United States Patent

Takeyama et al.

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[54] METHOD OF CONTROLLING THE ACTUAL STOCK REMOVAL IN SURFACE BELT GRINDING

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[51] **Int. Cl.**.....**B24b 1/00,** B24b 21/12

[58] **Field of Search**.....51/281, 328, 165.71, 165.87, 51/165.88, 165.91

[56] **References Cited**

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[57] **ABSTRACT**

A method of controlling the actual stock removal in a method of belt grinding wherein the infeed and elasticity of a contact roll serve to increase the contact pressure of the abrasive belt, so as to obtain the required amount of stock removal irrespective of deterioration in the grinding performance of the belt due to repeated use and of the thickness of the workpiece.

2 Claims, 7 Drawing Figures

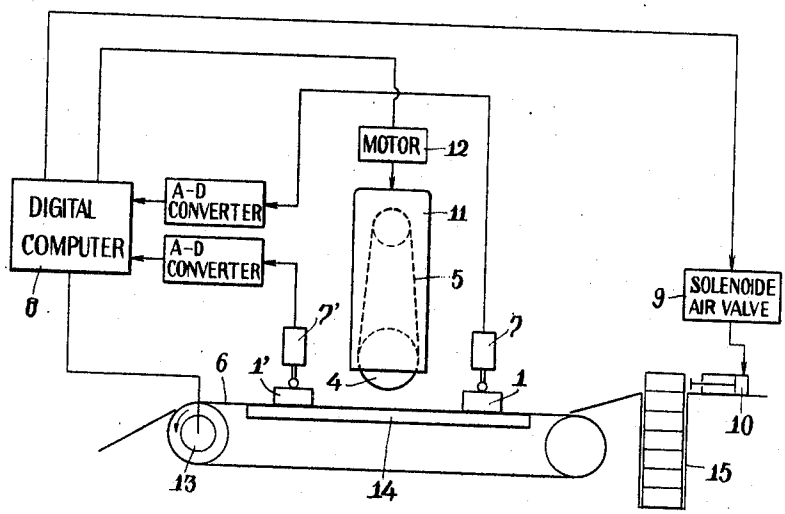


Fig. 1 (A)

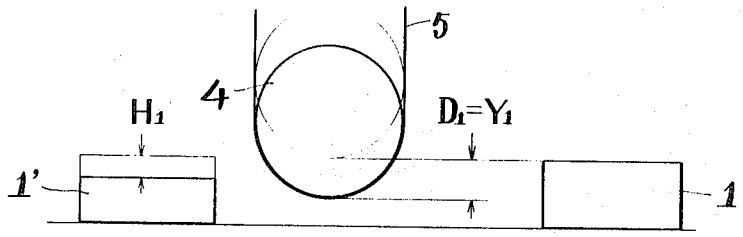


Fig. 1(B)

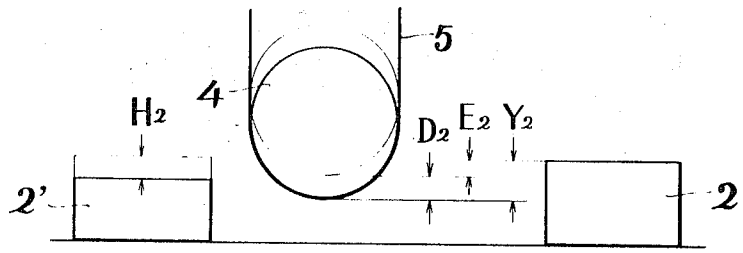
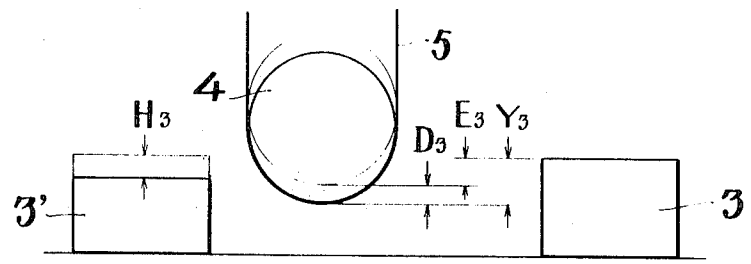


Fig. 1(C)



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Fig. 2 (A)

