PATENT SPECIFICATION

(11) 1 568 244

1 568 244

(21) Application No. 43964/76 (22) Filed 22 Oct. 1976
(31) Convention Application No. 630 011
(32) Filed 7 Nov. 1975 in
(33) United States of America (US)
(44) Complete Specification published 29 May 1980
(51) INT CL³ G05B 15/02
(52) Index at acceptance G3N 261 270 404 E2B

(19)

(54) MACHINE TOOL APPARATUS

(71) We, HURCO MANUFACTURING COMPANY, INC., a corporation organised under the laws of the State of Indiana, United States of America, of 6602 Guion Road, Indianapolis, Indiana 46268, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to machine tool apparatus including at least two linearly drivable members and at least two drive motor and screw combinations for driving said members.

United States Patent No. 3,618,349 discloses a system for operating front and rear gauges in a predetermined sequence automatically One of the references cited in that patent was U.S. Patent No. 3,176,556 describing a tape-controlled lead screw drive for the back gauge of a guillotine-type shearing machine. U.S. Patent No. 3,826,119 shows a rear gauge driven by a lead screw.

Although there are situations where a rear gauge bar is short enough that a single point of drive for it is suitable, there are many instances when, due to the substantial length of the gauge bar, drive for it must be provided in at least two horizontally spaced points along its length. The above-mentioned Roch patent provides for this by using a pair of horizontally spaced cylinders for driving the rear gauge. U.S. Patents Nos. 1,366,409 and 3,115,801 show rear gauges for metal shearing machines and which employ screw drives at spaced points, the earlier patent showing two handwheels, one for each screw, and the other showing a single handwheel with a cross-shaft for driving the two screws. Rear gauges using twin screw drives with a single motor driving the two screws, one of them by means of a cross-shaft, have been advertised by the organisation named "Colly Constructions Hydromechaniques" of Lyon-Villeurbanne, France. Its advertisement said the apparatus could provide for eight successive bends preselected manually by means of eight sets of digital switches.

A press brake rear gauge apparatus having two drive screws and motors has been advertised by the Niagara Machine and Tool Works of Buffalo, New York. It was referred to as the "Bend-A-Matic" and was intended to employ digital switches as in the aforementioned Roch patent for preselection of gauge stopping positions, together with an integrated solid state circuit control. It was said to be programmable for three different bend dimensions, each to be established by adjusting certain switches in three sets of digital switches, one set for each of the bend dimensions. There was no provision for alternate operation of front or rear gauges.

According to this invention there is provided machine tool apparatus comprising at least two linearly drivable members and at least two drive motor and screw combinations for driving said members, one motor and screw combination being for each of said members, and further comprising control means including a microprocessor, said control means being coupled to said motors and being operable to monitor mechanical movement of one of said members for each motor and screw combination and to control at least one of the combinations to regulate the difference between and thereby synchronise mechanical movements of the said two members.

In this specification the term microprocessor means an integrated circuit device or a part thereof capable of performing the essential functions of a digital computer control processing unit. A microcomputer comprises a microprocessor, its memory and input/output controllers, all of which may be included in a single integrated circuit device.

In one embodiment of the present invention, a basic frame and carriage drive assembly is provided for use with either rear gauges or front gauges. It employs a top-mounted dual-vee carriage way, with one carriage configuration for a rear gauge, and another for a front gauge. A dual-vee rail mounting is used for the front gauge frames. Each drive assembly includes a motor and screw.

For front gauging, a pair of separate front gauge members may be provided. For rear gauging, there may be at least one gauge bar member connected to a pair of carriages. A pair of power drive motors connected to a pair of gauge carriages, with the points of connection to be moved in synchronism toward a predetermined stopping point or target position, is controlled by a microprocessor synchronising the movement of the gauge carriages. The microprocessor recognises the carriage which is farther from the target position as the master, and slaves the other to it, driving the connection points at high speed (800 inches per minute for example) in precise synchronisation to a tolerance within .002 of an inch of each other during travel or traverse, for example, and within .001 of an inch of each other, for example, when traverse is stopped. In addition to controlling the drive motors for synchronisation during travel, the connector points are to stop within .001 of an inch, for example, of the predetermined target position.

The microprocessor control prevents either drive motor from going into saturation, thus enabling the slave motor to be driven at higher accelerations, without overloading, in the event of detection of a correction signal requiring acceleration. As gauges reach a target point, the control changes its operating mode so that each gauge drive servos to the predetermined gauge position independently of the other gauge motor. Also, when the gauge carriages are at rest, the control will cause the motor for one carriage to drive it in response to a manual repositioning of the other carriage so as to avoid structural damage, particularly where there is a gauge bar extending between the carriages as is usually the case for a rear gauge. Another safety aspect is that during carriage motion, if one carriage strikes an abutment or is otherwise abruptly slowed or halted, the control will cause the other to halt or slow likewise, even if neither has reached the target position.

Where both front gauges and rear gauges are used, while one set of gauges is in use for making a bend, the idle set may be retracted a fixed amount and the position of the idle gauges monitored so that, in the event they are inadvertently or intentionally jarred from position, the controller will take into consideration their misplacement at the beginning of the motion to the next predetermined position for them.

Accommodation may also be made in the control for lead screws having one given lead for the rear gauges, and for the control of front gauges having lead screws with a slightly different lead (within ±.016 inches maximum difference).

In another embodiment of the invention, a pair of screws is employed to drive the ram of a press brake. These are driven by separate motors, controlled by a microcomputer for synchronization.

The invention will now be described by way of example with reference to the drawings, in which:—

FIG. 1 is a simplified front view of a conventional mechanical press brake with gauges in accordance with the present invention mounted thereto.

FIG. 2 is a simplified top plan view of the portion of the press brake below the ram of the press brake, showing the two front gauge housings and the two rear gauge drive housings.

FIG. 3 is a top view of one of the rear gauge mount and drive assemblies.

FIG. 4 is a section therethrough taken at line 4—4 of FIG. 3 and viewed in the direction of the arrows.

FIG. 5 is a rear end view of the rear gauge drive and mount assembly.

FIG. 6 is a transverse section view illustrating some of the interior features of the rear gauge drive and mount assembly.

FIG. 7 is a top plan view of a front gauge mount and drive assembly.

FIG. 8 is a section therethrough taken at line 8—8 in FIG. 7 and viewed in the direction of the arrows.

FIG. 9 is a front end view thereof.

FIG. 10 is a typical transverse section therethrough showing interior details.

FIG. 11 is a simplified block diagram of the control for the twin screw drive.

FIG. 12 is a simplified perspective view of an overdriven-type press brake employing synchronized motors driving the ram by means of a pair of drive screws.

FIG. 13 is a simplified perspective view of an underdriven-type press brake employing synchronized motors driving the workpiece support by means of a pair of drive screws.

Referring to Figure 1, a press brake 11 has a bed 12, crank shaft driven ram 13, and front gauge housings 14 mounted to the front of the bed. The press brake may be hydraulically driven.

Figure 2 shows the same press brake in section as viewed from the top, the section being taken immediately above the lower die and wherein the twin mounts 16 for the rear gauge are shown mounted to the back of the bed 12. The rear gauge bar is shown at 17.

Referring now to Figures 3 and 4, the drawings show one of the rear gauge mounts 16. This includes the main frame member 18 having a mounting face 19 at its left-hand end, with a pair of bolt holes 21 for receiving mounting bolts for attachment to the rear face of the press brake bed. The carriage 22 is mounted to the frame by means of a set of four double-vee carriage support and guide wheels 23 mounted by means of ball bearing assemblies 24 (best shown in Figure 6) which are mounted to the four carriage mounting studs 26. Wheels 23 are guidingly received on carriage ways in the form of a pair of vee-way bars 27 received in the top of the main frame and clamped in place by means of the way-clamp 28 which is fastened to the main frame by means of the screws 29. The guide wheel bearings are secured on the studs 26 by means of flexible lock nuts 31, as shown in Figure 6. Perhaps it would be well to mention at this point, that Figure 6 is not representative of the particular cutting plane transverse of Figure 3, but rather shows sections at various points to best illustrate interior features in a minimum of views.

