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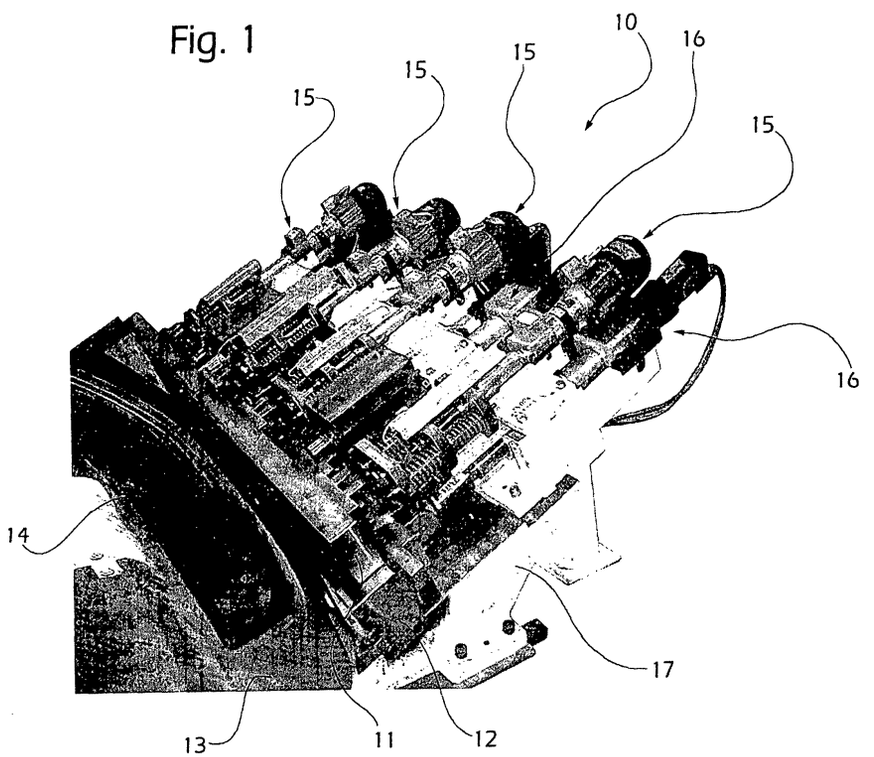
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(54) Numeric control machine for the cold forming of sheet metal parts

(57) The machine (10) comprises a blankholder (11) and a tool (12) for applying a clamping force and a forming force, respectively, on the sheet metal part (13) to be worked, and a drive system (15, 16) for moving the blankholder (11) and the tool (12). The drive system includes: first and second electro-mechanical actuator devices (15, 16) for controlling the motion of the blankholder (11) and of the tool (12), respectively; sensor means (34, 35, 36, 37) associated to the said first and second actuator devices (15, 16) for sensing the linear position thereof and/or the force applied thereby and for providing signals representative of the sensed measures; and a control unit (40) for receiving as input the signals coming from the said sensor means (34, 35, 36, 37) and for producing as output command signals for the actuator devices (15, 16) as a function of the said input signals, according to a closed loop control configuration.

Fig. 1



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Description

[0001] The present invention relates to a machine for the cold forming of sheet metal parts, for example for carrying out flanging and/or restriking and/or trimming and/or drilling operations.

[0002] Conventionally, for the working of sheet metal parts presses are employed in which the forces required to deform the parts being worked are produced either by mechanical members, possibly coupled with a flywheel acting as storage of energy (mechanical presses), or by pressurized liquids acting on one or more jacks (hydraulic presses). These two kinds of drive are determined by the high forces required for carrying out such workings (around tens or hundreds of tons).

[0003] The main advantages offered by the use of presses for the cold forming of sheet metal parts reside in the possibility to apply extremely high forces (up to thousands of tons) and to work with very fast production rate, as it is required in great series productions, such as those intended for example for the automotive industry. On the other hand, the presses are still very expensive and hardly flexible machines. In particular, as far as the latter aspect is concerned, it is necessary to point out that the presses do not allow an online control of the working process, that is, they do not offer the possibility to act on the process parameters in order to react to possible production drifts.

[0004] It is therefore the object of the present invention to provide a machine for the cold forming of sheet metal parts that can overcome the shortcomings of the prior art discussed above, offering a high operational flexibility and the possibility to control the process parameters in real time.

[0005] This and other objects are achieved according to the present invention by a machine having the characteristics defined in appended Claim 1.

[0006] In short, the invention is based on the idea of providing a machine for the cold forming of sheet metal parts provided with electrically-operated linear actuator devices for driving the blankholder and the forming tool, which devices are controlled in force and position by a feedback control system.

[0007] The characteristics and the advantages of the invention will result clearly from the detailed description which follows, given purely by way of non-limiting example, with reference to the attached drawings, in which:

Figure 1 is a perspective view that shows a whole embodiment of a numeric control machine for the cold forming of sheet metal parts according to the invention, suitable in particular for carrying out flanging operations;

Figure 2 is a prospective view that shows in detail the blankholder and the punch of the machine of Figure 1;

Figure 3 is a top perspective view that shows the whole system of electromechanical drive of the blankholder and the punch in the machine of Figure 1;

Figures 4 and 5 illustrate schematically the structure of the linear actuator devices arranged to move the blankholder and the punch of the machine of Figure 1;

Figure 6 is a perspective view that shows in detail a load cell and a position transducer associated to one of the linear actuator devices for moving the punch of the machine of Figure 3;

Figure 7 illustrates schematically the architecture of the machine of Figure 1; and

Figure 8 shows the block diagram of the simulation software used to implement the control algorithms intended to manage the operation of the machine of Figure 1.

