Jan. 26, 1960 W. J. DE VILLIERS ET AL 2,922,175

TUYERE PUNCHES AND LIKE MACHINES

Filed Dec. 11, 1956 6 Sheets-Sheet 1

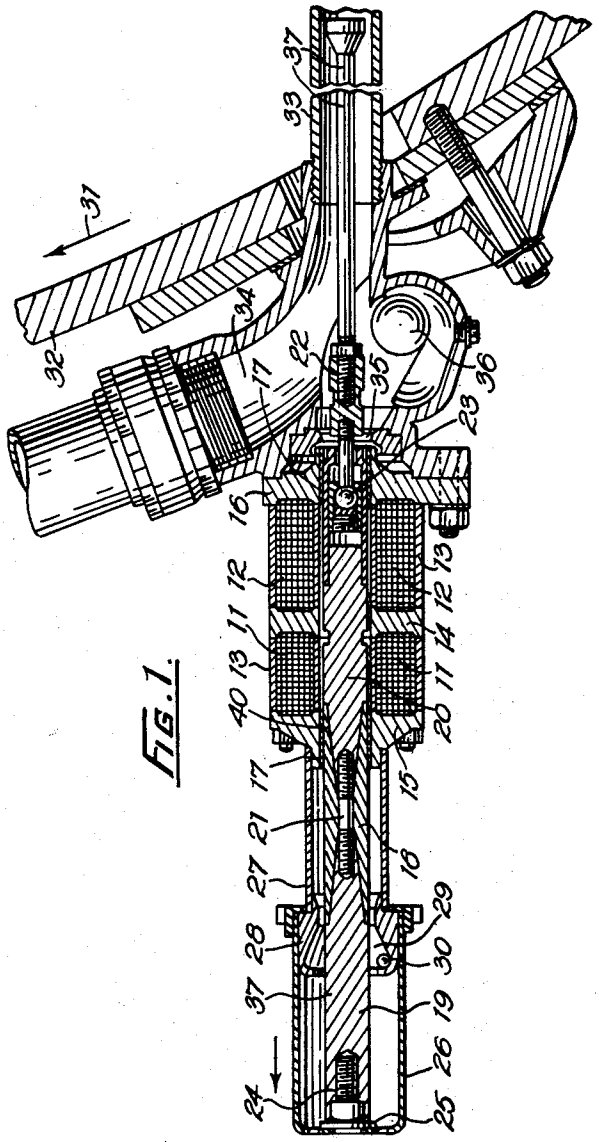


FIG. 1.

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TUYERE PUNCHES AND LIKE MACHINES

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FIG. 2.

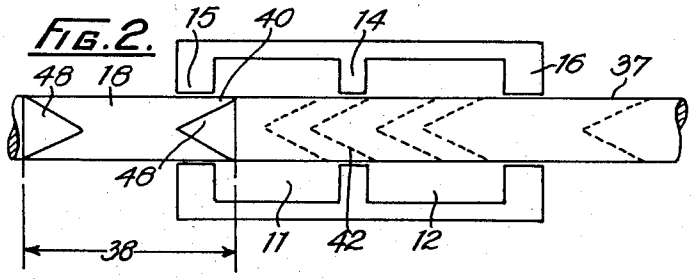
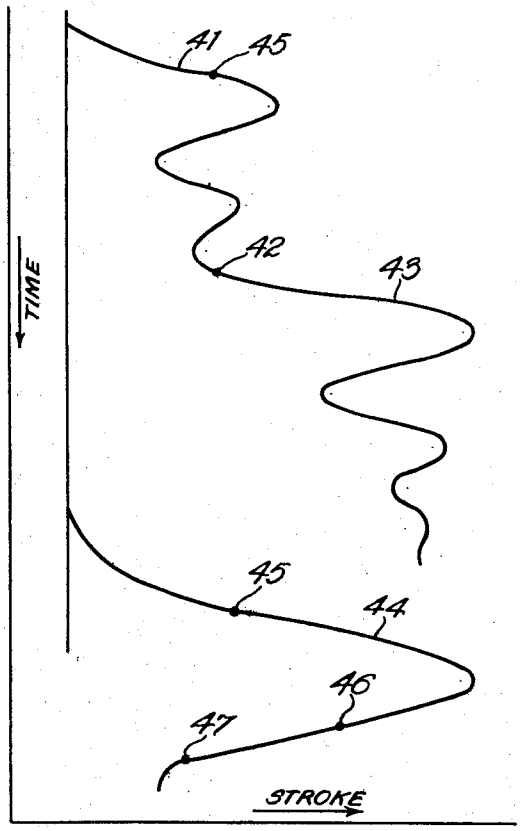


FIG. 3.