Two support rods 32 are secured to the top of the carriage and receive the gauge bar support block 33 thereon. A cap 34 is secured to the top of these rods by a pair of screws 36. A support block elevating handwheel 37 is secured by a spring pin 38 to an adjusting screw 39 threadedly received in the support block 33. The lower face of the handwheel is received on a thrust bearing 41 supported on the cap 34. By turning the handwheel on its axis, the support block is raised or lowered. The gauge bar support rod 42 is clamped in the support block 33 by means of the handle 43. The gauge bar 17 (not shown in Figure 3) is fastened to the front end 44 of the gauge bar support rod 42.

The carriage drive is provided by means which will now be described. Comparison of the Figures 3 through 6 will show a drive yoke which is a U-shaped member 46 having the upstanding arms 46U thereof received in grooves 47 in the opposite sides of the carriage 22, and secured thereto by means of screws 46S. The horizontal portion 46H of the yoke extends across and under the bottom of the main frame and has a plate 46P welded to the top of it. This horizontal portion is drilled and tapped to receive a screw 47 by which a drive mounting bracket 48 is fixed to the yoke. A front ball-nut 49 is fixed to the drive mounting bracket 48.

The front ball-nut is received on a ball-screw 51 which is supported in ball bearing assemblies 52 and 53 near the front and rear ends, respectively, of the frame. Bearing 52 os mounted in the front end bearing bracket 54 affixed to the frame by a pair of screws 56. The bearing is press fitted into the bracket. Bearing 53 is received in the drive end bracket 57 secured near the rear end of the frame by means of the screws 58. The bearing is retained in the bracket by a bevelled snap ring 59. The bearings at the opposite ends have their inner races secured to the ball screw by means of bearing lock nuts and washers. A rear ball-nut mounted on plate 62 is also received on the ball screw. A shoulder screw 63 is threaded into the drive mounting bracket 48 and passes through the flange of ball-nut mounting plate 62. Between the screw head 64 and the rear face 66 of the ball-nut mounting plate 62, there is a spring 67 which provides a load urging the ball-nuts toward each other to end load the front ball-nut and avoid any end play of the front ball-nut with respect to the ball screw.

Drive for the ball screw is provided by means of a direct current (DC) servomotor 68 fastened to a motor mounting bracket 69 bolted to the rear face 71 of the drive end bracket 57 by means of bolts 72 and 73 (Figure 6). A gear belt 76 passing between the motor pulley 73 and the ball screw pulley 74 provides the drive. The tension on belt 76 can be changed by pivoting the motor mounting bracket about the bolt 72 while the screw 73 is loosened and the slot 77 permits the pivoting motion. The screw 73 is then tightened to establish and maintain the adjustment. The adjusting screw 78, threadedly received in the ear 79 on the drive end bracket 57, facilitates the establishment of the desired belt tension, and a locknut 78L is provided on this screw. A rotary encoder 81 is mounted at the front end of the motor. A drive motor guard 82 is mounted to the main frame 18 by means of four cap screws 83. An electrical connector 84 is mounted to the side of the main frame.

There are three proximity switches 86, 87 and 88 mounted at spaced points along the length of the frame adjacent the drive screw. These are magnetic reed switches. An actuator 91 for these switches is secured to the drive mounting bracket 48 by a pair of screws. Switches 86 and 88 are mounted to the aluminium frame by aluminium mounting plates, while switch 87 is mounted by means of a steel plate and there is a switch shield associated therewith at 89 for good registry with the actuator for a purpose to be described later relating to the position marker for the encoder.

To further aid in the understanding of the drawing, perhaps it would be well to point out that the surface 92 in the drawing and covered by the end cap 93 in Figure 5, is actually of the shape shown at the line 92L in Figure 6. Similardly, the line 94 in Figure 6 simply represents the inner edge of the gussets 96 in the main frame 18.

Referring to Figures 7—10, showing a typical front gauge assembly, the main frame and carriage drive provisions are the same as in Figures 3—6. Therefore, many of the details thereof are omitted. Features which are different will now be described.

First of all, since the front gauge assemblies may be used to support the workpiece, the frame is provided with a pair of stock support clamp blocks 96 which are secured to the frame by means of a pair of cap screws 97. Each of these blocks receives a stock support rod 98 having a stock support rail 99 fastened to the upper end thereof by means of a cap screw 101. Rail 99 has an inverted

U-shaped cross section with a flat top surface 102, a flat and straight inner face 103 and outer face 104. Since the stock support rods 98 are vertically moveable in the stock support clamp blocks, the stock support 99 can be raised so that the upper face 102 thereof is above the upper face 106 of the carriage. When it has been raised or lowered to the desired position, the stock support can be clamped in place by use of the clamp handles 107 that are threadedly received in the stock support clamp blocks. The face 103 of the stock support can be used for squaring purposes. This is facilitated not only by the ability to raise the stock support above the upper face level of the carriage, but also by by the fact that the holes receiving the cap screws 101 are elongated in the direction of the arrows 108—109 in Figure 7. Accordingly, when the cap screws 101 are loosened, the stock support can be shifted in either direction 108 or 109 and at either end, in order to square it up perfectly with the tooling in the press brake. Then the screws can be again tightened to secure the stock support 99 in place.

The carriage has inverted Tee-slots 111 and 112 therein to receive appropriate front gauge fingers or members, depending upon the type of work to be performed.

Because of the fact that the front gauges may be used to support the stock, and because of the fact that their horizontal spacing may need to be varied from job-to-job, some unusual mounting features are employed. Although the mounting face 19 is the same as for the main frame described for the rear gauge, and the mounting is accomplished by a pair of cap screws 113, these cap screws are received in a vertical gauge way 114. This gauge way is received in vertically extending grooves 116 of the speed rail carriage 117. The speed rail carriage is mounted by means of six dual vee carriage guide wheels which are ball bearing mounted to studs secured in the speed rail carriage. These guide wheels are mounted on the vee way bars 119 and 121 received in the way mounting bar 122 which is affixed to the front face of the press brake bed. The way bars 119 and 121 are clamped to the way mounting bar by means of the clamp 123.

Vertical adjustment of the vertical gauge way 114 is accomplished by rotating the handwheel 124 which is secured to the shaft 126 threadedly received at 127 in the vertical gauge way. The shaft 126 is longitudinally confined by the portion 128 between the needle bearing assembly 129 and thrust face 131, the needle bearing assembly abutting a shoulder on the shaft and the thrust face abutting the upper face 132 of the handwheel, the latter being pinned to the shaft by a spring pin 133. The horizontal movement of the speed rail carriage can be prevented by a clamp or jam screw 134 threadedly received in the speed rail carriage and having the knob 136 at the outer end thereof.

Referring to Figure 11, there is shown a block diagram of the typical embodiment of the present invention as applied to a gauging system for press brakes in which synchronised twin screws are used to drive rear gauges, and synchronised twin screws are used to drive front gauges.

It has been found advantageous to use the M—6800 "family" of micro-computer components marketed by Motorola, Inc., and described in the "Micro-Computer System Reference Handbook" published in 1974 by Motorola, Inc. The microprocessor is at 141 and connected to the data buss 142. Random access memories (RAMS) are represented by block 143, and read-only memories (ROMS) or programmable read-only memories (PROMS) are represented by the block 144.

In the aforementioned Motorola "family" of chips, devices known as peripheral interface adapters (PIA) are employed to connect peripheral components to the central processor unit. These are employed to connect the central processor unit to the incandescent and the LED displays, to the switch scanner for the keyboard and limit switches, and to the motor controller. Referring again to FIG. 11 herein, block 146 represents PIA No. 1 connected to the incandescent and LED panel displays represented by block 147. Block 148 represents PIA No. 2 which is connected to the switch scanner 149 for scanning keyboard switches 151 and various limit switches 152, and any other switches associated with the particular apparatus being controlled.

Since there are two screw drive motors 68 and 153 for driving the rear gauge according to the illustrated embodiment of the present invention shown in FIG. 11, two peripheral interface adapters PIA No. 3A and PIA No. 3B are shown in block 154 and 156 for the left and right rear gauge motors, respectively. For the front gauge, there are also PIA No. 4A and PIA No. 4B in blocks 157 and 158 for the left front gauge drive and control and the right front gauge drive and control, respectively. In block 159 there is a PIA No. 5 which can be used for press brake ram drive and control components in block 161 for a hydraulically driven press brake ram stroke depth control, for example.