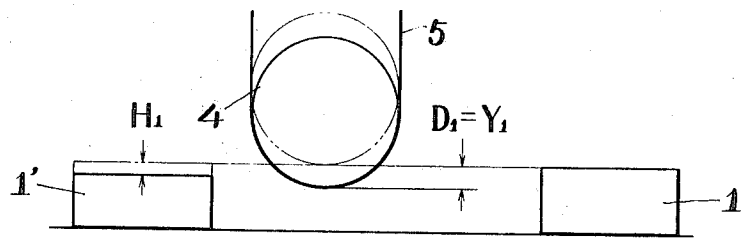


Fig. 2 (B)

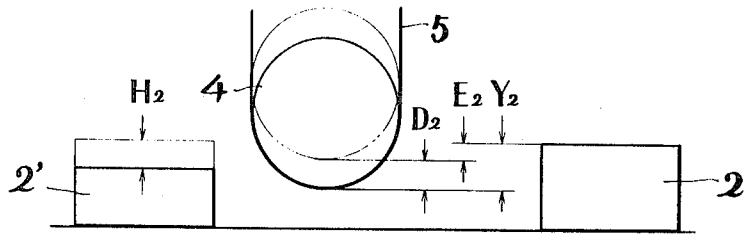
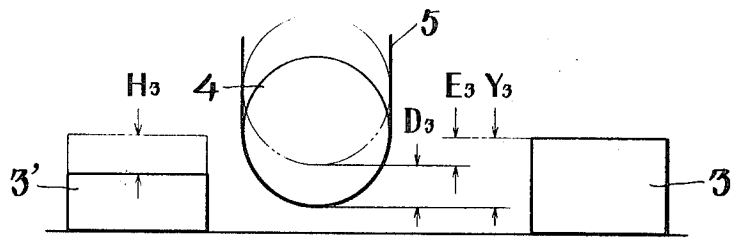


Fig. 2 (C)



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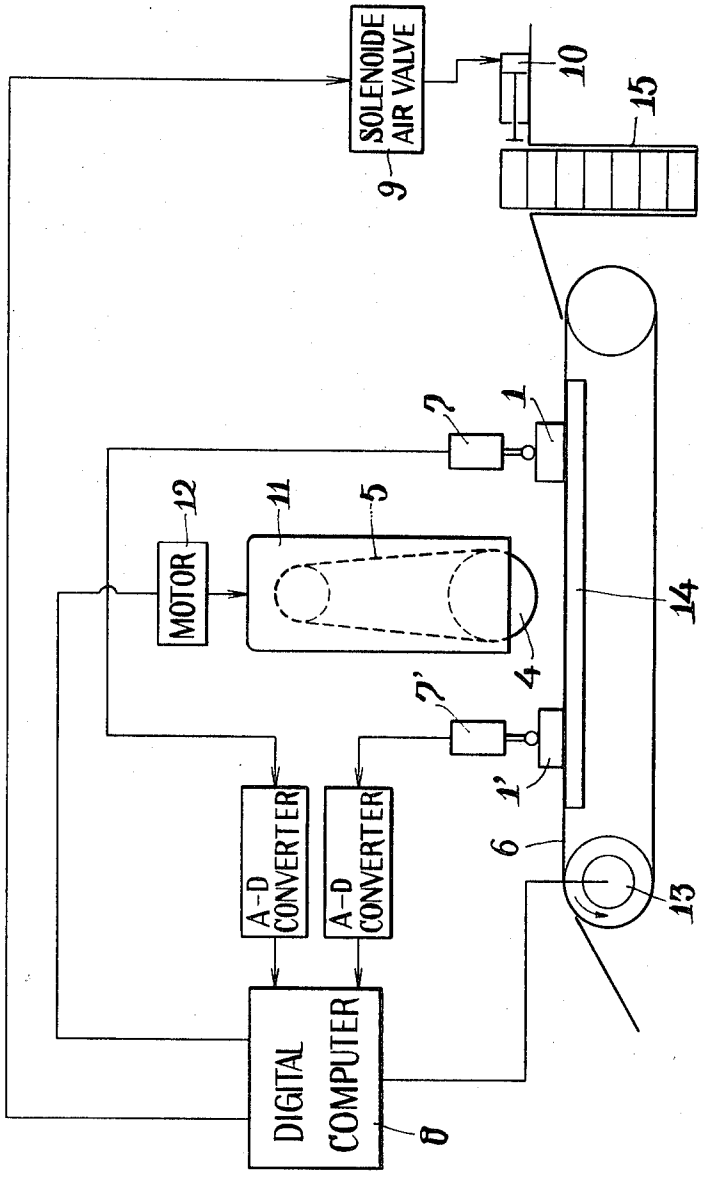