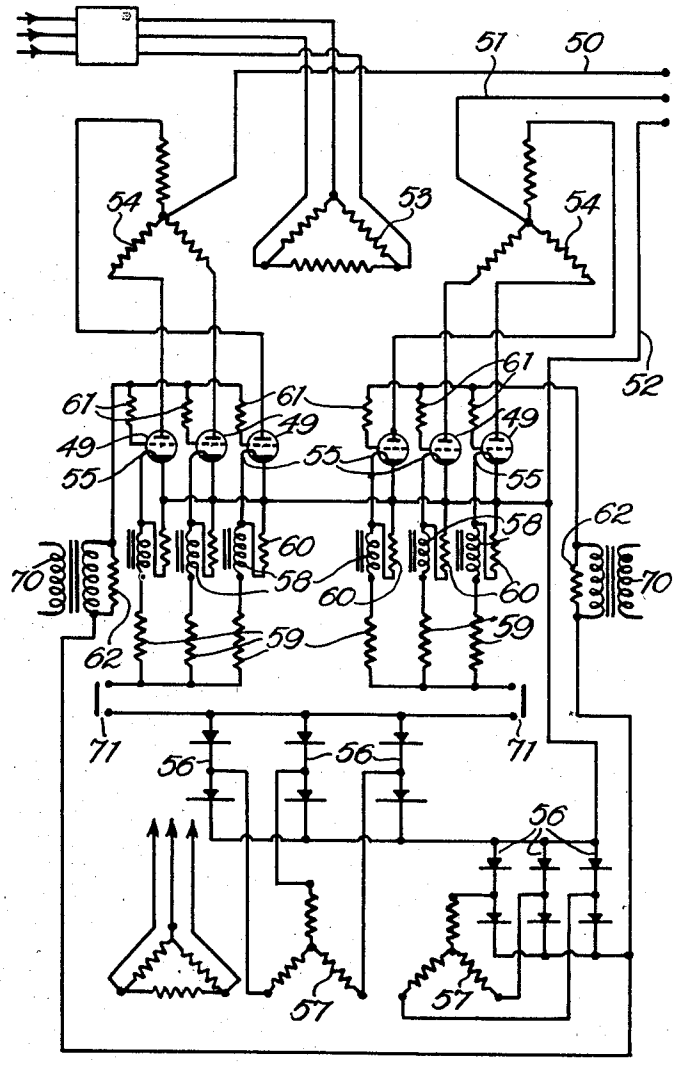


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FIG. 4.



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FIG. 5.

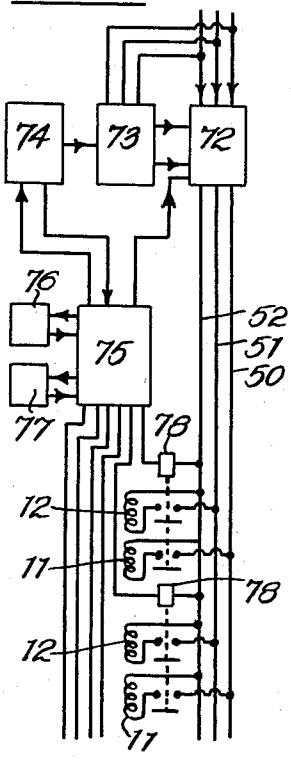


FIG. 8.

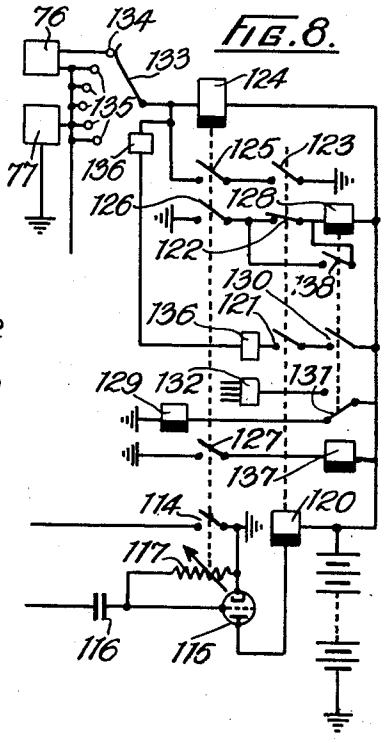


FIG. 9.

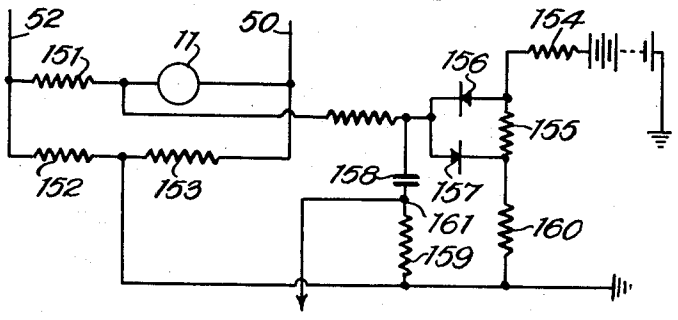


FIG. 6.

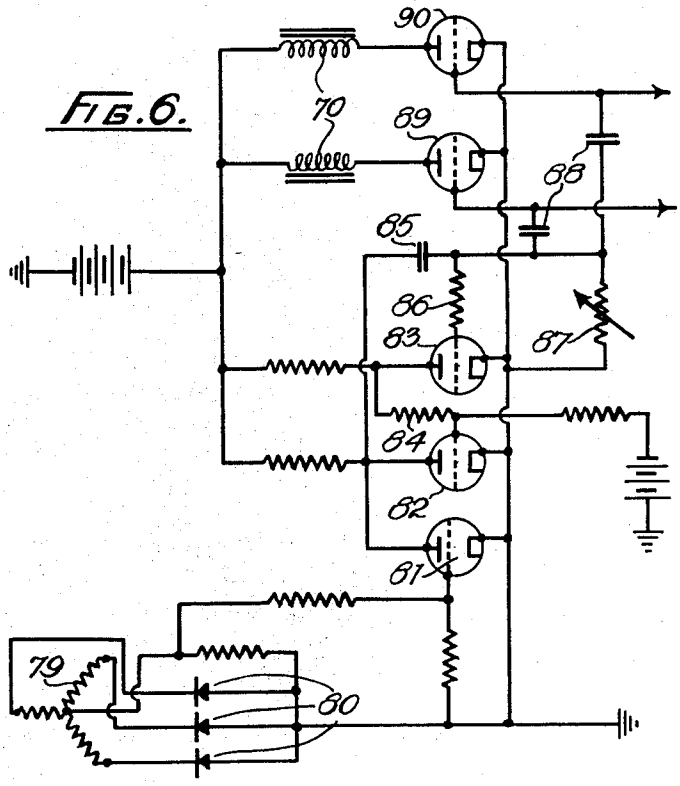
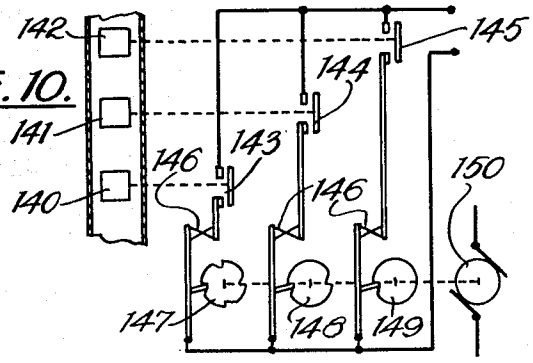

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FIG. 10.