Referring further to PIA No. 3A in block No. 154, input and output ports thereof are connected to components in the left rear gauge motor and drive block 162. This includes the screw drive motor itself which has a tachometer 163 on the output shaft thereof and a rotary encoder 81 on the output shaft thereof. The tachometer output is fed back into the motor amplifier at block 164 whereas the output of the rotary encoder is fed to an 8 bit up/down counter 166 whose output is applied to PIA No. 3A. The analog command input to the motor amplifier 164 is derived from a digital to analog converter 167 through an appropriate calibrating resistor or potentiometer 168. The input to the digital to analog converter is from the PIA No. 3A. The same type of arrangement is provided in the block 169 for the rear gauge right motor drive and control and in block 171 for the front gauge left motor drive and control and in block 172 for the right front gauge motor drive and control.

OPERATION.

The present invention is applicable not only to gauging systems for punch presses, bending presses or press brakes, shears and the like, but also to the drive of rams for presses, press brakes, or shears, and is also applicable to other equipment.

In a press brake, it is desirable for the rear gauge bar to remain parallel to the tooling, therefore the target dimension for both gauges will be the same. The procedure for the control of one motor will be described and then related to synchronism of the other motor. For that purpose, the following chart should be helpful for definition and understanding of terms.

VARIABLES	is an 8 bit word
TARGET	POSITION DESIRED number of .001 inches 0→32000
POSINR	RIGHT ACTUAL POSITION
SNR	Sign of right command OO= Plus FF= Minus
COMR	Value of right command
PCOMR	Past value of right command
POSINL	LEFT ACTUAL POSITION
SNL	Sign of left command
COML	Value of left command
PCOML	Past value of left command
PRIOR R	Past Encoder reading right
PRIOR L	Past Encoder reading left
ELR	Error left to right Absolute value
SNLR	Sign of error left to right
COMLIM	Command limit (VALUE)

The motor and motor amplifier and tachometer comprise a servomechanism of conventional nature. It is controlled according to a position loop servo program stored in the ROM 144. The microprocessor 141 can implement the program about 400 times per second in accordance with target information data and gauge selection (as between front and rear gauges) information data previously stored in the RAM 143 by entry from keyboard switches in block 151. Instruction cards or tapes or other forms of data input could be employed. These latter two forms of entry are not specifically shown in the specific embodiment illustrated in FIG. 11.

The steps performed in accordance with the SERVO program as applied to the rear gauges, may be described briefly as follows:

1. Position Update (POSUPD).
   a. For each gauge reads the present value of the up/down counter which is driven by the encoder.
   b. Subtracts the prior reading to determine the incremental change which has occurred since the last reading.
   c. Adds the incremental change (which may be a + or −) to the actual position (POSINR & POSINL).
   d. Updates the prior reading for use on the next sampling.

Thus POSINR & POSINL contain the actual instantaneous location of the right and left gauge.

2. Obtain position errors and save them.
   a. Form TARGET-POSINR for the right gauge as a 16 bit value.
   b. Convert this to a sign-magnitude number with the sign in SNR and the magnitude in COMR.
   c. Perform gain change and limiting on COMR as follows:
      1. If COMR less than .025″, no change.
      2. If COMR between .025″ and .050″, divide it by 2.
      3. If COMR between .050″ and ≈1.0″, divide it by 4.
      4. If COMR greater than ≈1.0″, set it = .256″* *8 bit word maximum value.
   d. Perform operation a, b, c specified above for the left gauge.

Thus COMR and COML are the error values between target and actual.

3. Servo left to right OR right to left (Match).
   a. Form single precision sign magnitude of POSINR-POSINL and put into ELR, SNLR.
   b. Fetch sign of largest error COMR or COML.
   Compare this sign with sign of ELR, If they are the same, select Right axis. If they are different, select Left axis.
   c. If right axis was selected, reverse sign of ELR (i.e. SNLR).
   d. Limit selected command to (0.256″-[ELR]).
   e. Do sign magnitude addition of ELR and selected COMX [COMR] [COML] and put into COMX.

This has "adjusted" the command of the axis which is ahead, slowing it down in order to drive POSINR = POSINL i.e. ELR = O.

4. UPRATE.
   a. Each command is compared with its previous value and is allowed to increase only two counts over what it was. No limitation is imposed on decreases.
5. OUTSPD.
   a. Each command is outputed through the PIA to the D/A to provide a ± analog viscosity command.
6. Motor Control.
   The velocity commands control the rate of motion of the gauges. Resulting gauge motion is read by the digital encoders.
7. Loop to 1.

Now referring more specifically to FIG. 11 with reference to paragraph 1.a. above, encoder 81 drives the eight-bit up/down counter up or down, depending upon which direction the motor axis is rotating to drive the gauge toward or away from the press brake tooling. The count is read into an input port of the peripheral interface adapter 3A for temporary storage in the computer. In this example, the rotary encoder produces a pulse for each .001 of an inch of travel of the ball nut on the lead screw. Therefore each increment of the counter represents .001 of an inch of travel.

The output from the computer is applied through the PIA No. 3A to the digital to analog converter 167 producing an output command through the calibrating device 168 to the motor amplifier. Typically this command is an analog voltage from minus 5 volts to plus 5 volts. The sign of the output depends upon the sign applied to the converter 167 from the PIA No. 3A as determined by the direction of motion needed.

Some specific limit switches are shown in block 173 connected to block 152 in FIG. 11, and should be understood to be included in block 152. They are only shown here to indicate that for the left and right rear gauges there are inputs from limit switches such as RLS+ and RLS− for the right gauge, and RCS which is the center switch for the right gauge, and LLS+ and LLS− and LCS for the extreme limit and center limit switches for the left gauge. Also the RMP represents the right marker pulse input from the encoder and LMP represents the left marker pulse input from the encoder. For the left rear gauge, the LLS+ could be switch 86; LLS− could be switch 88; and LCS could be switch 87. The left marker pulse comes from the encoder 81. It should be recognized that if it were desired to provide another motor and lead screw to drive still another carriage for the rear gauge, or where there would be devices other than gauges mounted to or driven by nuts on motor-driven lead screws, additional limit switches and marker pulse inputs could be provided for cooperation with the additional motor, drive, counter and other components such as in block 162 for each additional motor and screw. Some changes in program details would be needed, but would be of a type well within the skill of the art. Therefore the above-described program operation to produce the velocity commands for the motor controllers such as 164 in FIG. 11 can be expanded to drive more than two motors. The sign of the velocity command designates the direction in which the motor is to move, and the level is proportional to the velocity at which the gauge is to be moved. An example of a suitable motor controller is the Aerotech Model No. 4020 servo controller manufactured by Aerotech, Inc. of Pittsburgh, Pa.

In the use of the apparatus, assuming that it is applied to gauging, it can be placed in a calibrate mode in which the motors 68 and 153 drive the gauges until their respective carriages are so positioned as to establish coincidence of the left center switch signal with the left marker pulse and coincidence of the right center switch signal with the right marker pulse. This provides the reference position for the carriage with respect to the frame. The particular dimensional read-out in the display 147 of that dimension is established by the adjustment of the horizontal support arm for the gauge with respect to the carriage, so that when the dimensional read-out is four inches, this signifies that the work-piece abutting face of the gauge bar is four inches from the center line of the punch in the press brake. Therefore, any target dimension which has been keyed in on the keyboard and stored in a RAM, will be sought by the motors for the gauge bar at the correct time for the particular bend to be made in the workpiece.