[0008] In Figure 1 there is shown a numeric control machine for the cold forming of sheet metal parts according to the present invention, generally indicated 10. In the illustrated embodiment, the machine is arranged to carry out flanging operations, in particular to fold and form edges of sheet metal body sides of motor vehicles. Evidently, such application is definitely not to be intended as limiting the field of application of the invention. On the contrary, given the high degree of flexibility offered by the proposed configuration, a machine according to the invention can be used, with appropriate measures, to carry out any other cold forming operations on sheet metal parts.

[0009] The machine 10 includes, in per-se-known manner, a blankholder 11 for holding the metal sheet component to be worked, in this case a body side 13 of a motor-vehicle, on a die 14 (partially illustrated in Figure 2), and a punch 12 for plastically deforming a portion of the component 13, in this case an upper edge, in cooperation with the die 14.

The blankholder 11 and the punch 12 are each driven by a set of electromechanical linear actuator devices 15 and 16, in the illustrated example four actuator devices 15 for the blankholder and five actuator devices 16 for the punch, installed on a support structure 17. In the illustrated example the two sets of actuator devices 15, 16 are disposed parallel to each other. However, it is possible just the same any other configuration in which the sets of actuator devices are inclined with respect to each other. As it will be better explained in the following part of the description, the use of a plurality of actuator devices for the blankholder and for the punch offers the advantage of controlling the force exerted along the profile of the piece being worked.

[0010] The actuator devices 15 for driving the blankholder 11 include each a screw linear actuator 18, a three-phase induction electric motor 19 for driving the actuator 18 through a reduction gear 20 (for example a planetary reduction gear or a worm gear), and a power inverter of per-se-known type (not illustrated) for supplying the electric motor 19. In the illustrated embodi-

ment, the actuator devices 15 are each able to apply a maximum force of 8.000 N with a stroke of 200 mm at a speed of 5 mm/s.

[0011] The actuator devices 16 for driving the punch 11 include each a ball screw linear actuator 21, a three-phase brushless electric motor 22 for driving the actuator 21 through a reduction gear 23 (a planetary reduction gear or a worm gear), and a power inverter of per-se-known type (not illustrated) for supplying the electric motor 22. In the illustrated embodiment, the actuator devices 16 are each able to apply a maximum force of about 50.000 N with a stroke of 200 mms at a speed of 5 mm/s.

[0012] Therefore, the maximum forces which can be applied on the blankholder and on the punch, respectively, amount altogether to 32.000 N, or about 3.200 kg, and to 250.000 N, or about 25.000 kg, which values are comparable to those usually achieved in the hydraulically-operated machines mentioned in the introductory part of the description.

[0013] The use of three-phase brushless electric motors and of ball screw linear actuators for the actuator devices 16 intended to drive the punch 12, although not essential, is however preferred in comparison to less expensive solutions, as it ensures the possibility of fine adjustment both of the stroke and of the force of each actuator. On the other side, as far as the drive of the blankholder 11 is concerned, as function of this latter is simply to ensure a minimum force to hold the sheet metal component to be worked, without particular requirements of modulating or modifying the applied forces during the work cycle, a less expensive solution can be easily used, for example the screw actuators illustrated with reference to the present embodiment. However, it is possible to use, for both the blankholder and the punch, other kinds of electric motors, reduction gears and linear actuators than those here described and illustrated, depending on the required operational specifications of the particular application.

[0014] Every linear actuator 18 includes, in per-se-known manner, an axially slideable rod 24 connected at its free end to the blankholder 11 through a ball joint 25. Likewise, every linear actuator 21 includes an axially slideable rod 26 connected at its free to the punch 12 through a ball joint 27.

[0015] Moreover, as observable in the schematic illustration of Figure 4 and in the detail view of Figure 2, every linear actuator 18 is provided with a spring compensation device, generally indicated 28, for compensating possible load variations on the rod during the working. In the illustrated embodiment, the device 28 includes four coil springs 29 mounted two by two in series around a pair of guide rods 30 (partially visible in Figure 2). The guide rod 30 of the springs 29 extend beside the rod 24 of the actuator 18, parallel to this latter, between a pair of plates 31 and 32 fixed to the body and to the rod of the actuator 18, respectively. A first pair of springs 29 are interposed between the plate 31 fixed to the body of the actuator 18 and a further intermediate plate 33 axially slideable along the guide rods 30. Conversely, the second pair of springs 29 are interposed between the intermediate plate 33 and the plate 31 fixed to the rod 24 of the actuator 18.

[0016] Every linear actuator 18 is also provided with a pair of linear position transducers 34, 35, arranged to provide both a measure of the linear deformation of the spring package 29, from which to indirectly obtain the measure of the force applied by the rod 24 on the blankholder 11, and a measure of the position of the rod 24.

[0017] Conversely, the linear actuators 21 associated to the punch 12 are each provided with a force transducer 36, such as a load cell, adapted to provide a direct measure of the force applied by the rod 26 on the punch, and with a respective linear position transducer 37 adapted to provide a measure of the position of the rod 26. The measures provided by the load cell 36 and by the position transducer 37 are processed by a control unit of the machine, as will be explained in detail afterwards, in order to control the actuator devices 16 by means of appropriate load- or position-feedback control logics depending on the step of the work cycle.

[0018] As schematically illustrated in Figure 7, an electrical cabinet 40 is associated to the machine 10, which cabinet contains the power drives and the electrical signal conditioning and the machine control unit. Command signals leave the cabinet 40, through electrical connections 41, for the electric motors 19, 22 of the actuator devices arranged to move the blankholder 11 and the punch 12. Signals coming from the force and the position transducers associated to the actuators 18, 21 arrive at the cabinet 40 through electrical connections 42 (one of such connections, associated to the load cell of an actuator 21 for driving the punch, is visible in Figure 6). The electrical cabinet 40 is also operatively connected to a computer 43 which acts as operator interface to the machine and allows both the control of the actuator devices 15, 16 that drive the blankholder 11 and the punch 12 and the processing of the data coming from the force and position 34-37 sensors associated to the actuators.