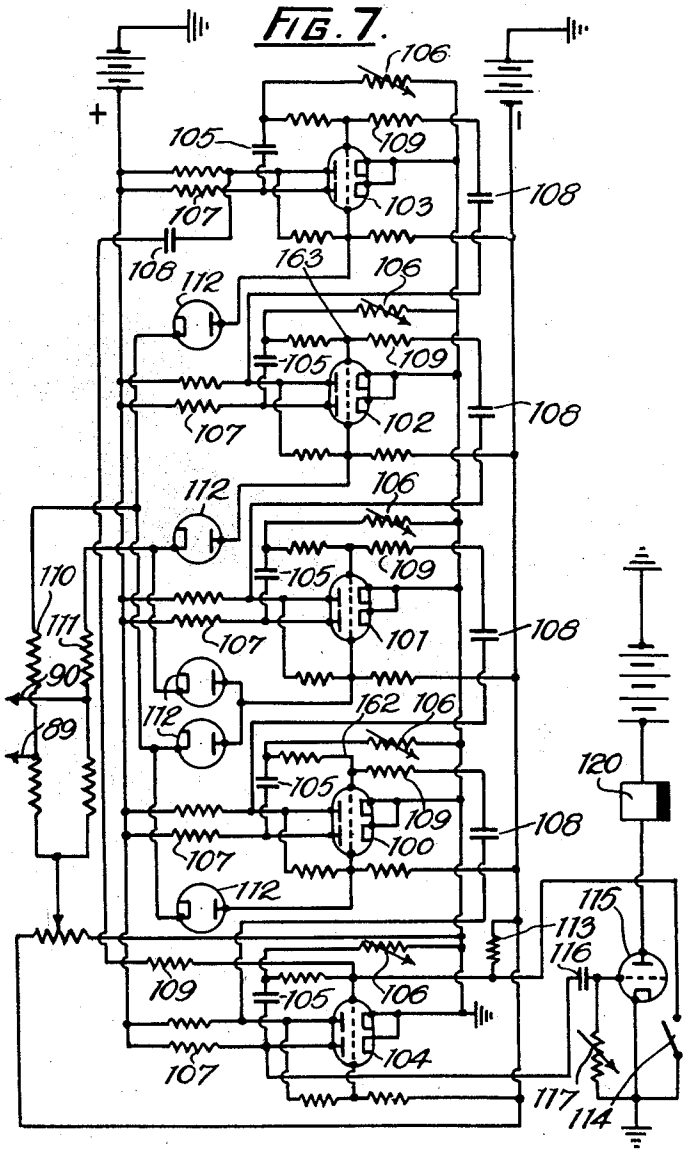

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FIG. 7.



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TUYERE PUNCHES AND LIKE MACHINES

Willem Johannes De Villiers and Denis Bruckman, Kitwe, Northern Rhodesia

Application December 11, 1956, Serial No. 627,604

Claims priority, application Union of South Africa December 12, 1955

10 Claims. (Cl. 15—104.16)

This invention relates to tuyere punches of the kind used to clear fluid passages leading into a mass of molten material in a furnace such as a copper converter.

The most widely used practice in punching tuyeres during the operating cycle of a copper converter involves the use of manual labour. The tuyeres are provided with ball valves. These are displaced by the insertion of a punch rod which is manually reciprocated to clear the tuyere passage. Thus on each converter a number of manual labourers are required.

It has been proposed to replace manual labour with mechanical devices. One such device consists in a pneumatic punching machine arranged to travel from hole to hole like a manual labourer. The disadvantage here is that a furnace seldom keeps to its original shape and that the lining up procedure may be very difficult. In another arrangement a pneumatic machine is mounted at each tuyere. In this case it has been found that the machine operates satisfactorily except at some plants where the slag encountered seems to be of too refractory a nature for existing machines.

A big drawback of pneumatic machines is that constant preventative servicing is necessary and that maintenance costs are high. In fact the maintenance and servicing personnel may be as large as the labour force required for manual punching.

An object of the invention is to provide a machine which allows of faithful service over relatively long periods and which is automatic to a relatively large extent.

In a machine according to the invention a tuyere punch rod is actuated by means of an armature to which a magnetic force is applied at least during the working stroke of the rod. Preferably magnetic forces are applied to the armature on both the working and return strokes of the punch.

Conveniently the magnetic force is applied by means of one or more solenoids (which are preferably iron clad) through which the armature passes. In order to achieve the long stroke necessary, there will usually be at least two solenoids. In the latter case current is applied to one solenoid to start the working stroke and move the armature into the sphere of influence of the next solenoid and the current is switched from the first to the next solenoid while the armature is moving at speed.

Optimum operating efficiency is obtained where the active length of the armature lies between $1.5D+K$ and $2D+K$, where D is the distance between the pole pieces and K is a design constant.

The invention also provides that the armature is built into or forms part of the punch rod.

In the preferred form of the invention the armature length extending beyond the pole pieces of any one solenoid when the armature is in mid-position between the pieces is formed to provide a magnetic path of reducing cross-sectional area as the ends of the armature are approached. As a result the armature continues to exhibit thrust after the longitudinal air gap between a pole piece and the armature has closed. Thus the leading

end of the armature is extended into the sphere of influence of the adjacent solenoid.