1. Position Update.

Assuming now that the motors are driving the gauge toward a target dimension, the servo program procedure goes through the steps outlined above. Assuming that it is the rear gauge that is being driven for the "position update" algorithm outlined above, the computer reads the values of the counters 166 and 174 and stores the information temporarily. It then subtracts the counts stored in the prior scan to determine the incremental change in content of the counters. The incremental change indicates how far the carriage driven by that particular motor has moved within the sampling time. It then adds the incremental change to a variable in the computer which is known as actual position right (POSINR) for the right-hand gauge, and the incremental change noted from the left counter is added to the variable for the left gauge to provide the actual position left (POSINL) for the left gauge. Then the stored count from the previous sample is updated to the present sample for use on the next sampling. The absolute values of POSINR and POSINL may have been initialized at, for example, 12 inches, which is the position halfway between end positions on a 24-inch stroke carriage, and at which the registry of the marker pulse and center switch is achieved. The position update algorithm provides a continuous updating of gauge position so that if, for any reason, the two carriages are not moving at the same rate, the computer will be provided with the information as actual position of each. The algorithm provides actual instantaneous location of the right and left gauges, regardless of whether they were moved by the drive motor or by hand or otherwise. This leads to the second algorithm outlined above which obtains and stores position error.

2. Position Error, Obtain and Store.

The position error for the right-hand gauge with respect to the target position is obtained by subtracting the POSINR value from the TARGET value previously keyed into the controller keyboard 151 manually, and forming the result as a sixteen-bit value. This is converted to a sign-magnitude number with the sign in the SNR register and the magnitude in the COM register. The value of this number tells how far the gauge is from the target dimension and the sign tells whether it is at a dimension greater or less than the target dimension.

Position loop servo gain change and limiting are employed. The maximum command word is only an eight-bit word. Thus if the position error is greater than one inch, the velocity command COMR value is set at the maximum value of the eight-bit word for rapid traverse. At position errors less than one inch the velocity command value is decreased proportionally. Maximum fixed gain is applied when the gauge is very close (.010 to .020 inches) to the target position. For position errors greater than .025 inches, the gain applied to COMR is divided in accordance with the rules set forth in the outline above, such that the effect is that the servo is tightened as the COMR approaches 0. Since the COMR value is the one which is sent to the motor control, its change in value determines the slowdown of the gauge as the gauge approaches the target. The slowdown occurs within a one-inch interval and is governed by the rules set out above in order to avoid an abrupt impact-type stop. After the operations of steps 2.a., 2.b., and 2.c. outlined above are performed, the COMR and COML are velocity command values derived from the calculated position error values between target position and actual position, with appropriate gain changes and limiting applied to them. These are the commands applied to the digital to analog converters for the right and left gauges, respectively, after checking and possible modification by MATCH, outlined below.

3. Servo left-to-right or right-to-left (MATCH).

The algorithm #3 outlined above, which is referred to as the "match" routine, servos the left gauge motor control to the right, or the right to the left, whichever is farther from the target dimension. It servos the gauge nearer the target dimension to the gauge which is farther from the target dimension. This is the significant thing done to keep them moving together while they are moving toward the target position. In the algorithm #3 step b., by fetching the sign of the largest error, it is determined which gauge is "ahead" of the other in the movement toward the target. Thereafter, until the gauges have arrived at the target dimension, that gauge which was ahead is slaved to the one which was behind, but not so much so that it gets behind. The sign reversal in step 3.c. is simply for convenience in the computer. The command limitation on step 3.d. avoids the slowdown of the leading gauge from ever causing it to get behind the gauge which it was behind at the time of the formation of the ELR, SNLR word and signal designating which gauge would serve as the master during the approach to the target position. The gauge which was behind is permitted to run at the maximum COMR or COML value until it reaches a point within one inch of the target, whereupon the slowdown occurs as described above with reference to algorithm #2. The COMX command arrived at in step 3.d. will always be a slowdown signal to slow down that gauge which was closer to the target position.

It is important to recognize that, although the controller will normally seek the target position for both gauges, if it happens that one gauge is stopped abruptly short of the target position, or having arrived at target position, is knocked off the target position, beyond the capability of its motor to control such movement, the other gauge will be preferentially maintained within one eighth inch of the one gauge. That is to say that the higher priority objective of the controller is to maintain the gauges within one eighth inch of each other (ELR less than .125 inches) that it is to reach or hold the target position.

4. Uprate.

With regard to the uprate limitation outlined at #4 above, for a normal gauge movement to a new target dimension for the next bend in sequence, or if by some accident or otherwise, the target dimension is suddenly changed substantially, or if the gauge is bumped off the target position, the COMR and COML will not instantly rise to full value, but rather will increase corresponding to a counter change of two counts for each scan of the loop, thus avoiding an excessive voltage surge at the controller. In this way, a reasonable acceleration rate is achieved.

Referring now to FIG. 12, there is shown in perspective a new type of press brake 176 having bed 177 with an upper edge thereof at 178 to which tooling can be secured. C-shaped side frames 179 and 181 are affixed to the bed and provide supports for drive mounting brackets 182 at the upper front edges thereof. These brackets support drive assemblies including a D.C. motor 183 connected to the gear box 184 and driving a ball nut 186 which receives a vertically extending lead screw 187. The two lead screws support the opposite ends of the RAM 188 to which the upper tooling is mounted at 189. The motors 183 thereby serve to drive the ram up and down by rotating the ball nuts which thereby drive the lead screws. The operation of the motors is synchronized in the same manner as has been described above with reference to FIG. 11 for driving gauges.

Referring now to FIG. 13, an underdriven-type of press brake is shown wherein a cross frame 191 is affixed to side frame uprights 192 to which an upper cross member 193 is affixed. The upper tooling is fastened to the lower edge of the upper cross member at 194.

Two horizontally spaced and parallel outer and stationary bed plates 196 and 197 are affixed together and to the platen or tool-holder member 198 to which the lower tooling is affixed. A pair of ball lead screws such as that shown at 199 is affixed to the platen, one such screw being located at each end. In a manner similar to that described with reference to FIG. 12, a gear box 201 secured to each end of the cross frame 191, has a D.C. drive motor 202 secured thereto and driving a ball nut 203 therein. The ball nuts are received on the lead screws and the drive thereof serves to drive the cross frame 191 to which the gear boxes are affixed, and thereby the upper cross member 193 up and down with the gibs 204 secured to the side frame uprights at the front and rear of the press brake guided by plates 196 and 197. The gibs thereby serve to guide the upper cross beam assembly on the front and rear stationary bed plates as the upper cross beam or ram is driven up and down by the drive motors. The motors are synchronised in the same manner as described above with reference to Figure 11 for gauge drive motors, to be certain that the opposite ends of the frames 191 and 193 are driven in unison.

Features of the above described apparatus are claimed in our co-pending Application No. 27909/77 (Serial No. 1568245).

WHAT WE CLAIM IS:—

1. Machine tool apparatus comprising at least two linearly drivable members and at least two drive motor and screw combinations for driving said members, one motor and screw combination being for each of said members, and further comprising control means including a microprocessor, said control means being coupled to said motors and being operable to monitor mechanical movement of one of said members for each motor and screw combination and to control at least one of the combinations to regulate the difference between and thereby synchronise mechanical movements of the said two members.

2. Apparatus according to claim 1 wherein each of said members has workpiece locating gauge means connected to it.

3. Apparatus according to claim 2 wherein the gauge means include a rigid gauge bar connected to each of said members.

4. Apparatus according to claim 1 wherein each of said members is coupled to a tool slide of a material shearing, bending, or punching press.

5. Apparatus according to claim 4 wherein

said members are the screws of the combinations and are connected to a tool slide, and nuts are threaded on the screws and rotationally driven by the motors.

6. Apparatus according to claim 4 or claim 5 wherein the tool slide is a ram of a press.

7. Apparatus according to any of claims 4 to 6 wherein the tool slide is the rigid combination of lower and upper cross members with connecting side frames of a press.

8. Apparatus according to claim 2 or claim 3 wherein the control means include servo amplifier means controlling the motors; memory means storing gauge position data and instructions; a microprocessor coupled to the memory means to process data and execute instructions; and means coupling the microprocessor to the servo amplifier means for motor control in response to said data and instructions.

9. Apparatus according to claim 8 wherein the coupling means include peripheral interface adapters and digital to analog converters.

10. Apparatus according to any of claims 1 to 3 having first and second gauge mounting carriages which are linearly drivable in synchronism with each other and which are respectively coupled to first and second drive motor and screw combinations, each combination comprising a lead screw and a drive motor coupled thereto, the two screws being mounted in frame means; and wherein the control means are operable to control the drive of the motors thereby to cause the lead screws to drive the carriages in synchronism.