[0019] The work cycle comprises essentially the following steps:

a) bringing of the blankholder 11 and the punch 12 near the component 13;
b) clamping of the component 13 on the die 14 by means of the blankholder 11;
c) flanging of the component 13 to be worked by means of the punch 12;
d) removing of the punch 12 from the worked component 13;
e) moving of the punch 12 out of the working zone;
f) releasing of the component 13 by removal of the clamping action of the blankholder 11; and
g) return of the blankholder 11 and of the punch 12 to the initial position.

[0020] This work cycle is automatically operated by the machine control unit. Also the further steps of loading of the sheet metal component 13 to be worked on the die 14 and of unloading the worked component 13 can be automatically carried out by means of automatic loading/unloading devices of per-se-known type, such as for example robotic arms (not illustrated), in order to decrease the overall duration of the work cycle.

[0021] The control system of the machine can be advantageously realized by means of a rapid prototyping system, which allows fast implementation and debugging of the control algorithms, which are at first verified through simulation and then implemented in real time on the plant.

[0022] With reference to Figure 8, the simulation program of the machine provides for:

a first block 101 which represents the model of the control system and is realized for example into Simulink® software,

a second block 102 which represents the model of the actuator devices 15, 16 and is also realized for example into Simulink® software, and

a third block 103 represents the model of the blankholder 11, of the punch 12 and of the metal sheet component 13, and is realized for example into Adams® finite element simulator from MSC Software Inc., associated to MotionView® pre- and post-processing software from the applicant.

[0023] The block 101 (control system) receives as input data the force and the position of the punch coming from the block 103 (blankholder - punch - component to be worked), as well as predetermined reference values, processes such data according to the implemented control algorithms and sends proper control signals to the block 102 (actuators) for controlling the actuators of the blankholder and of the punch. The block 102 receives as input the control signals produced by the block 101, as well as information relating to the speed of the punch sent by the block 103, and sends as outputs to the block 103 the data associated to the actuation force of the blankholder and to the blocks 101 and 103 the data associated to the actuation force of the punch. Finally, the block 103 receives as input the actuation forces of the blankholder and of the punch and computes the position and the speed of the punch, which are sent to the blocks 101 and 102, respectively.

[0024] The control and management logics of the flanging machine aims to achieve a high degree of flexibility of use and configuration, both through manual settings and through the possibility to implement expert systems capable to carry out a quality control of the process.

[0025] To this end, feedback-controlled and distributed actuators have been used, which can be driven independently, although co-ordinately. In fact, it is necessary for the actuators to be driven according to force or position references different from each other, depending on the step of the process. For example, during the movement steps (closing and opening) all the actuators must be aligned, so as to avoid blocks of the punch and/or of the blankholder. Therefore, these steps provide for the control system to compute the proper current and/or speed references for the different actuators, thereby ensuring a limited maximum offset. Possible misalignments may actually occur due to the load distribution associated to geometric factors, for example, but also to more hardly quantifiable and predictable reasons, such as frictions. The drive control system is though able to compensate for such disturbances, by continuously verifying all the position measures (and possibly also the force measures, for safety reason).

[0026] Moreover, as far as the real forming step is concerned, a flexible control system as the proposed one allows the operator to set different work forces and/or different work depths. This allows to act simply on the control parameters via software in order to set up the machine, rather than rely on time consuming and expensive workings. The control system provides for a set of parameters, independent for each actuator, which can be set within certain limits defined in the calibration phase. The operator has an easy-to-use graphic interface, provided by the computer 43, which allows to set the aforementioned parameters and to visualize the trends of the quantities of interest in each working. In this way it is possible to analyze in real time the progress of the manufacturing process and, if necessary, to compensate, either automatically or with the operator's consent, possible production drifts (for example, variations in the sheet metal thickness, either local or general).

[0027] The force and position measurements necessary to the control feedback can be obtained directly, as in the case of the above-described machine, but can also be indirect, for example achieved by means of software-implemented observers which exploit measures already available for the motor. This second option offers the advantage of reducing the costs of the control system hardware, but involves a greater complexity in the control algorithms and in the signal conditioning.

[0028] In the illustrated embodiment, the overall duration of the machine working cycle is around 2'30". Such duration is mainly related to the motion speed of the linear actuators, which depends in its turn on the type of electric motors used to drive the actuators. Using electric motors with higher performances and actuators able to operate at higher motion speed, it is obviously possible to reduce the cycle duration. A machine according to the invention, therefore, turns out to be suitable especially for the production of small series, for example several tens of worked parts per day. It is clear, however, that the values indicated above may change even widely according to the sizing of the drive system

that controls the blankholder and the punch.

[0029] In the light of the previous description, it is apparent that a numeric control machine for working sheet metal parts according to the present invention offers the following advantages:

- it is a equipment which can be reconfigured depending on the type of operation to be performed and/or on the type of component to be worked;
- it allows to perform the setting up in a simple and precise manner by virtue of the information coming from the position and force sensors associated to the actuators controlling the blankholder and the punch;
- it allows to reduce the preproduction time and to control the process in real time by virtue of the force- and position-feedback control and of the possibility of implementing more sophisticated work cycle control logics;
- it allows to quickly act on the working process parameters to effectively compensate for possible production drifts;
- it offers the possibility of automating in an easier way the operations of load and unloading of the parts to be worked, by virtue of the absence of the encumbrances typical of the conventional presses;
- it allows to adjust along the profile of the work piece the force exerted by the tool which causes the deformation of the piece.