To provide the path of reducing cross-sectional area the armature is tapered and preferably by forming conical indentations at its ends. The angle of slope has not been found to be critical and in any case the angle is dictated by design considerations.

With the small space usually available behind tuyeres, it is essential to keep the solenoid dimensions as small as possible. The result is that the solenoids handle large currents for small periods of time. The supply and control of such currents is of prime importance. It has been found that the supply should be in the form of pulses of the required duration and properly phased to give the required thrust characteristics. At the current levels and switching speeds involved, mechanical switches will not have a long life and for that reason it is preferred to control the current supply electronically.

With two coils it is necessary to have a pulse to start movement under the action of the first coil, a pulse in the second coil to take over from the first and also to act as a braking force at the end of the stroke and a third pulse to the first coil to return the rod to its starting position. The invention provides in this case that the coils be fed from two separate supply lines each of which carries the required pulses. Although it is possible to achieve this pulsing by electromagnetic or electronic chokes in a three phase alternating current supply, it is preferred to use direct current with two electronic rectifiers having a common return.

Grid biased rectifiers give the best result, the grids being normally biased to prevent current from flowing and the bias being lifted according to the current pulses required to work the solenoids. The lifting of the grid bias is controlled by electronic timing circuits which also control the switching to the various punching machines in a series.

The invention is further discussed hereunder by way of example with reference to the accompanying drawings, in which:

Figure 1 is a section through a punching machine attached to a tuyere;

Figure 2 is a diagrammatic section through the solenoids and armature section of the machine;

Figure 3 is a graph showing armature movements in the configuration of Figure 2;

Figure 4 is a wiring diagram showing the power supply circuit of the machine;

Figure 5 is a block diagram showing the various electrical circuits;

Figure 6 is a circuit diagram of an arrangement for generating triggering pulses for the power circuit;

Figure 7 is a circuit diagram of the master timing circuit;

Figure 8 is a circuit diagram of the distribution circuit;

Figure 9 is a circuit diagram of an addition to the timing circuit, and

Figure 10 is a circuit diagram of an ancillary circuit.

The machine shown in Figure 1 and its associated circuitry have been designed for use on the tuyeres of a copper converter. The converter has a horizontal line of about fifty tuyeres the centres of which are spaced at six inches so that the maximum outside diameter of each punching machine is 5.75 inches.

Basically the machine consists in two coils **11** and **12** housed in mild steel barrels **13** separated by a mild steel disc **14** which provides a centre pole piece. The ends of the barrels are closed by mild steel plates **15** and **16** (the end pole pieces) which support Phosphor bronze bushes **17**. These bushes act as the bearings and guides for a composite plunger **37** comprising an armature **18** of soft iron which is cone-spigoted on two pieces of non-

magnetic stainless steel 19 and 20 by means of a high tensile steel screwed stud 21, and a punching section 22 secured to the front end of the piece 20. The section 22 is secured by means of a ball and socket connection 23 so that the section 22 has a limited degree of play to follow distorted tuyere pipes and to be pulled loose when stuck.

At the rear the piece 19 has a recessed screwed member 24 which provides an annular projection 25. The piece 19 moves in a rear cover 26 which is adapted to telescope on a pipe 27 projecting from the pole piece 15. The arrangement is such that the projection 25 clears the pipe 27 and abuts against the pole piece 15. At the rear of the pipe 27 there is a cap 28 providing an annular recess 29 having a sloping wall converging forwardly towards the axis of the punch rod. A ball 30 is housed in the recess 29.

If the machine is moved out of its normal working plane, e.g. to tilt the furnace, in the direction of the arrow 31, the ball rolls down the sloping recess 29 and obstructs the projection 25 (see Figure 1) thus preventing the punch rod from moving into the cavity of the furnace. At the same time the telescopic cover 26 moves down until its back contacts the cap 28. The total clearance of the machine while tilting is thus considerably reduced and provided the punch rod is brought to rest at the rear of its stroke, the end 22 cannot drop into the melt in the furnace.

In Figure 1 the outer shell of the converter has been shown as 32, the tuyere pipe as 33 and the air inlet to the tuyere as 34. The machine is secured to the tuyere body over an aperture 35. A ball 36 normally lies in the position indicated but if the machine is removed the ball 36 is caused to move by air turbulence to seal the aperture 35.

The plunger 37 is actuated by means of the two coils 11 and 12. The magnetic circuit involved is diagrammatically illustrated in Figure 2. As shown the armature 18 is at its starting position relatively to the rear pole 15. The dotted line positions are positions relatively to the other poles 14 and 16 of the front end 40 of the armature 18.

The first point to be noted in connection with the magnetic circuit is that the length 38 of the armature 18 is between $1.5D+K$ and $2D+K$ where D is the distance between the centres of the pole pieces 15 and 14 and K is a design constant. The distance between the centres of the pole pieces 14 and 16 is larger than D for reasons indicated below, but in this case also the equation should be satisfied, with the same constant K and D1 being the distance between the poles 14 and 16 the length 38 of the armature must lie between $1.5D1+K$ and $2D1+K$.

Assuming that current be applied to the coil 11 then movement of the leading end 40 of the armature 18 in relation to time is shown in the graph 41 plotted in Figure 3. At about the point 42 (corresponding to dotted line position 42 in Figure 2) the armature will come to rest. If now the coil 11 is de-energised and the coil 12 fed with current, the curve 43 represents further movement of the armature 18. The punching stroke is achieved by a combination of the curves 41 and 43 to the form shown in the curve 44, i.e. an almost sinusoidal stroke may be achieved. The stroke shown in curve 44 is attained by switching off the current in coil 11 when the leading end 40 has passed the pole piece 14 (e.g. at point 45) and applying current to the coil 12. The amplitude of the oscillation will be larger than for coil 11 because the armature possesses the combined kinetic energies imparted by the two coils. If at point 46, the coil 12 be switched off and the coil 11 energised, the armature 18 will again be acted upon by coil 11 and be withdrawn towards its starting position. If current be then switched off at point 47 the plunger 37 moves until its movement is arrested by the cover 26.