Fig. 3

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METHOD OF CONTROLLING THE ACTUAL STOCK REMOVAL IN SURFACE BELT GRINDING

The invention relates to a method of controlling the actual stock removal in surface belt grinding. In particular it relates to a method of controlling the actual stock removal in a method of belt grinding wherein the infeed and elasticity of a contact roll serve to increase the contact pressure of the abrasive belt, so as to obtain the required amount of stock removal irrespective of deterioration in the grinding performance of the belt due to repeated use and of the thickness of the workpiece.

The actual depth H of stock removal in a belt grinding method can be expressed by the equation (1):

$$H = \beta \cdot Y \tag{1}$$

where Y stands for a nominal depth of cut, and β for a proportionality constant. β is alternatively termed the depth of cut ratio and depends on the grinding speed, feed rate of workpieces to be processed, abrasive grain to be employed, elasticity of contact roll, mechanical properties of the workpieces, grinding performance of abrasive belt, etc.

According to a conventional method, in order to attain an actual cut corresponding to the required stock removal, the depth of cut ratio is estimated on the basis of a number of grinding tests under the given conditions. However, repeated use of the abrasive belt results in deterioration of the grinding performance making it difficult to attain the required stock removal because of the reduction in the depth of cut ratio and great pains have to be taken to compensate for this reduction.

The object of this invention is to provide a method of controlling a belt grinder so as to attain the required stock removal with a high degree of accuracy irrespective of deterioration in the grinding performance of the abrasive belt due to repeated use, by introducing to a computer beforehand information on the relationship between the thickness of the workpiece before and after grinding and the displacement of the grinding head necessary to accomplish the appropriate depth of stock removal for each workpiece, carrying out in-process measurement of the thickness of the workpiece and driving the grinding head in response to the output signal of the computer.

The other objects and characteristics of the invention will be clarified by the detailed explanation with reference to the accompanying drawings in which an embodiment of the method according to the invention is represented.

FIG. 1*a*, *b* and *c* show an example wherein a predetermined depth is ground from the surface of the workpiece.

FIG. 2 *a*, *b* and *c* show example workpieces of various thickness which are ground to the same thickness.

FIG. 3 shows a block diagram illustrating an embodiment of the controlling method according to the invention.

In FIG. 1, E stands for the error in the thickness of an unprocessed workpiece as determined from the standard value specified in the drawing. E is considered plus when the workpiece is thicker than the standard value and minus when thinner than the standard value. Y is the apparent or nominal depth of cut necessary to achieve the required stock removal, and D is the displacement of the contact roll from its zero position necessary to achieve the required stock removal. D is considered plus when the contact roll moves from the zero position toward the workpiece and minus when the contact roll moves from the zero position away from the workpiece surface. H denotes the actual depth of stock removal. 1 and 1' represent the first workpiece before and after processing. 2 and 3 represent the second and third workpieces before processing, while 2' and 3' represent the second and third workpieces after processing. FIG. 1*a* shows the locational relationship of the contact roll 4 and the first workpiece 1, FIG. 1*b* shows the locational relationship of the contact roll 4 and the second workpiece 2, and FIG. 1*c* shows the locational relationship of the contact roll 4 with the third workpiece 3, respectively.

In FIG. 1*a*, the unprocessed workpiece 1 whose thickness coincides with the standard value ($E_1 = 0$) on the drawing for the preceding processing is brought into contact with an abrasive belt 5 wound on the contact roll 4, by adjustment of the grinding head 11. This position is designated the zero position of the contact roll 4 and is designated by a dotted line in FIG. 1*a*, *b* and *c*.