[0030] Naturally, the principle of the invention remaining unchanged, embodiments and manufacturing details may vary widely with respect to what has been described and illustrated purely by way of non-limitative example, without thereby departing from the scope of protection of the present invention defined by the attached claims. In particular, although the description and the figures refer to a flanging machine, it is clear that a machine according to the invention can be arranged to carry out any other cold working by plastic deformation, as well as cutting or blanking operation, just by virtue of its extreme flexibility of structure and operation.

Claims

1. Machine (10) for the cold working of sheet metal parts (13), particularly for folding or flanging operations, comprising a blankholder (11) and a tool (12) for applying a clamping force and a forming force, respectively, on the sheet metal part (13) to be worked, and a drive system (15, 16) for moving the blankholder (11) and the tool (12), **characterized in that** the said drive system includes:
   - first and second electro-mechanical actuator devices (15, 16) for controlling the motion of the blankholder (11) and of the tool (12), respectively;
   - sensor means (34, 35, 36, 37) associated to the said first and second actuator devices (15, 16) for sensing the linear position thereof and/or the force applied thereby and for providing signals representative of the sensed measures; and
   - a control unit (40) for receiving as input the signals coming from the said sensor means (34, 35, 36, 37) and for producing as output command signals for the actuator devices (15, 16) as a function of the said input signals, according to a closed loop control configuration.
2. Machine according to Claim 1, **characterized in that** the said first and second electromechanical actuator devices (15, 16) for controlling the motion of the blankholder(11) and of the tool (12), respectively, comprise each a mechanical linear actuator (18, 21) and an electric rotary motor (19, 22).
3. Machine according to Claim 2, **characterized in that** the linear mechanical actuators (18) of the first actuator devices (15) are screw actuators.
4. Machine according to Claim 2, **characterized in that** the linear mechanical actuators (21) of the second actuator devices (16) are ball screw actuators.
5. Machine according to Claim 2, **characterized in that** the electric rotary motors (19) of the first actuator devices (15) are three-phase induction motors.
6. Machine according to Claim 2, **characterized in that** the electric rotary motors (19) of the first actuator devices (15) are three-phase brushless motors.
7. Machine according to Claim 1, **characterized in that** the sensor means associated to each of the said first actuator devices (15) comprises a spring device (28) arranged to be deformed depending on the force applied by the actuator device (15) on the blankholder (11) and a position sensor (35) for sensing the deformation of the spring device (28), so as to provide an indirect measure of the force applied by the actuator device (15) on the blankholder (11).
8. Machine according to Claim 1, **characterized in that** the sensor means associated to each of the second actuator devices (16) comprise a linear position transducer (37) for sensing the instantaneous

position reached by the actuator device (28) and a load cell (36) for sensing the instantaneous force applied by the actuator device (16) on the tool (12).

9. Machine according to Claim 1, **characterized in that** the said control unit (40) is arranged to receive as input a series of control parameters which can be set by the operator and to control the said first and second electromechanical actuator devices (15, 16) according to these control parameters.

10. Machine according to Claim 9, **characterized in that** the said control parameters can be independently set for each of the said first and second actuator devices (15, 16).