The length of the working stroke has been found to depend on the starting point, the distance between pole pieces, the overshoot of the plunger and the timing of the switching.

In practice the switching will be determined by the dynamic response of the machine. The overshoot has been found to depend on the depth of the conical indentations 48 and the starting point may be chosen at will within limits. Thus the stroke of the machine is largely a question of geometry.

The actual length of the coils is determined by the current loading and the desired length of the power stroke. The maximum displacement being dependent only on the length of the armature, the depth of the cone and the starting point, the percentage of the total stroke under power depends on the length of the coil 12. To ensure that at least 75 percent of the plunger stroke is under power the coil 12 has been increased in length relatively to the coil 11 by about one third.

Any suitable form of switching may be used, but there are several important factors that have to be taken into consideration. Firstly the current pulses applied to the coils must be very accurately controlled. Secondly due to space limitations the coils are relatively small and extremely large current densities (of the order of 1500 amps. per square centimetre) are involved. The basic switching problem is then to handle large power pulses for very short but well-defined periods and to ensure that the loading on any one coil is not repeated too often.

By using grid-controlled mercury arc rectifiers the switching problems are simplified to a large extent. The rectifiers serve the functions of converters and contactors. As said above, the use of direct current is preferred for the reason that suitable magnetic materials for the use of alternating current are not easily available.

Figure 4 shows a circuit which was devised to use mercury arc rectifiers of the kind made by the English Electric Company and known as excitrons. In this circuit six excitrons 49 have been arranged in sets of three, each set feeding a supply line 50 or 51 and the sets having a common return 52 in a well known manner. Briefly all the cathodes of the excitrons 49 are connected to the common return 52. The anodes in a set are connected to a secondary 54 of a double wound three phase transformer 53.

In addition to grid control the excitrons have dipping anodes 55 for striking the arcs. Both grid and excitation voltages are provided by separate rectifiers 56 from transformer secondaries 57. The dipping anodes 55 are extracted by excitation chokes 58. Resistances 59 are on-load current limiting resistances and 60 are stabilising resistances. Grid limiting resistances 61 and loading resistances 62 for pulse transformers 70 are also provided.

The excitation current is interrupted by contact 71 in a manner to be described later on.

The arrangement is such that the grids of the excitrons are normally sufficiently biased to prevent the tubes from firing even if the dipping anodes are extracted. The transformers 70 are arranged to provide triggering pulses (by means to be discussed later on) synchronised with the main supply and phased to trigger the excitrons off as the voltage on their anodes rises in the positive direction.

The overall circuit arrangement is shown in Figure 5 where 72 represents the power circuit such as that discussed with reference to Figure 4, 73 represents the pulse generator for providing incipient triggering pulses, 74 represents a timing circuit, 75 a distribution control circuit, and 76 and 77 ancillary circuits. In this scheme the circuit 73 continuously produces trigger pulses, synchronised to the main supply. The timing circuit 74 is arranged to provide gating pulses to the circuit 73 to allow only some of the incipient trigger pulses to pass and become trigger pulses which actuate the excitrons in the circuit 72. The timing circuit is also interlocked

with a distribution circuit **75**, so that gating pulses are only generated when the distribution circuit is in order and so that the distribution connections are made relatively in phase with the gating pulses. The circuit **76** is arranged to act manually or automatically to allow the distribution circuits to operate as and when punching strokes are desired or required. The circuit **77** is arranged to interrupt the distribution circuit when certain predetermined outside conditions are not satisfied or when manually operated for maintenance or other purposes. The circuit **75** also includes a relay which is adapted to close the contacts **71** in the circuit **72**.

If the frequency of the main alternating current supply is at fifty cycles, the frequency of the trigger pulses from the circuit **73** must be at 150 cycles per second. The gating pulses are conveniently of such a nature that the line **50** carries power pulses suitable to energise the coils **11** of a series (say fifty) of punching machines. The line **51** carries the pulses necessary to work the coils **12** of the series. The sequence is then a pulse on line **50** to start an armature **18** moving, a pulse on line **51** to continue such movement and return the armature toward the first coil and finally a pulse on line **50** to move the armature back to its starting position. While the circuit **75** switches over to the next punching machine there is an interval during which neither line **50** or **51** carries any pulses. At the end of a salvo, i.e. when all the machines in a series have been operated to punch, there may be a predetermined delay or the circuit **76** could take over. It is, however, essential that the three power pulses must follow each other in sequence to ensure that a punch rod returns to its starting position and the circuit **77** is therefore so arranged that it can only interrupt a salvo at the end of a set of three power pulses to the same machine. The circuit **75** operates power contactors **78** which close the circuits to the solenoids **11** and **12** just before a set of power pulses is due to arrive and open them just after such power pulses have terminated.

Numerous detailed circuit arrangements are possible to achieve the general conditions outlined above. Figure 6 illustrates a circuit suitable for generating the incipient trigger pulses. A separate three phase secondary winding **79** is wound on one of the excitation transformers **57** (Figure 4) and feeds a bank of star connected germanium diodes **80**. The ripple voltage superimposed upon the rectified voltage is applied inverted to the grid of a triode **81** which modulates a unistable flip-flop circuit comprising triodes **82** and **83**. This circuit is adjusted to pass square waves of a time duration depending on the value of the grid resistance **84**. The 150 cycles per second ripple voltage locks the flip-flop to the third harmonic of the mains frequency.