11. Apparatus according to claim 10 wherein the frame means include a pair of frames, each frame having a pair of horizontally-spaced, longitudinally-extending carriage ways thereon, each way having a running edge of V-shaped cross section; the carriages each having grooved rollers thereon mounted for rotation thereon and engaging the running edge of one of the ways of the respective frame whereby each respective carriage is supported and guided as it is driven by one of the lead screws.

12. Apparatus according to claim 11 further comprising a pair of ball nuts and connectors, one of the ball nuts being on each of the lead screws and having one of the said connectors secured thereto; a pair of U-shaped drive yokes, one yoke for each carriage, each yoke being secured at its bottom to one of the connectors and extending outwardly and then upwardly therefrom around the one of the frames having therein the lead screw driving the said one connector, the upper ends of each yoke being affixed to one of the carriages.

13. Apparatus according to claim 11 further comprising two pairs of posts, one pair of posts being affixed to each of the carriages and projecting upwardly therefrom; a pair of horizontal support brackets, each bracket being mounted to the posts of one pair of said pairs of posts and vertically movable thereon; and two height adjusting screws mounted to the posts and operable to change the height of the brackets.

14. Apparatus according to claim 13 further comprising a pair of horizontal support rods, each clamped in one of said horizontal support brackets and, upon unclamping, relatively movable therein parallel to the running edges of said ways, and a pivoting gauge bar extending between and pivotally mounted to said support rods to pivot about a horizontal axis.

15. Apparatus according to claim 11 further comprising means on said carriages for locating material to be fed into the machine tool and vertical guideways extending transverse to the direction of extension of said carriage ways, the rear end of each of said frames being affixed to one of said vertical guideways, a front mounting rail securable to a press or the like, upper and lower horizontally extending carriage support guideways affixed to said rail, a pair of front mounting speed carriages having grooved rollers thereon received and guidingly supported on said guideways for horizontal movement of said speed carriages side-to-side on the machine tool, said vertical guideways being received in said speed carriages and means on said speed carriages and vertical guideways for raising and lowering said vertical guideways.

16. Apparatus according to claim 15 wherein said means for raising and lowering include height adjustment screws, one of said screws being on each of said speed carriages and threaded into said vertical guideway and each having a handwheel on said screw for convenient manual rotation thereof to raise and lower the frames and thereby raise the material locating means.

17. Apparatus according to claim 15 further comprising a combined stock support arm and side squaring bar member clamped to at least one of said frames and, by unclamping, vertically adjustable on the frame to which the member is mounted.

18. Apparatus according to claim 10 further comprising additional frame means having third and fourth lead screws therein; third and fourth screw drive motors, said third motor being coupled to said third screw for driving said third screw, and said fourth motor being coupled to said fourth screw; third and fourth gauge mounting carriages coupled to said third and fourth screws respectively and linearly drivable thereby; said control means being coupled to said third and fourth motors for controlling the drive of said third and fourth motors and thereby controlling the driving of said third and fourth screws, said control means including electric synchronising means for causing said third and

fourth motors to drive said third and fourth carriages in synchronism.

19. Apparatus according to claim 11 wherein said control means include four motor controlling servo amplifiers, one for each of said motors.

20. Apparatus according to claim 18 further comprising a press brake bed, the first mentioned frame means being mounted to the rear of said bed for supporting a rear gauge, and said additional frame means being mounted to the front of said bed, for supporting a front gauge.

21. Apparatus according to claim 20 wherein the first mentioned of said frame means, and said additional frame means each include a pair of frames, each frame having a pair of horizontally-spaced, longitudinally-extending carriage ways thereon, each way having a running edge of V-shaped cross section; said carriages each having grooved rollers thereon mounted for rotation thereon and engaging the said running edge of one of the ways of the respective frame whereby said carriage is supported and guided as it is driven by one of said lead screws.

22. Apparatus according to claim 21 further comprising drive nuts on said screws; U-shaped drive yokes connected to said drive nuts, each of said yokes having a central bottom portion connected to one of said nuts and having arms extending outwardly therefrom and then upwardly around the one of said frames having the nut receiving screw therein, with the upper ends of the arms of the yoke being attached to that one of said carriages which is to be driven by said nut.

23. Apparatus according to claim 22 further comprising rear gauge means mounted to said first and second carriages, and front gauge means mounted to said third and fourth carriages.

24. Machine tool apparatus comprising at least two spaced apart drive motor and screw combinations mounted with their respective screws parallel and arranged to impart linear movement to a member which extends transversely to the direction of the said movement, each combination applying a driving force to the member through a respective point of connection, the points of connection being spaced along a line extending transversely relative to the said direction of movement, the apparatus further comprising control means including a microprocessor, which control means are coupled to the motors and are operable to monitor the mechanical movement of each point of connection relative to a fixed reference position and to control at least one of the combinations so as to regulate the difference in position between, and thereby to synchronise the movement of, the points of connection.

25. A method of synchronising linear movement of the linearly movable members of at least two nut-screw combinations, each of which combinations includes a nut which is threaded to a screw and driven by a motor, and comprising the following steps at least some of which are controlled by a microprocessor:—

a) generating from each of said combinations, pulses in response to movement of a portion of the combination caused by motor operation;

b) counting pulses produced and referencing the count to a fixed location for each linearly movable member, to provide for each member a value of a variable which represents member location lengthwise of its path of movement;

c) scanning the pulse count periodically, and subtracting the count of a later scan from the count of an earlier scan to obtain the incremental change in count;

d) adding to the variable an amount representing the incremental change, to designate any new location of the member, to thereby provide from the later scan the actual instantaneous locations of said members;

e) establishing a target location for each member;

f) driving said motors to move said members to said target locations;

g) determining for each member, the distance between the target location and the actual instantaneous location of the member;

h) and causing the movement of one of said members to slow down if the said distance is less for that than for the other member.

26. The method of claim 25 further comprising the step of slowing the movement of the one member by slowing its drive motor in proportion to the difference in distances.

27. The method of claim 25 or claim 26 further comprising the step of limiting acceleration of said motors.

28. The method of any of claims 25 to 27 wherein the microprocessor is used to control the counting, scanning, adding, establishing, driving, distance determining, and causing steps.

29. The method of claim 25 further comprising the steps of:—

a) forming a precision absolute value and sign of a difference between said distances;

b) determining the sign of the largest of the distances between target location and actual instantaneous location of the member and comparing with the sign of the difference;

c) and selecting for slowdown that one of the members designated by the result of the sign comparison.

30. The method of claim 29 wherein the result of the sign comparison is fed to a digital to analog converter to provide a positive or negative analog velocity command to a motor controller amplifier.

31. The method of claim 29 or claim 30

further comprising the step of using a microprocessor to control the counting, scanning, adding, establishing, driving, distance determining, causing, forming, comparing, and selecting steps.

32. The method of claim 29 further comprising the steps of:—

ceasing to drive the motors when the members have reached target locations;

continuing to scan the pulse count periodically while the motors are at rest and subtracting the count of a later scan from the count of an earlier scan to obtain any incremental change in count;

repeating steps d) and g) of claim 30;

forming a precise absolute value and sign of any difference between said distances;

and driving the motor for one member as needed to limit the absolute value of any difference.

33. The method of any of claims 29 to 32 further comprising the steps of causing at least one of said motors to run at maximum speed until said distance for the nut driven thereby is within a predetermined amount from the target location, and thereafter reducing motor speed as the distance decreases toward zero.

34. The method of claim 33 wherein the predetermined amount is one inch, and the maximum speed is at least 800 inches per minute.