Designating the errors in the thickness of the unprocessed workpieces to be:

$$E_1, E_2, E_3 \ldots E_n$$

the displacement of the contact roll (grinding head) from the zero position denoted as $D_1, D_2, D_3 \ldots D_n$ for each workpiece is:

$$\begin{aligned} D_1 &= Y_1 - E_1 \\ D_2 &= Y_2 - E_2 \\ D_3 &= Y_3 - E_3 \\ &\cdot \\ &\cdot \\ &\cdot \\ D_n &= Y_n - E_n \end{aligned} \tag{2}$$

where $Y_1, Y_2, Y_3 \ldots Y_n$ stand for the adequate nominal depth of cut to be predetermined for each workpiece. Hence, if the depth of cut ratios of the workpieces from the first to the n^{th} are $\beta_1, \beta_2, \beta_3 \ldots \beta_n$, respectively, the following is obtained from equation (1):

$$\begin{aligned} D_1 &= (Ho/\beta_1) - E_1 \\ D_2 &= (Ho/\beta_2) - E_2 \\ D_3 &= (Ho/\beta_3) - E_3 \\ &\cdot \\ &\cdot \\ &\cdot \\ D_n &= Ho/\beta_n - E_n \end{aligned} \tag{3}$$

where βi is a function of i, the number of the workpiece in the series of workpieces, and Ho is the required depth of stock removal for the workpiece of standard thickness. βi has been experimentally been found to be representable by the following equation:

$$\beta i = K \cdot i^{-k} \tag{4}$$

where K and k are constants that depend upon the conditions in the processing concerned.

Since β_1 is the depth of cut ratio of an entirely new abrasive belt, its value is determined beforehand on the basis of a number of tests run with new belts under the same conditions. Thus the displacement D_1 of the grinding head for the first workpiece is determined by equation (3), and the first workpiece is processed.

Before processing of the second workpiece is started, the stock removal H_1 of the first workpiece is obtained, and from this value and Y_1, memorized by the computer, the experimental value β'_1 for the first workpiece is determined. Utilizing β'_1 in place of β_2, the displacement of the grinding head for the second workpiece D_2 is determined and the second workpiece is processed. The experimental value β'_2 is obtained in the same way as the previous time.

This experimental value β'_2 is used as the value of β_3.

Since the depth of cut ratios for the workpieces wherein N equalled 1, 2, 3 were experimentally determined to be $\beta'_1, \beta'_2, \beta'_3$, the undetermined constants K and k in the equation (4) are determined by the least square method, and k_4 is obtained. Thus in determining the value of βi from β_3 on, the experimental values of the depth of cut ratios up to the $(n-1)^{th}$ workpiece, $\beta'_1, \beta'_2, \beta'_3 \ldots \beta'_{n-1}$ are calculated by the least square method to determine the unknowns of equation (4). The experimental values are not applied as they are because these values include the effects of disturbance and measurement errors.

FIG. 2 shows an example wherein the workpiece 1 is processed to a fixed thickness irrespective of its thickness before processing.

If E is the error in the thickness of the unprocessed workpiece relative to the standard value specified in the drawing for the preceding process and Ho is the stock removal relative to the standard thickness of the workpiece specified in the drawing, the displacement Di of the contact roll 4 is:

$$D_1 = Y_1 - E_1$$
$$D_2 = Y_2 - E_2$$
$$D_3 = Y_3 - E_3$$
$$\cdot$$
$$\cdot$$
$$\cdot$$
$$D_n = Y_n - E_n \quad (5)$$

If the depth of cut ratios for the first to the n^{th} workpieces are $\beta_1, \beta_2, \beta_3 \ldots \beta_n$, respectively, then in consideration of the relationship:

$$Yi = (Ho + E_i)/\beta i$$

the equations of (5) become:

$$D_1 = \frac{Ho + E_1}{\beta_1} - E_1$$
$$D_2 = \frac{Ho + E_2}{\beta_2} - E_2$$
$$D_3 = \frac{Ho + E_3}{\beta_3} - E_3$$
$$\cdot$$
$$\cdot$$
$$\cdot$$
$$D_n = \frac{Ho + E_n}{\beta_n} - E_n \quad (6)$$

The procedure for setting the zero point of the contact roll and determining the depth of cut ratios $\beta_1, \beta_2, \beta_3 \ldots \beta_n$ are the same as in the previous case where a predetermined depth is removed from the surface of each workpiece.

An embodiment of the control method according to the invention is represented in FIG. 3.