The resultant square wave pulse is differentiated in the circuit including condenser **85** and resistance **86**, so that its trailing edge develops a positive going pip the phase of which in relation to the ripple pulse is controlled by a variable resistance **87**. These positive going incipient trigger pulses are applied through condensers **88** to the grids of a pair of power amplifiers **89** and **90** to the bias voltage of which is such that they will not normally conduct even in the presence of the incipient trigger pulses. If the bias is reduced by, say fifty volts, the tubes **89** and **90** wil conduct for the period of each incipient trigger pulse. This bias is controlled by gating pulses from the timing circuit to be described later on.

The outputs of the amplifiers **89** and **90** are fed to the transformers **70** described with reference to Figure 4.

A suitable timing circuit for deriving gating pulses is illustrated in Figure 7. This circuit is well known in the art and fundamentally consists in what are known as univibrator circuits. The circuit therefore includes pairs of triodes, the pairs being numbered **100** to **104**. The members of each pair are so interconected that they provide a unistable circuit. Normally, i.e. in the stable state, the one tube conducts and the other does not. When a negative going signal is applied to the grid of the conducting tube (the right hand one in th drawings) its anode potential will rise thus progressively reducing the bias of the second or left hand tube until the bias exceeds the cut-off potential of the second tube. If the input signal is sufficiently large in amplitude the second tube begins to conduct. This results in a violent feed back between the tubes causing the grid of the first tube to be depressed to the full of the change of voltage on the condenser **105** between the anode of the first tube and the grid of the second tube, thus cutting off the first tube and attempting to raise the potential of the second tube. The pair remains in this condition until the charge on the condenser **105** gradually leaks away through a variable resistance **106** and a resistance **107**. As soon as the potential of the first tube passes the cut-off point, violent feed back again results and rapidly restores the circuit to the normal stable state.

The period of the quasi-stable state depends on the supply voltage, the load resistance of the tubes and the coupling time constant of the condenser **105** and the resistance **106** and **107**.

As shown the anode of the first tube in a pair is connected to the grid of the first tube of the next pair of the five pairs via a small capacitance **108** and a large resistance **109** for the next pair to trigger into the unstable state as soon as the former pair returns to the stable state. In this way the pair **100** triggers the pair **101** and so on to the fifth stage **104** which in turn starts the cycle. It should be noted that the values of the various resistances are so chosen that a stage cannot trigger any stage beyond the next stage.

The grid voltage of the left hand tube of each of the stages **100** and **103** is applied to a potential divider **110** which feeds the grid of the power amplifier **89** (see Figure 6) with the result that only if the stages **100** and **103** are in the unstable state, the tube **89** allows current to pass through its transformer **70**. Likewise the grids of the left hand tubes of the stages **101** and **102** are connected to a potential divider **111** which feeds the tube **90**.

Diodes **112** are provided to prevent paralleling of the grid circuits of the timing circuits.

The output from stage **103** is fed to stage **104** which is the interval timing stage. The latter is arranged for a much longer quasi-stable state to provide the time interval for switching from one punching machine on to the next. The right hand grid of stage **104** is also permanently conected to a negative supply potential through a resistance **113** and to ground through a pair of contacts **114**. The latter form part of the interlock with the distribution circuit discussed below. It should at this stage be noted that if the contacts **114** are bridged, the stage **104** operates in the normal way. With the ground point removed, this stage is held in the unstable state. By operating the contacts **114** gating pulses may be initiated or stopped at will but only in complete batches.

Stage **104** also feeds into a further stage consisting of a single tube **115** which works in tanden with it. The tube **115** cuts off with the second tube of stage **104** to de-energise a relay **120** in the distribution circuit. As soon as the time delay involved in the circuit including a condenser **116** and a variable resistance **117** allows, the relay **120** is re-energised.

Depending on the number and time intervals of the individual timing stages in the circuit, so a wide variety of output pulses may be applied to the power amplifiers **89** and **90**. It has been found in practice that good punching results are obtained by arranging stage **100** to gate five trigger pulses, stage **101** one such pulse, stage **102** eleven pulses and stage **103** five pulses. The fifth stage **104** is arranged to give a delay to suit the reaction time of the distribution circuits. In each situation it is best to determine the correct timing by experiment.

The time delay of branch stage **115** is conveniently arranged to be about fifty milliseconds.

As said above the distribution circuit (Figure 8) includes the relay **120**. This relay when energised closes pairs of contacts **121** and **123** and opens contacts **122**. A second relay **124** closes three pairs of contacts **125**, **126** and **127** and the pair **114** discussed with reference to the timing circuit. There is also a third relay **128** which locks itself to ground through contacts **138**, closes a pair of contacts **130** and moves a contactor arm **131** from the position shown to a position where it puts a selector **132** in circuit.

The relay **124** is connected to a uniselector the arm **133** of which sweeps across a bank of contacts **134** (the first one) and **135** of which there are as many as there are punching machines. The uniselector **133** and the selector **132** if it is of the traction type are driven by magnets **136**. The contact **127** is in circuit with a relay **137** which closes the contacts **71** referred to with reference to Figure 4.

The circuit **76** includes means to complete it for the purpose of initiating a salvo or a train of salvos. The circuit **77** includes various means for interrupting a salvo or a train of salvos.

Starting from the position where the selector arm **133** connects the contact **134**, if the circuits **76** and **77** are completed, the relay **124** is energised by being connected to ground. This relay then locks itself to ground by means of the contacts **125** (which it closes) and the contacts **123** which are normally held closed by the relay **120**. At the same time the contacts **114** are closed to initiate the timing circuit to start a train of power pulses. The relay **124** also closes the contacts **127** which by means of the relay **137** close the excitation contacts **71**. The other contacts **126** governed by the relay **124** are also closed, but the relay **128** remains de-energised as the relay **120** holds the contacts **122** open.

As the first timing cycle is completed, the relay **120** is momentarily de-energised and the contacts **122** close to energise the relay **128**, so that the arm **131** moves to connect the selector **132** in circuit, the contact **130** is closed in the circuit of the magnets **136** of the selectors **133** and **132** and the contacts **138** are bridged to by-pass the contacts **122**.