35. Machine tool apparatus constructed and arranged substantially as herein described and shown in the drawings.

36. A method of synchronizing movement substantially as herein described with reference to the drawings.

WITHERS & ROGERS,
Chartered Patent Agents,
4, Dyer's Buildings, Holborn,
London, EC1N 2JT.
Agents for the Applicants.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1980.
Published by the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

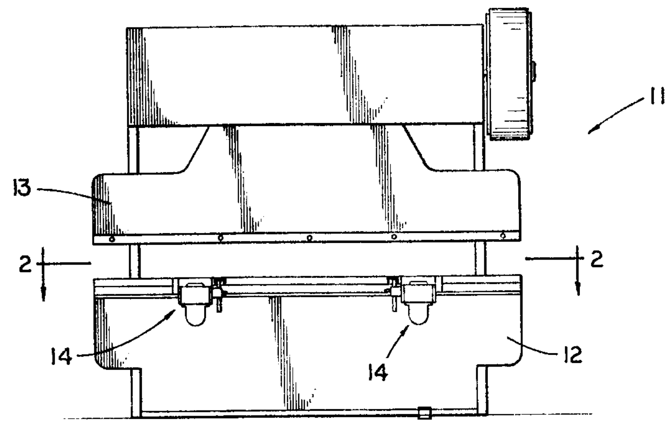


Fig. 1

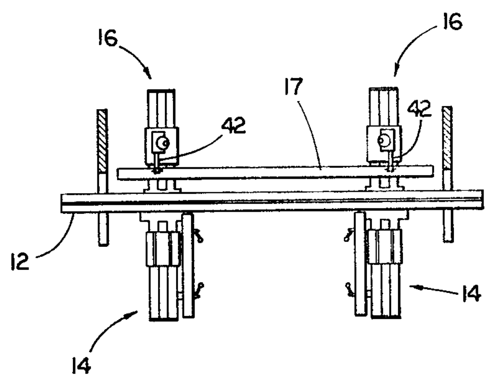


Fig. 2

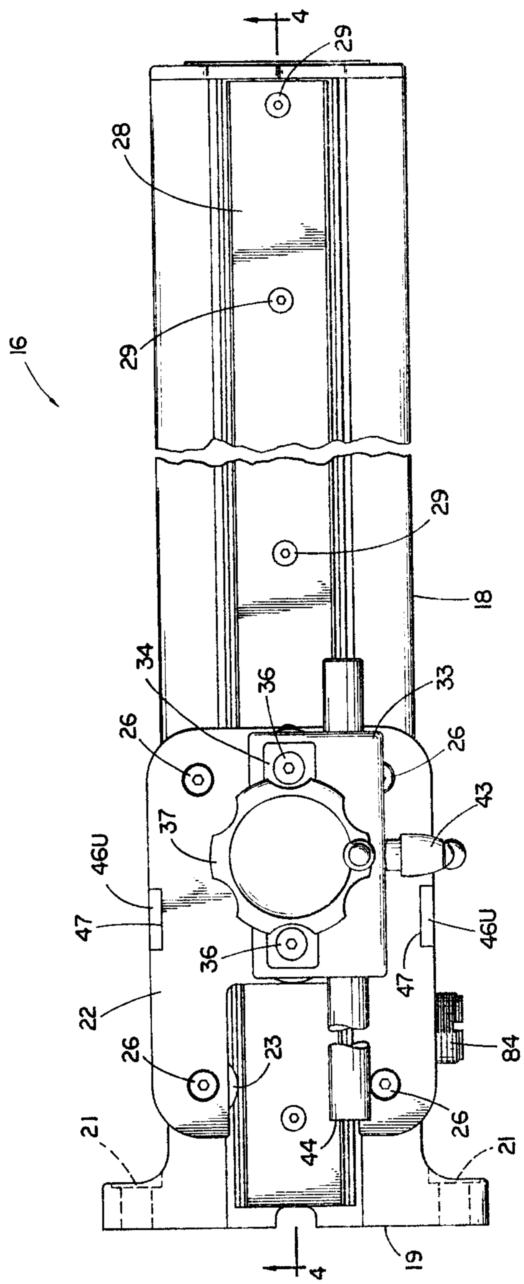

4
29
28
29
16
29
18
34
36
33
26
26
43
37
46U
47
46U
47
36
22
84
26
23
26
44
21
21
4
19

Fig.3

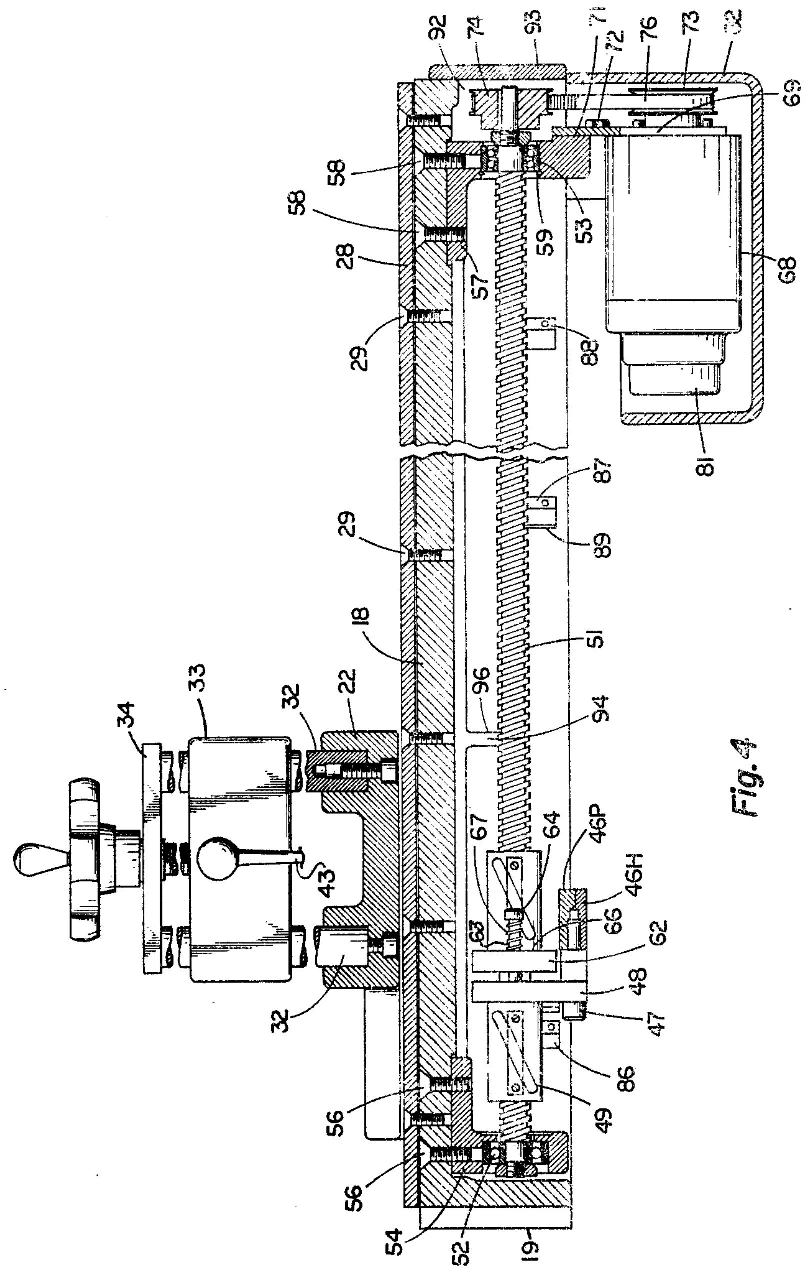
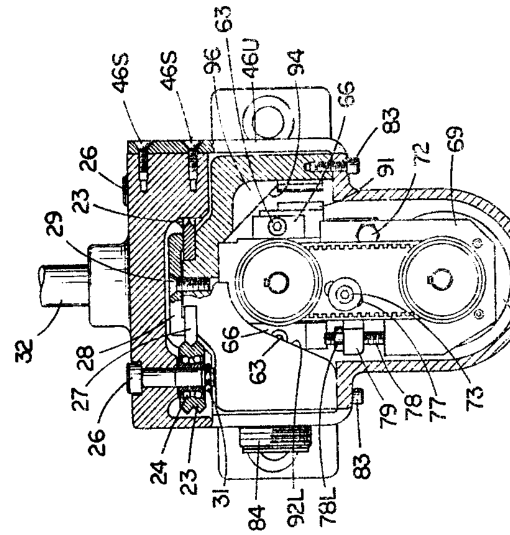
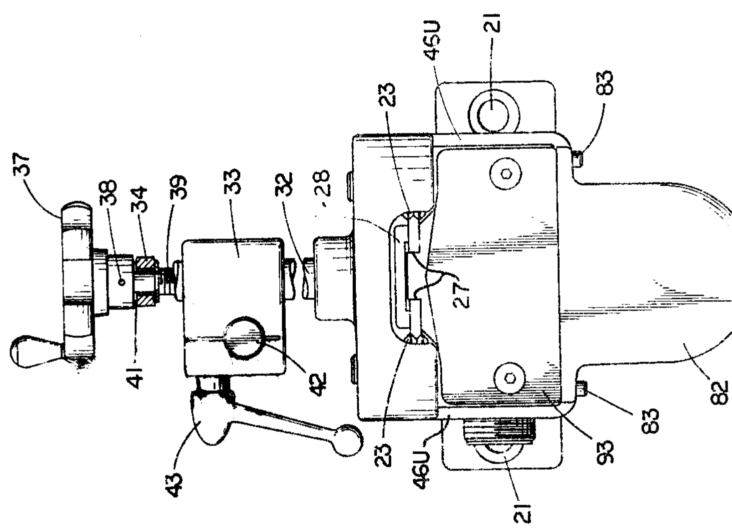