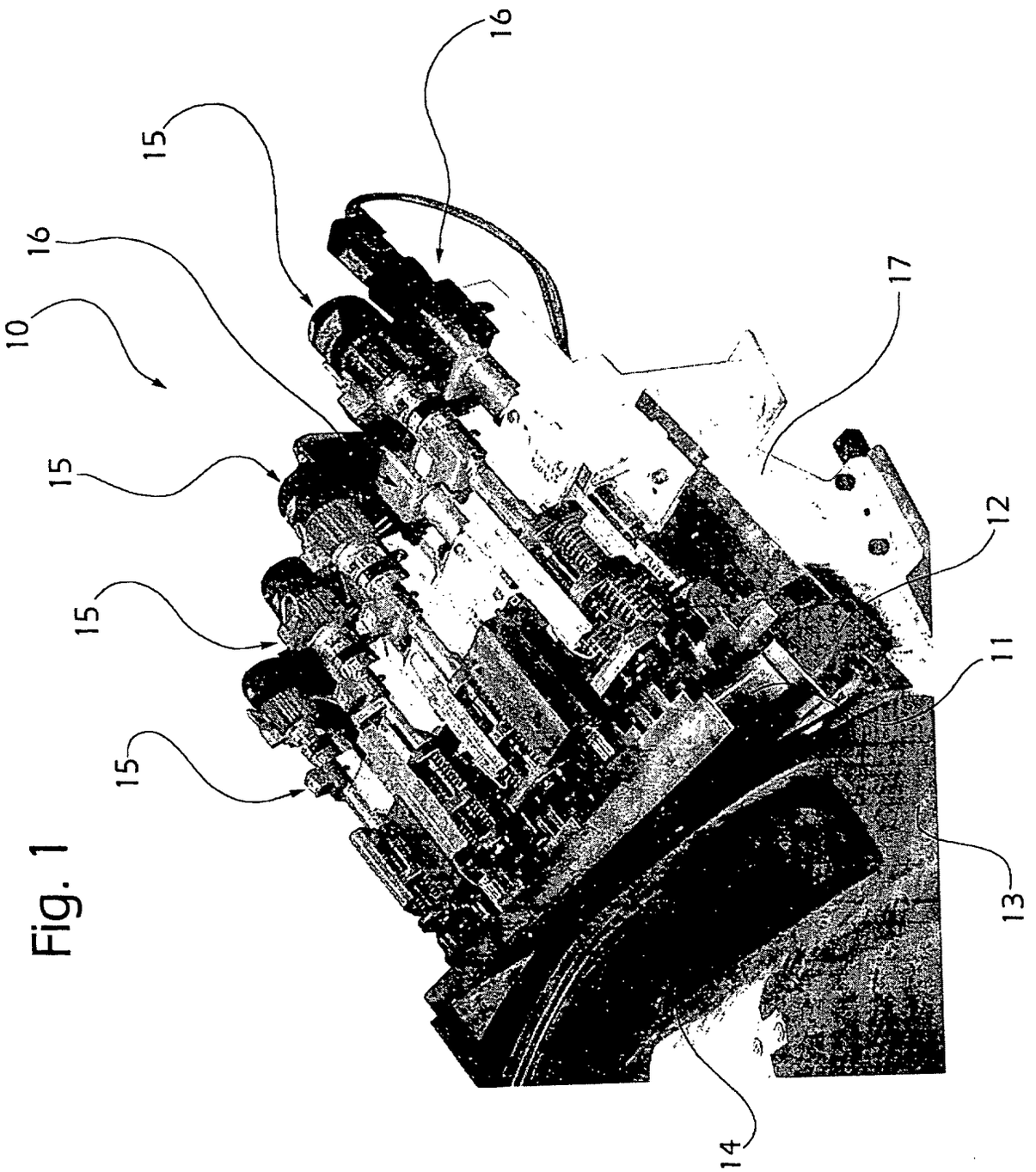


Fig. 1

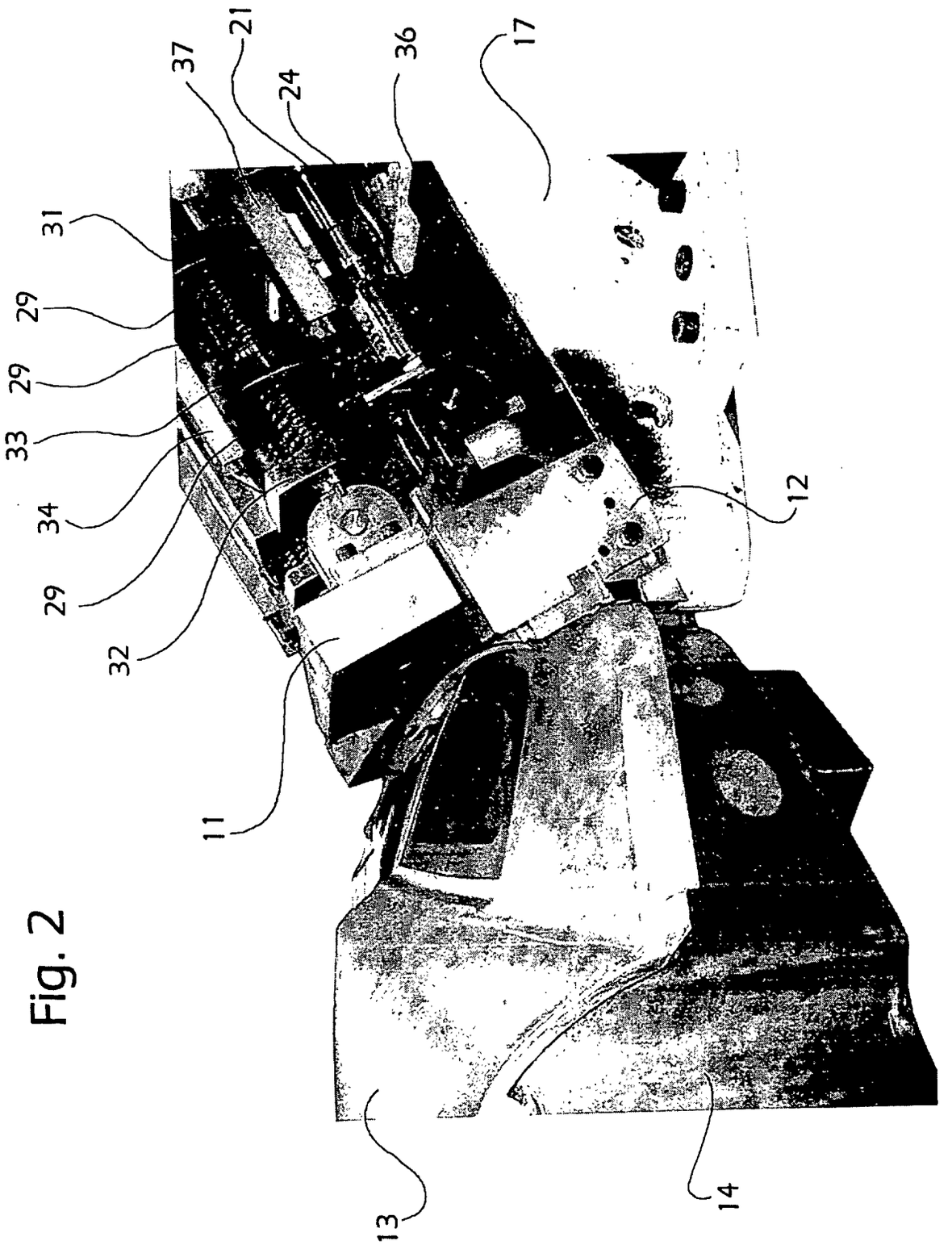


Fig. 2

Fig. 3

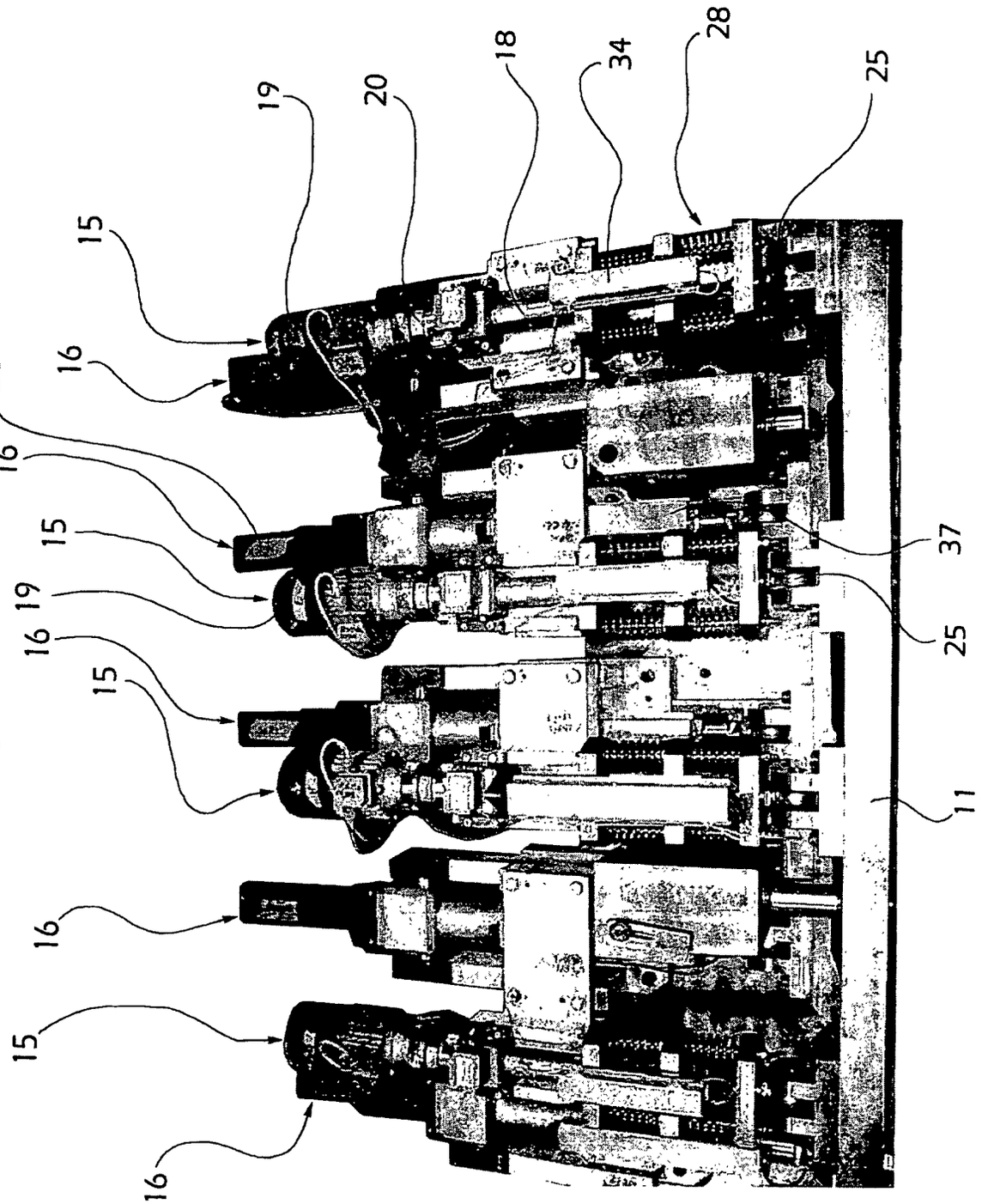


Fig. 4

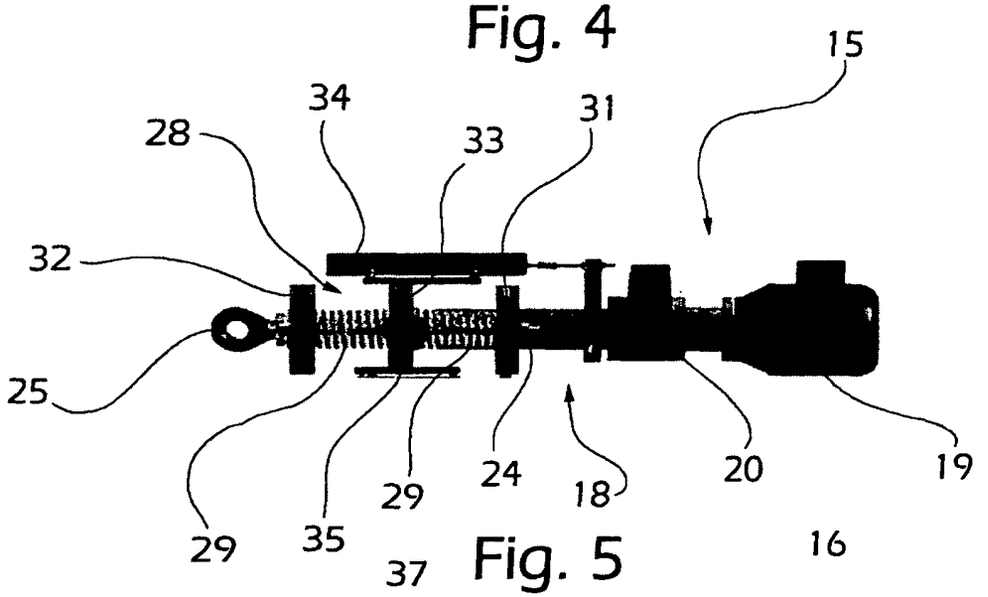