If the circuit **77** remains complete, the relay **124** remains closed and a second cycle begins. In this cycle the selector **132** actuates a line contactor **78** (Figure 5) to connect the coils **11** and **12** of the first punching machine to the power supply lines **50** and **51**. At the end of the cycle the relay **120** on being momentarily de-energised again causes the relay **128** to close and step on the selectors. If the contact **135** in question is still connected to ground via the circuit **77** the next cycle proceeds and so on until all the contacts **135** in the bank have been wiped by the arm **133**. The latter now again proceeds to the contact **134** and if the circuit **76** is now open the relay **124** which has no ground connection when the relay **120** is momentarily de-energised, drops out and punching stops until such time as the circuit **76** is again completed. If for any reason the circuit **77** is interrupted at any time during a salvo, the relay **124** will act in the same way, but only at the end of a cycle.

The contactor arm **131** is initially connected to a relay **129** which when energised actuates a contactor to connect a dummy load across the lines **50**, **51** and **52**. Thus whenever the relay **124** has dropped out, at the end of a salvo or as a result of an interruption of a salvo, the dummy load is first connected to the power supply before punching machines are connected in circuit. The arms **133** and **131** are prevented from moving as the relay **128** is not energised. Thus the excitrons **49** have time to settle down before being called upon to operate a punching machine. After the first power pulses, the relay **120** is momentarily de-energised and the relay **128** comes into operation and remains energised as long as the relay **124** is energised. The selectors **133** and **132** are stepped on by opening and closing the contacts **121**.

In order to ensure that the line contactors do not open before the heavy current impulses to the punching machine coils have terminated, the contacts of the relay **120** are arranged to have a ten millisecond delay on opening.

The circuit **77** includes various means for stopping punching operations. Thus there may be manual switches at the main control room and on strategic points at the punching site. Furthermore where air pressure drops below a predetermined minimum it is desirable to stop punching altogether. For this purpose a pressure switch operating on this low pressure is included in the circuit. As it is also undesirable, in the case of a rotary converter to punch during tilting, the circuit also includes a mercury tilt switch on the converter as well as a limit switch on the tilting motor brake arranged to open while the motor is in motion. Any of these switches will immediately stop the next punching cycle and a salvo will be completed only if the stop circuit **77** is again completed.

For initiating a salvo a timing clock may be arranged to operate the circuit **76**. A suitable arrangement is shown in Figure 10. In this case salvo frequency is determined by overall air flow to the tuyere. Differential pressure switches **140**, **141** and **142** are arranged to be responsive to different minimum volumes of air flow and on such minimum flow being reached each allows a pair of contacts **143**, **144** and **145** respectively to close. The switch **140** is responsive to a predetermined low air flow, switch **141** to an intermediate and the switch **145** to a relatively high flow of air. The contacts **143**, **144** and **145** are included in parallel circuits which also include spring contacts **146** which are held open by cams **147**, **148** and **149**. The cams have notches to allow closing of the contacts **146** depending on the speed at which the cams are rotated by the motor **150** of a timing clock. If the switch **140** allows the contacts **143** to close, the overall initiating circuit by means of the cam **147** with four notches will be closed four times per revolution of the motor **150**. The switch **141** and the cam **148** closes the circuits twice and the switch **142** and the cam **149** once only.

Thus the cams in sequence initiate a lesser number of salvos per revolution of the motor **150** until at a predetermined maximum flow the punching machines remain inoperative.

It has been found that there is a dip in the back E.M.F. developed by the coils **11** and **12** as they are straddled by the armature **18**. This fact may be utilised for automatically switching the coils. A suitable circuit is illustrated in Figure 9. In this case the coil (say **11**) is connected to the power supply lines **50** and **52** through a resistance **151**. Two further resistances **152** and **153** are connected between the lines in series with one another and in parallel with the resistances **11** and **151**.

The ratio of the resistance of the coil **11** to the reistance **151** is the same as that of the reistance **153** to the resistance **152**. The centre point between the resistances **11** and **151** is connected to a coincidence differential circuit comprising a high tension supply, a limiting resistance **154**, a resistance **155** across which the volt drop is the co-incidence circuit differential, two rectifiers **156** and **157**, a condenser **158** and two further resistances **159** and **160**. The centre point of the reistances **152** and **153** is connected to ground as shown. Normally the point **161** is at zero potential. When a change of back E.M.F. of a predetermined magnitude takes place a pulse having the voltage of the co-incident circuit differential is formed at **161**. This pulse may be injected at point **162** in Figure 7 in order to step the timing sequence on. If this circuit is used the timing circuits are set at longer intervals than usual, but these would be automatically shortened by the back E.M.F. characteristic.

A similar circuit could be used for coil **12** and the resulting pulse injected at a point such as **163**. In this case the timing circuit of the pair of triodes **101** must gate that portion of the pulse which performs the forward stroke in coil **12** and the timing circuit of the pair of triodes **102** must control the return stroke.

By using the circuits of Figure **9** the velocity of the plunger **37** is maintained at a maximum level. Furthermore if an encrustation is encountered in a tuyere pipe the machine automatically adjusts its stroke to suit the free length of the tuyere pipe. In other words the machine automatically assesses the conditions encountered by the plunger **37** and adjusts the power pulses accordingly.

Instead of the timing circuit shown in Figure 7, a circuit employing dekatron tubes may be used. In this case the pips developed in the circuit of Figure 6 are fed to the grids of the dekatron tubes and required groups of dekatron cathodes are connected to the grids of the power amplifiers **89** and **90**. Dekatron tubes may also be used as the selector **132** (Figure 8) and in this case the power to the line contactors **78** is supplied by thyratron tubes the grids of which are connected to the dekatron cathodes.