Fig. 4


46S
46S
96
46U
63
94
66
83
91
72
69
26
23
29
32
28
27
26
24
23
31
66
63
92L
78L
79
78
77
73
68
83
84
Fig.6


37
38
34
39
33
32
28
23
46U
21
83
41
42
43
27
23
46U
21
93
83
82
Fig.5

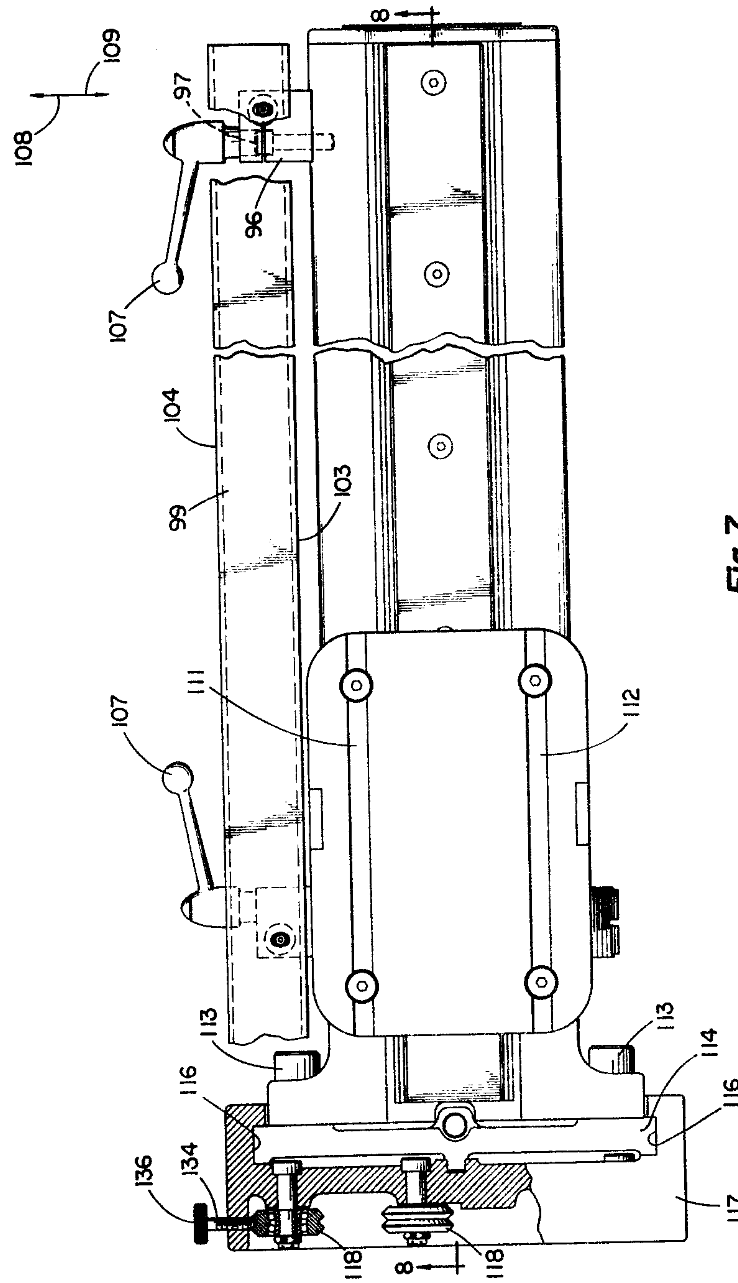

108
109
97
96
107
104
99
103
8
111
112
107
113
113
114
116
116
117
136
134
118
118
8