Fig. 5

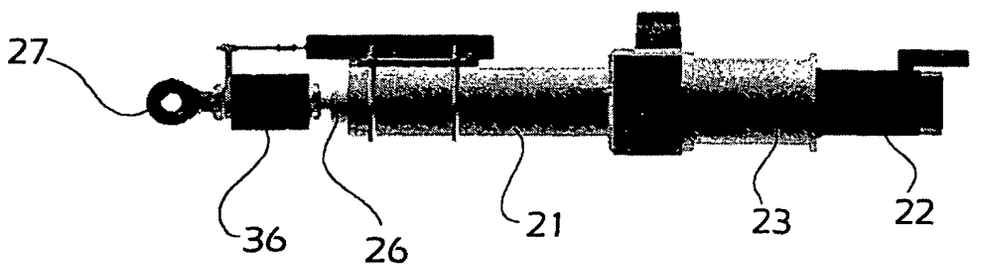


Fig. 7

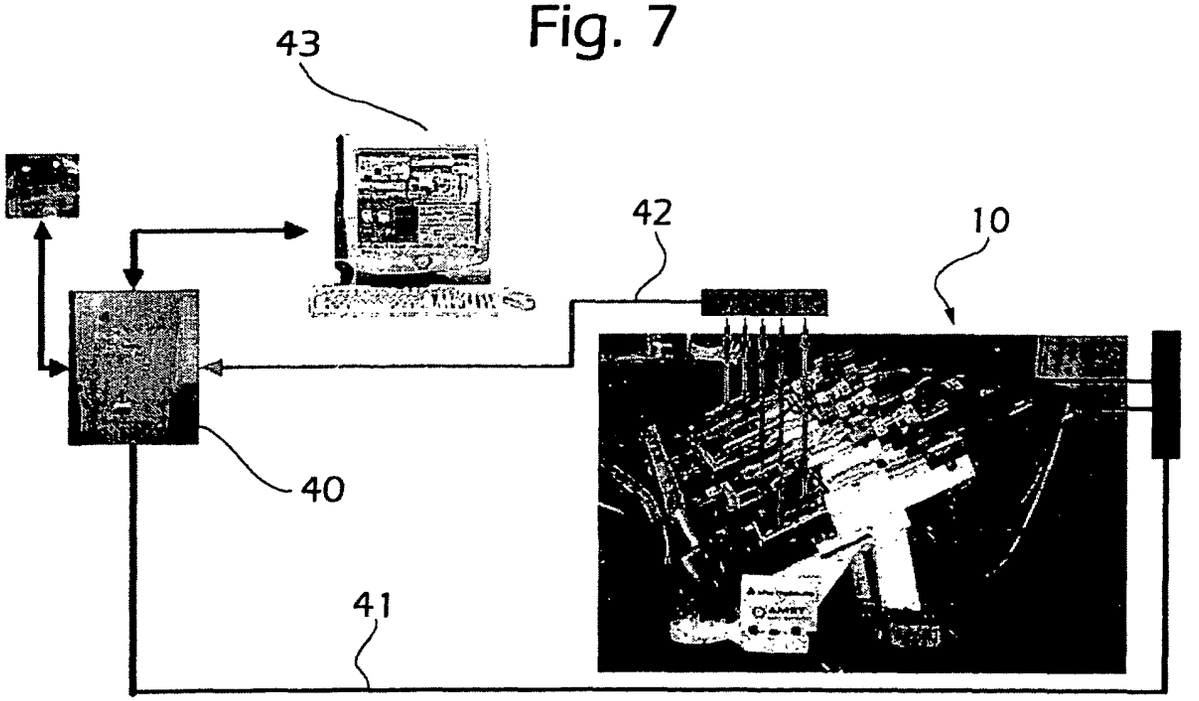


Fig. 6

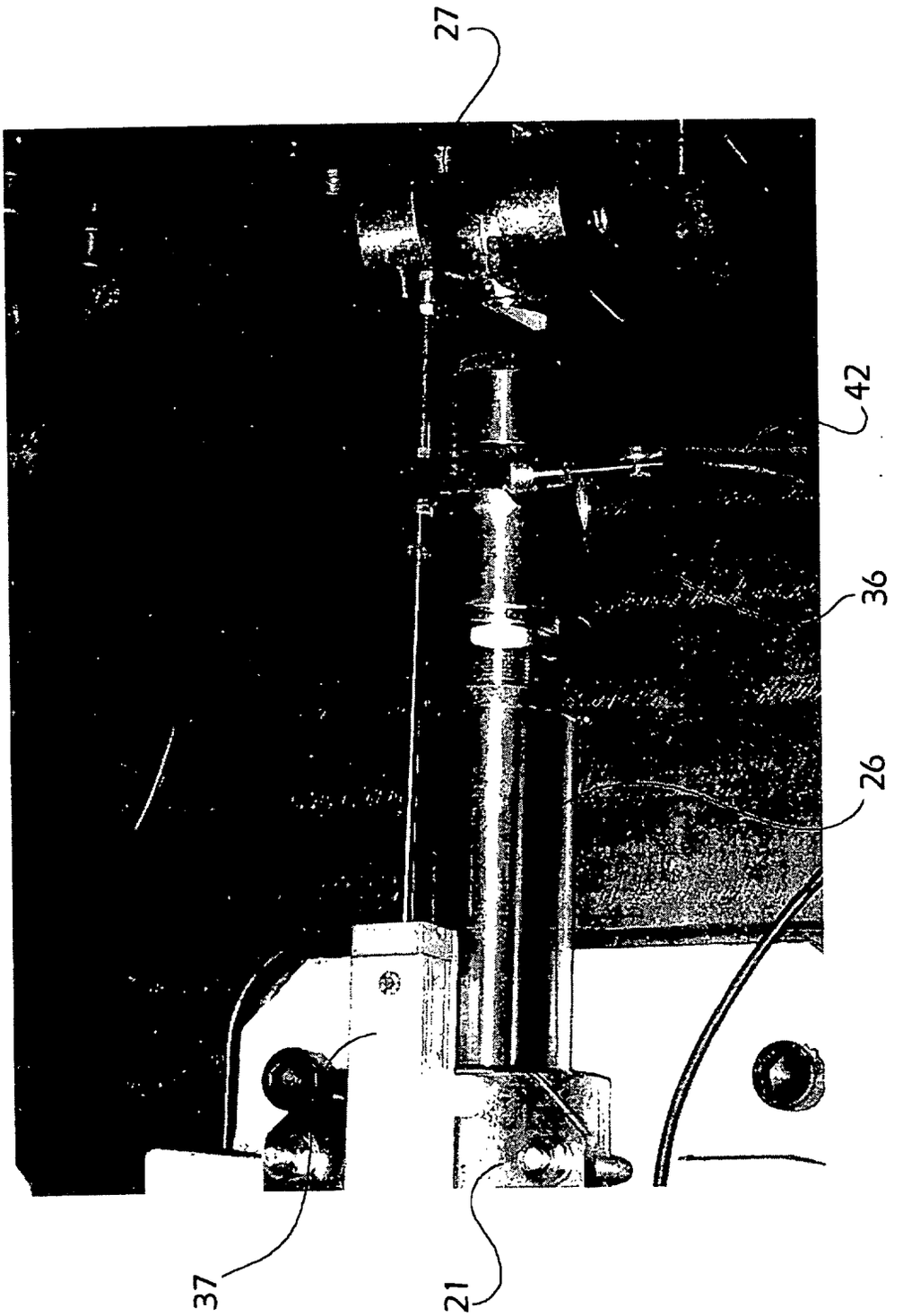