The punching machine provided by the invention gives satisfactory service under most difficult conditions. A stroke as long at 12.5 inches has been maintained with the machine.

We claim:

1. Tuyere punching apparatus including a series of punching machines each of which has a punch rod, an armature of magnetic material forming part of the punch rod, and a forward and a backward solenoid surrounding the path of the armature, the armature comprising a main portion of substantially uniform cross-sectional area and hollow tapering ends of sufficient length so that by means of the continual increase of cross-sectional area after a solenoid has been bridged, the armature continues to have thrust in the direction of its leading end and while current is flowing in the first solenoid; including two current supply lines, a common return to the supply lines, means to switch any one machine from the series to the supply lines so that when a machine is thus switched the backward coil is connected to the first line and the forward coil to the second line, means to supply current pulses to the supply lines after a machine has been switched to the lines, the current pulses being such that a first pulse in the first line causes the backward solenoid to move the armature from a starting position into the sphere of action of the forward coil, a second pulse in the second line follows the first pulse immediately to cause the forward solenoid to move the armature to the end of the working stroke of the rod and to return the armature into the sphere of action of the backward coil and a third pulse in the first line follows the second pulse immediately to move the armature back to its starting position, the switching means being arranged to connect the machines to the lines in turn.

2. The apparatus claimed in claim 1 including two groups of grid biased power rectifiers connected to an alternating current supply, one group being connected to the first line and the other to the second line, and means to generate trigger pulses to lift the bias of the grids to the power rectifiers in phase with the required supply current pulses.

3. The apparatus claimed in claim 2 including a pair of secondary grid biased rectifiers for supplying the trigger pulses to lift the bias of the grids to the power rectifiers, means for generating incipient trigger pulses in phase with the alternating current supply of the power rectifiers, the incipient pulses being so phased that if they were of sufficient amplitude to allow the members of the rectifier pair to conduct, trigger pulses for each half cycle of the alternating current supply would be provided, but being of insufficient amplitude to lift the bias of the grids of the pair sufficiently for the pair to conduct, and means to generate gating pulses interlocked with the switching means which added to the incipient trigger pulses allow the members of the pair of conduct and to provide a predetermined pattern and number of trigger pulses to the power rectifiers.

4. The apparatus claimed in claim 3 in which the gating pulses are so interlocked with the switching means that each machine is switched to the lines before the first power pulse arrives and disconnected from the lines after the third power pulse has terminated.

5. The apparatus claimed in claim 4 including a stop circuit so connected with the gating pulse generating means that on the stop circuit being open the gating pulse generating means only supplies gating pulses to operate that machine which is then connected to the lines to the position of rest of the armature.

6. The apparatus claimed in claim 4 including means sensitive to the flow of air to the tuyeres to cause the gating pulse generating circuit to operate.

7. The apparatus claimed in claim 1 in which the switching means and the current supply means are so interlocked that each machine is switched to the lines before the first pulse arrives and disconnected from the lines after the third pulse has terminated.

8. In combination a series of identical linear electric motors each of which has a thrust arm, an armature of magnetic material forming part of the arm, at least two solenoids surrounding the path of the armature, current supply lines equal in number to the number of solenoids in a motor, a common return for the supply lines, means to switch any one motor of the series to the supply lines so that its solenoids are connected to the lines in a predetermined sequence common to all motors, means to supply current pulses to the supply lines after a motor has been switched to the lines, the current pulses being such that a first pulse in the first line causes the backward solenoid to move the armature from a starting position into the sphere of action of an adjacent solenoid, following pulses in the other lines follow the first pulse and one another immediately to cause the adjacent solenoid and following solenoids to move the armature towards the end of the thrust stroke of the arm and the pulse to the forward solenoid acting also to initiate movement of the armature in the reverse direction, pulses follow in reverse order and the final pulse to the backward solenoid moves the armature back to its starting position, the switching means being arranged to connect the motors to the lines in turn.

9. In combination a series of identical linear electric motors each of which has a thrust arm, an armature of magnetic material forming part of the arm, two solenoids surrounding the path of the armature, a current supply line for each solenoid, a common return for the supply lines, means to switch any one motor from the series to the supply lines so that its solenoids are connected to the lines in a predetermined sequence common to all motors, means to supply current pulses to the supply lines after a motor has been switched to the lines, the current pulses being such that a first pulse in the first line causes the backward solenoid to move the armature from a starting position into the sphere of action of the forward solenoid, a second pulse in the second line follows the first pulse immediately to cause the forward solenoid to move the armature to the end of the working stroke of the armature and to return the armature into the sphere of action of the backward coil and a third pulse in the first line follows the second pulse immediately to move the armature back to its starting position, the switching means being arranged to connect the motors to the lines in turn.

10. Tuyere punching apparatus including a series of identical punching machines each of which has a punch rod, an armature of magnetic material forming part of the punch rod, at least two solenoids surrounding the path

of the armature, current supply lines equal in number to the number of solenoids in a machine, a common return for the supply lines, means to switch any one machine of the series to the supply lines so that its solenoids are connected to the lines in a predetermined sequence common to all machines, means to supply current pulses to the supply lines after a machine has been switched to the lines, the current pulses being such that a first pulse in the first line causes the backward solenoid to move the armature from a starting position into the sphere of action of an adjacent solenoid, a following pulse in another line follows the first pulse immediately to cause the adjacent solenoid to move the armature towards the end of the working stroke, and a pulse in the last line connected to the forward solenoid follows immediately on the pulse for the solenoid adjacent the forward solenoid to cause the forward solenoid to move the armature to the end of the working stroke of the rod and to reverse the direction of movement of the armature, pulses are fed to the solenoids in reverse order to the working stroke and the final pulse to the backwards solenoid moves the armature back to its starting position, the switching means being arranged to connect the machines to the lines in turn.

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