Fig. 7

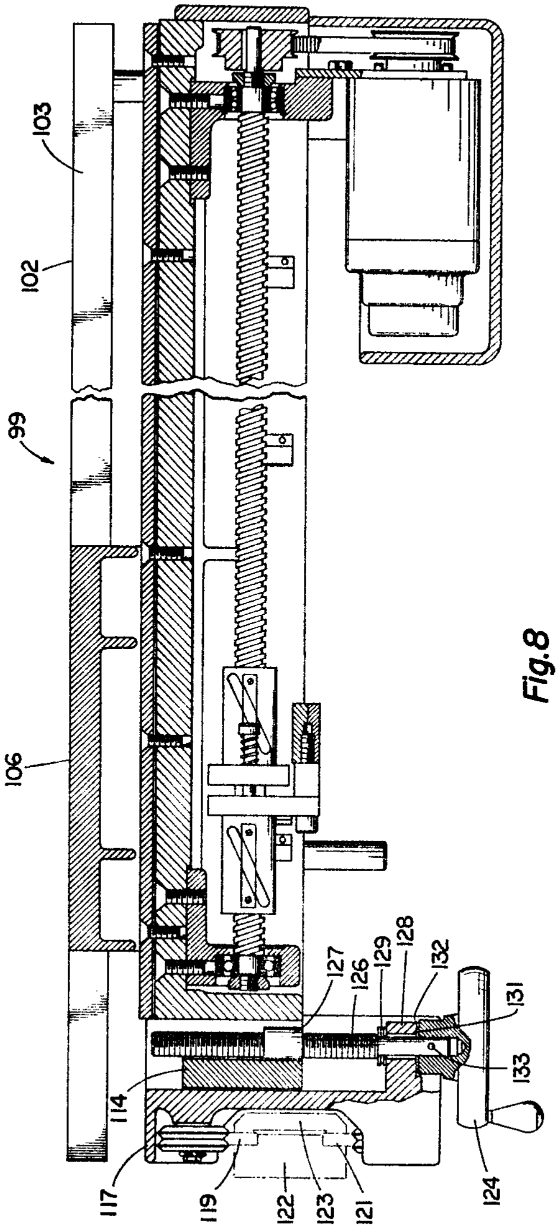

103
102
99
106
127
126
129
128
132
131
133
114
117
119
122
123
121
124

Fig.8

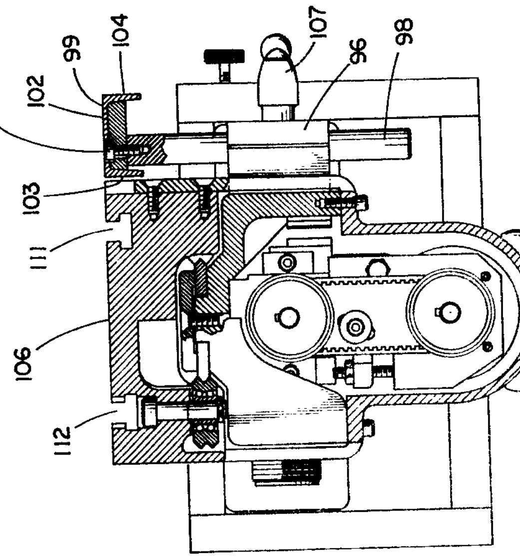


Fig. 10

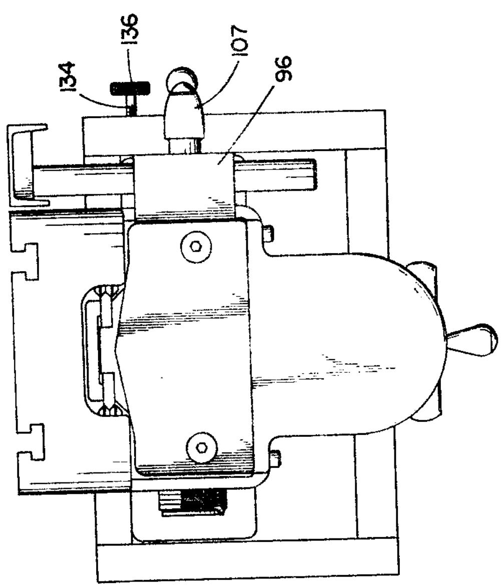


Fig. 9

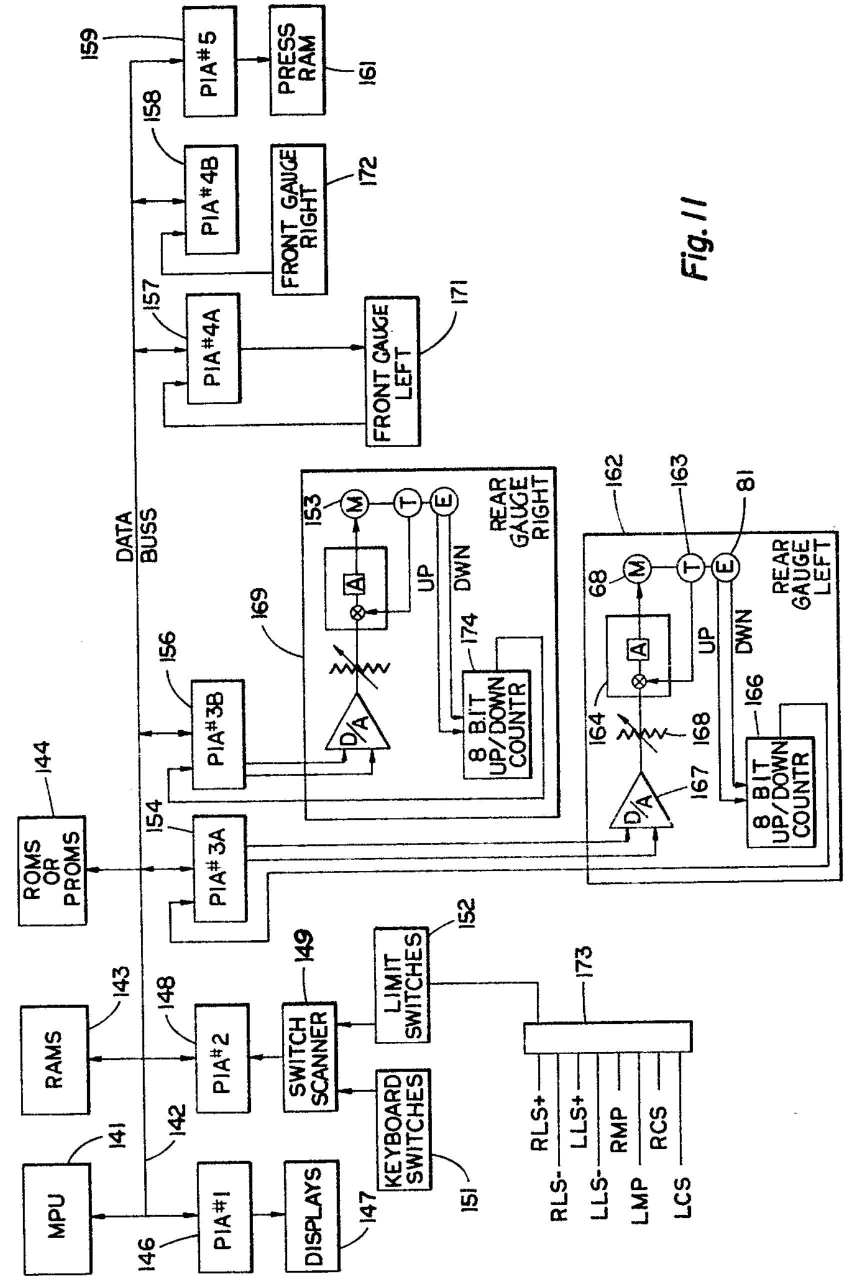

MPU
PIA#1
DISPLAYS
RAMS
PIA#2
SWITCH SCANNER
KEYBOARD SWITCHES
LIMIT SWITCHES
ROMS OR PROMS
PIA#3A
PIA#3B
DATA BUSS
PIA#4A
PIA#4B
PIA#5
FRONT GAUGE LEFT
FRONT GAUGE RIGHT
PRESS RAM
REAR GAUGE RIGHT
REAR GAUGE LEFT
D/A
A
M
T
E
UP
DWN
8 BIT UP/DOWN COUNTR
RLS+
RLS-
LLS+
LLS-
RMP
LMP
RCS
LCS
141
142
143
144
146
147
148
149
151
152
153
154
156
157
158
159
161
162
163
164
166
167
168
169
171
172
173
174
68
81

Fig. 11

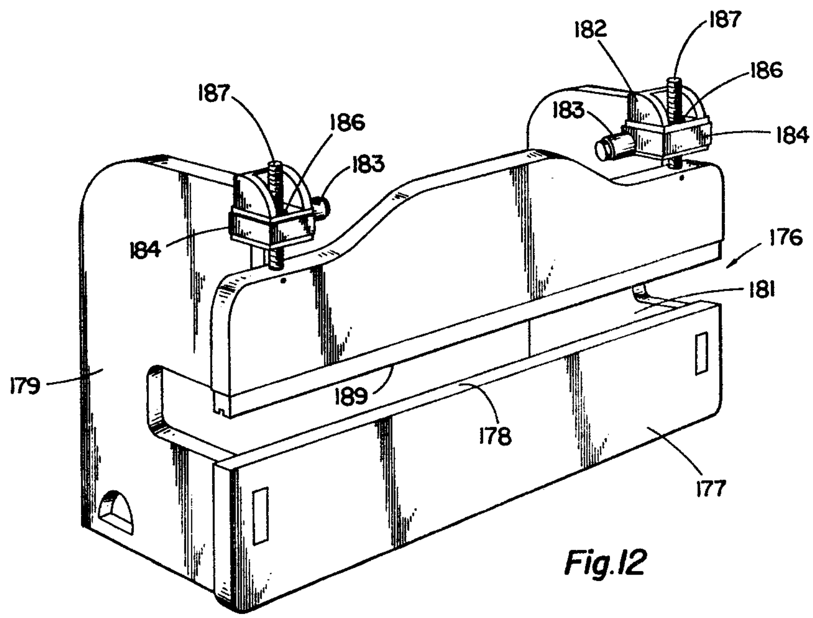

187
186
183
184
182
187
186
183
184
176
181
179
189
178
177

Fig.12

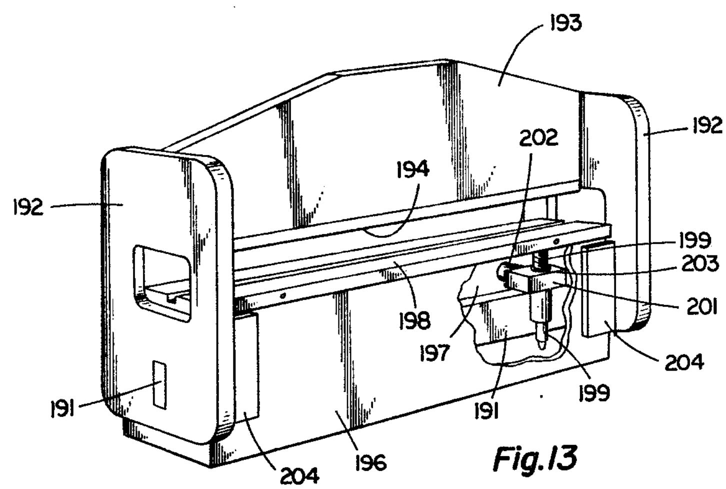

193
192
202
194
192
199
203
201
198
197
204
191
199
191
204
196

Fig.13