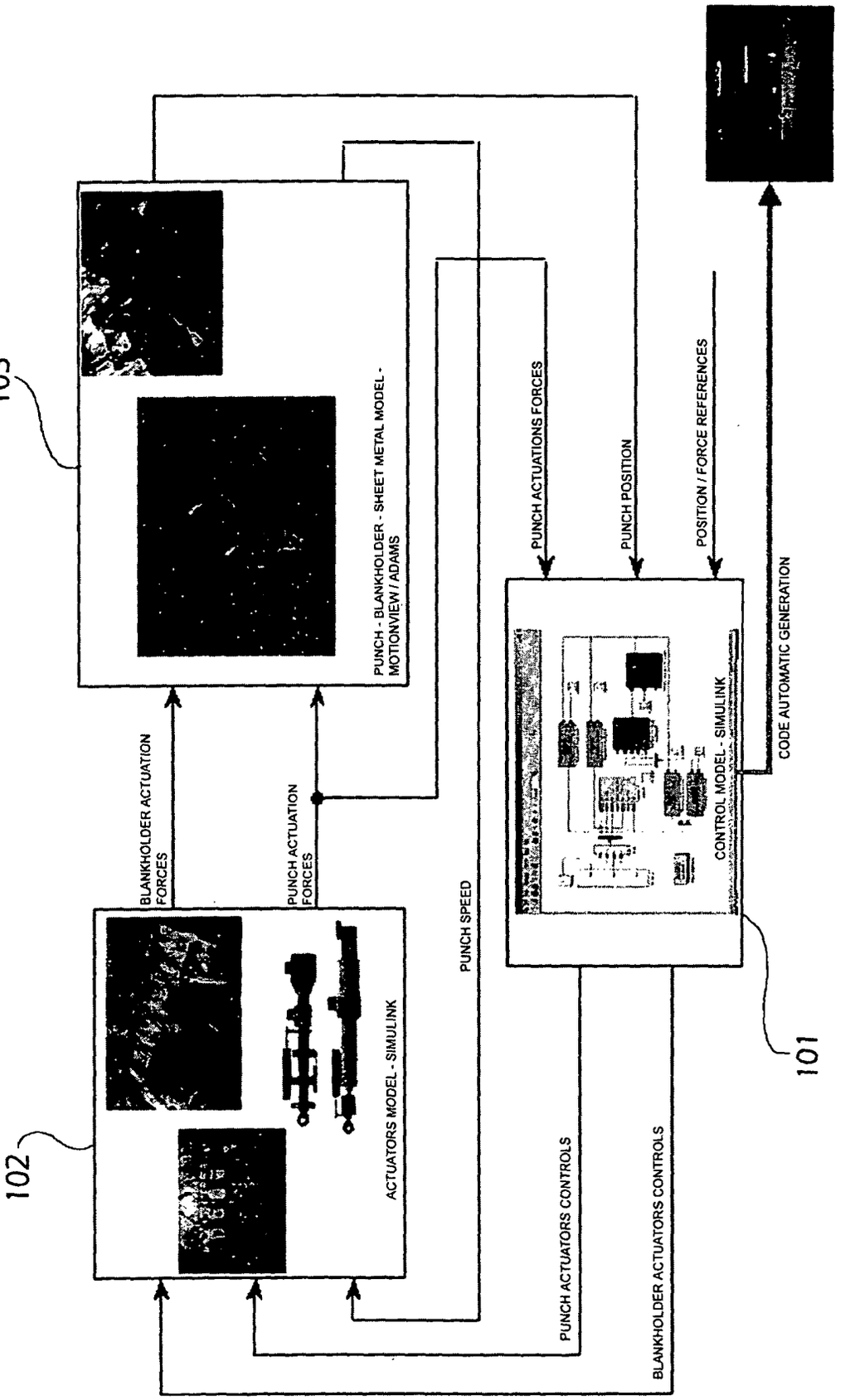


Fig. 8


103
PUNCH - BLANKHOLDER - SHEET METAL MODEL - MOTIONVIEW / ADAMS
BLANKHOLDER ACTUATION FORCES
PUNCH ACTUATION FORCES
PUNCH SPEED
PUNCH ACTUATIONS FORCES
PUNCH POSITION
POSITION / FORCE REFERENCES
CODE AUTOMATIC GENERATION
CONTROL MODEL - SIMULINK
ACTUATORS MODEL - SIMULINK
PUNCH ACTUATORS CONTROLS
BLANKHOLDER ACTUATORS CONTROLS
102
101