminals T1 and T2 are selected so that the servo-valve 14 will not be activated when a null signal is applied to the adder 35. It should be understood that in this particlar embodiments, the reference voltage applied to the terminal T2 is higher than that applied to the terminal T1. Respective collectors R and T of the transistors 36 and 39 are connected to the electric-hydraulic servo-valve 14 for controlling the rotations of the hydraulic motor 8. The emitters of the transistors 36 and 39 are connected together and grounded.

The operation of the grinding machine, wherein an input signal is applied to the input terminal W1 so that an optimum infeed speed for a particular workpiece is imparted to the wheel slide 6, is described hereinafter. As a first step, the wheel slide 6 and the slide base 21 are integrally advanced toward a predetermined position at a rapid speed by the hydraulic actuator 10. Subsequent thereto, the wheel slide 6 is advanced by the hydraulic motor 8. During this operation, the counter circuit 16 does not produce an output signal, and thus, the inverter 17 will generate an output signal. Since an input signal is now applied to the AND circuit A1 at the terminal W1 and from the inverter 17, the AND circuit A1 will allow an output signal to be applied to the base of the transistor Q1 to thereby make the same conductive. Since the transistor Q2 is at this time nonconductive, an electric voltage in accordance with the variable resistor VR1 is obtained and is supplied through diode D1 to the servo-amplifier 13 along with the output of the pressure differentiator 11.

Until the grinding wheel 4 is engaged with the workpiece 2, the output of the differentiator 11 will be zero. Thus, the amplifier 34 will produce an electric voltage which corresponds to the output of the speed set circuit I-1 and the same is supplied to the adder 35. Since the adder 35 sums the signals applied thereto from the amplifier 34 and from the terminal T1, the adder 35 will supply a high voltage to the transistor 36 to make the same conductive, whereby a zero or significantly low electric voltage will be obtained at the terminal R. The adder 38 is supplied with electric signals from the adder 35 through the sign converter 40, and from the terminal T2, and serves to calculate the summation of the inputs thereto. The summed output from the adder 38 is applied to the base of the transistor 39. At this time, the transistor 39 is less conductive than the transistor 36, since the summed output from the adder 38 is significantly low and the signal from the adder 35 is thereby changed into a minus voltage by means of the sign converter 40. Accordingly, a high electric voltage, which corresponds to the output of the speed set circuit I-1, is obtained at the terminal T, to thereby rotate the hydraulic motor 8 at the maximum speed V1 max as shown in FIG. 4*e*.

When the grinding wheel 4 is engaged with the workpiece 2, the grinding resistance is increased and thus, the output of the differentiator 11 is increased. The subtractor 30 will produce the differential between the two electric signals supplied thereto from the pressure differentiator and the speed set circuit. Consequently, the amplifier 34 will apply the resultant electric voltage, which is of a lower value than before, to the adder 35. The summation of the two inputs to the adder 35 will now become lower with the result that the output thereof will become lower to thereby make the transistor 36 less conductive than before.

The summation of the two inputs to the adder 38 will now become larger with the result that the output of the adder 38 will become higher to thereby make the transistor 39 more conductive than before, since the

signal from the adder **35** through the sign converter **40** is a minus voltage and is lower in its absolute value. Thus, the difference between the electric voltages at the terminals R and T becomes smaller than before so that the infeed speed of the wheel slide **6** is reduced as a function of the grinding resistance and the selected optimum value, in this particular case V1.

Sometimes, at the moment when the grinding wheel **4** is engaged with the workpiece **2**, the schmitt circuit **15** will produce a first signal to thereby switch the flip-flop I of the counter circuit **16**, since the response of the wheel slide **6** is sometimes slow. However, despite this occurrence, the output of the counter circuit **16** will still be zero, and the speed set circuit I-1 will still be in operation. Thus, the grinding operation will continue under the control of the speed set circuit I-1 as long as the schmitt circuit **15** is not applied with another signal above the predetermined value. In case the workpiece **2** is unexpectedly non-circular or has a rough face, the grinding resistance will be large and the predetermined value will be periodically exceeded so that another succeeding signal will be produced by the schmitt circuit **15**. Accordingly, the flip-flop I will be switched and in turn, the flip-flop II will be switched whereby the output of the counter **16** will become **1**. Thus, the AND circuit A1 will be closed, since the output of the inverter **17** will now be "zero." The AND circuit A1′ will then be supplied with an electric signal from the counter **16** and the input terminal W1 to thereby open so that the speed set circuit I-2 will be energized to supply to the servo-amplifier **13** an electric voltage corresponding to the speed V1′ which is slower than the speed V1 by a predetermined amount. Thus, the servo-amplifier **13** will control the infeed speed of the wheel slide **6** in accordance with the differential between the signal from the differentiator **11** and the signal set by the speed set circuit I-2 and thus, the grinding resistance will be maintained at a substantially lower value than that of before.