With the abrasive belt **5** and the conveyor belt **6** kept in the stationary state, unprocessed workpiece **1** whose thickness is equal to the standard value specified in the drawing is inserted in turn under the transducers **7** and **7'** of, for example, the differential transformer type, and the analog outputs from the transducers are accurately adjusted to zero after activating the magnetic chuck **14** to fix the workpiece. This workpiece is then laid under the contact roll **4**, and the abrasive belt **5** is brought into contact therewith and this position is stored in the memory of computer **8** as the zero position of the contact roller **4**. Further stored in computer **8** are the initial depth of cut ratio β_1, the required stock removal *Ho*, the number of workpieces to be processed *i*, and whether the grinding is to be controlled so as to remove a predetermined definite depth from each surface or to grind each workpiece into a definite thickness.

After the completion of the above-mentioned preparation, the abrasive belt **5** and the conveyor belt **6** are started, and the solenoid air valve **9** of the air cylinder **10** is activated on instruction from computer **8**, to place a workpiece **1** on the conveyor belt **6**. The error in the thickness of the workpiece from the standard value is measured as it passes through the gate of the transducer **7**, and this information is passed on to computer **8** via the analog-digital converter. The computer **8** determines the displacement *Di* of the contact roll **4** from the given depth of cut ratio βi and the required stock removal *Ho* by means of either equation (3) or equation (6), activates motor **12** connected to the grinding head **11**, the motor being a pulse motor or other type of motor of small inertia, before the workpiece has been brought in contact with the abrasive belt **5** in order to infeed the contact roll **4** by the amount *Di* from the zero position, and the workpiece is ground.

The thickness of the processed workpiece **1** is measured as it passes through the gate of transducer **7'**, and this information is passed on to the computer **8** via the analog-digital converter. The computer determines stock removal H_1 from error E_1 measured by transducer **7** and stored in the memory, and from $Y_1 = Ho/\beta_1$, also stored in the memory, it determines the experimental value β'_1 which is used as the value of β_2 for the second workpiece.

On completion of the calculation of β_2, automatic loader **15** is instructed to feed the second workpiece onto the conveyor belt **6**. This procedure is repeated as many times as required, and on the completion of the processing of the predetermined number of workpieces, the computer brings the automatic loader and the belt grinder to a halt. Here, the determination of the depth of cut ratio is accomplished in the same way as mentioned previously.

Rotary encoder **13** issues pulses in proportion to the movement of conveyor belt **6**, so that the thickness of the workpiece at a definite distance from the initial contact of the transducer contactor and the workpiece may be measured at all times, and the analog output at that point may be transferred to the computer **8**.

By this invention, the required stock removal from the surface of the workpiece can always be obtained by grinding, and a finished workpiece of definite and constant thickness can be obtained irrespective of deterioration in the grinding performance of the belt, so that a great increase in working accuracy can be expected.

We claim:

1. In surface belt grinding wherein the grinding pressure is exerted by means of the displacement and the elasticity of a contact roll, the method for controlling the stock removal by grinding so as to grind a required definite stock or depth from the surface of the workpiece comprising,

carrying out in-process measurement of the thickness of each workpiece before and after grinding processing,

computing the amount of stock removal,

calculating βi for a next workpiece by utilizing the data and the function form obtained by said before and after in-process measurement and including the computed amount of stock removal, where βi is the depth of cut ratio, and

controlling the degree of displacement for the i^{th} workpiece *Di* of the contact roll from its zero position so as to conform with the equation $Di = (Ho/\beta\, i) - Ei$, wherein *Ei* is the error in the thickness of the i^{th} workpiece before processing, *Ho* is the depth of stock removal required in reference to the standard value specified on the drawings.

2. In surface belt grinding wherein the grinding pressure is exerted by means of the displacement and the elasticity of a contact roll, the method for controlling the stock removal by grinding so as to grind a series of workpieces into a definite required thickness within a small tolerance comprising,

carrying out in-process measurement of the thickness of each workpiece before and after grinding processing,

computing the amount of stock removal

calculating βi by utilizing the data and the function form obtained by said before and after in-process measurement and including the computed amount of stock removal, where βi is the depth of cut ratio, and

controlling the degree of displacement for the i^{th} workpiece *Di* of the contact roll from its zero position so as to conform with the equation

$$Di = \frac{Ho + E_i}{\beta_i} - Ei$$

wherein *Ei* is the error in the thickness of the i^{th} workpiece before processing, *Ho* is the depth of stock removal required in reference to the standard value specified on the drawings.

* * * * *