When the output of the counter circuit **16** becomes **1**, the timer coil **18** will be energized. When the time determined by the timer coil **18** has lapsed, that is, when the workpiece **2** has been ground into an almost circular shape, the OR circuit **19** will be operated by the timer coil **18** to thereby reset the flip-flops I and II so that the wheel slide **6** may again be advanced at an infeed speed set by the speed set circuit **I-1**, since the counter circuit **16** will stop supplying the output thereof to the inverter **17**.

While the above mentioned operation is taking place, the outputs of the counter circuit **16**, the timer coil **18** and the infeed speed of the wheel slide **6** become respectively as shown in FIGS. **4***c*, *d* and *e*.

The above-mentioned infeed speed control is performed in the same way if one of the other pairs of speed set circuits (II-1, II-2), - - -, (N-1, N-2) are selected and thus, a description of the operation thereof is omitted.

It is to be appreciated that an electric pulse motor may also be used instead of the electric-hydraulic motors **8** and **14**. Also, it should be understood that the grinding resistance may be detected by the pressure differential between the input and output ports for a hydraulic drive motor which rotates the workpiece.

obviously, many modifications and variations of the present invention are possible in light of the above teachings. It is to be understood, therefore, that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described herein.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A grinding machine comprising:
a bed,
a wheel slide slidably mounted on said bed and being provided with a rotatably grinding wheel,
a table slidably mounted on said bed for supporting a workpiece thereon,
power means for moving one of said wheel slide and said table to perform a grinding operation on a workpiece,
resistance detecting means for detecting a resistance applied on one of the grinding wheel and the workpiece during said grinding operation, and for generating an output proportional thereto;
a signal generating circuit for generating a signal when the output of said detecting means exceeds a predetermined value,
speed set means having at least one set of speed set circuits which are respectively capable of generating a first output value and a second output value,
first control means for counting the signal out of said signal generating circuit and generating a control signal when the number of the signals out of said signal generating circuit reaches a predetermined value during one cycle of the grinding operation on the workpiece,
second control means for switching said speed set circuits so as to select said second output value in place of said first output value generated therefrom when said control signal out of said first control means is applied thereto, so that the relative feed speed of said wheel slide with respect to said workpiece is reduced,
third control means for maintaining said second output value out of said speed set means during a predetermined period during which the same is generated, and thereafter operating to change an output of said speed set means to said first output value,
fourth control means for controlling said relative feed speed by said power means so as to substantially equate a resistance detected by said resistance detecting means with an output value of said speed set means.

2. A grinding machine according to claim **1**, wherein said signal generating circuit is a schmitt circuit for generating a signal when the output of said detecting means exceeds a predetermined value, and said first control means is a counter circuit operable to count the number of signals generated by said schmitt circuit.

3. A grinding machine according to claim **2**, wherein each of said one set of speed set circuits respectively provides a constant output value therefrom in accordance with a predetermined number of signals being supplied to said counter circuit.

4. A grinding machine according to claim **1**, wherein said wheel slide is provided with hydraulic bearing means for supporting the grinding wheel, and said resistance detecting means is responsive to the pressure differential produced on pressure pockets of said hydraulic bearing means during a grinding operation.

5. A grinding machine according to claim **1**, wherein said speed set means comprises a plurality of sets of speed set circuits each set of which respectively in-

cludes at least a high output circuit for said first output value and at least a low output circuit for said second output value, and selecting means is provided for selecting one set of said speed set circuits in accordance with a condition on a grinding operation on a workpiece.

6. A grinding machine according to claim 1, wherein said fourth control circuit responsive to the output of said speed set means and resistance detecting means comprises:

a first computing circuit for calculating a differential between the selected constant output value from said speed set means and the output from said resistance detecting means, and for generating an output corresponding thereto, and

a second computing circuit for adding the output from said first computing circuit and the output from said speed set means.

* * * * *