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A B S T R A C T

This report deals with linear step drives. It presents the Czechoslovak alternative as well as the Czechoslovak-Soviet solution developed for the VVER-1000 reactor control. Mechanical part of the motor, power control unit, and motor position indicator are described.

KEY WORDS:

Linear step drive, control element drive, power control unit, position indicator

L I N E A R   S T E P   D R I V E

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A B S T R A C T

The paper describes a linear step drive developed in Czechoslovak-Soviet cooperation and intended for driving VVER-1000 reactor control rods. The authors explain the functional principle of the motor and describe both mechanical and electrical part of the drive, power control, and the indicator of position. Because the motor has latches situated in the reactor at a distance of 3 m from magnetic armatures, it has a low construction height over reactor cover, which suggests its suitability for seismic localities. Used magnetic circuits work with counterpoles, mechanical shocks at completing each step being damped using special design features. The position indicator is of special design and evaluates motor position within ± 1% of total travel. Drive diagram as well as functional scheme of both control electronics and position indicator are presented.

Key words:
LINEAR STEP DRIVE, CONTROL ELEMENT DRIVE, POWER CONTROL UNIT, POSITION INDICATOR

1. INTRODUCTION

The majority of nuclear reactors is controlled by means of control rods. At their ends situated in the core, these rods are provided with neutron absorbers whose inserting in or withdrawing out of the core constitutes the process of neutron flux control in the core, the flux being directly proportional to reactor power. As the working motion of the control elements is straight, the majority of modern control systems abandoned the rotary-type motors necessitating to convert the rotational motion into translatory motion, and took advantage of linear motors whose functional principle complies with the requirements imposed on the control elements.

Control rods are used with advantage to accomplishing all three functions which are to be fulfilled in nuclear reactor control. These functions are as follows:

To begin with, it is the control of both stationary and transient states. As a second, it is the compensation of long-term changes of reactivity and, thirdly, the control rods are used for ensuring safety in such occurrences when reactor parameters exceed the preset limits.

2. LINEAR STEP DRIVE

Linear step drive denotes an equipment comprising the stepping motor, an assembly for connecting the control cluster, and the indicator of position of the draw rod. It should be added that an integrate part of the linear step drive is the control and feeding electronics which imparts to the linear step drive the principal drawing and dynamic properties.

2.1. Linear step drives in the world

All leading producers of nuclear devices are engaged in developing linear step drives. There exist many different designs which are solved as single-purpose solutions for a given type of reactor, but individual designs are not directly interchangeable.

Basic solution in the west is the design of the American company Westinghouse. This company uses a draw bar with ridges into which engage latches which control the movement of the bar. The latches are lightweight, are situated within a coil system, are easily controllable and ensure good dynamic properties of the motor.

The Czechoslovak alternative is derived from this solution and enhanced it by adding an additional set of latches, thereby enabling the motor to operate in the push-pull mode. Structural solution is presented in fig. 1. The motor has two systems of electromagnets, with each system having two coils. The blocking coils 10 control the closing and opening of latches 2 meshing with the ridges of the draw bar 1. The pitch of the circumferential ridges is 1 cm. The drawing coils 9 control the poles of electromagnets (fixed pole 4 and moving pole 2), the motion of the poles carrying out the required step. Timing of current into electromagnet coils is accomplished by a feeding unit. A magnetic shunt engages into the coils of the position indicator 21 and closes their magnetic circuits. Under loading this motor provided an output of 40 kg (which is double the weight of the control organ), and a velocity up to 8 cm/s (as compared to 2 cm/s required).

A system principally similar to that of Westinghouse is used also by KWU and other producers.

If the control element is fully inserted into reactor core, the end of the drawing bar meshes with the system of latches. In the upper position of the control element, the upper end of the bar shifts up above the motor by full working length (i.e. 3 - 4 m). Most producers take advantage of this fact and situate the position indicator package also over the motor. This package comprises a continuous coil (with a length of 3 - 4 m according to the working length of the motor) wherein moves a drawing bar consisting of magnetically conductive material and constituting a magnetic core which influences coil inductance.

By evaluating this inductance it is possible to determine the position of the draw bar and, consequently, the position of the control element. The continuous coil may be substituted by a set of coils spaced e.g. 10% of the working length, and the position of the draw bar may be determined with a discretization given by the pitch of the indication coils.

The main advantage of these systems consists in that the position indicator coils are situated in a relatively low temperature environment, the indication of position is nondestructive, and the actual position of the bar is given either in a continuous manner or with a preset discretization. On the other hand, the main disadvantage of these designs lies in the fact that the height of the motor is increased by full working length of the draw bar which constitutes a weakpoint when the power plant is intended for a seismic locality.

2.2. Step drive for VVER-1000 reactors

2.2.1. Mechanical part

Nuclear power plants equipped with VVER-1000 reactors are designed in a unified manner also for seismic localities. One of the requirements imposed on the components of such power plants is to withstand seismic activity up to 9 MSK. It is therefore necessary that the structures be short and the building heights of the objects as low as possible.

These conditions led to choosing for the control element drive a linear step drive with latches situated 3 - 4 m below the magnetic armatures. Pictorial representation of this type of motor is presented in fig. 2.

The control element (cluster) is connected to the draw bar 1 via a bayonet. This bar forms a part of the drive and is provided in its upper section with circumferential ridges meshing with two sets of latches which control the draw bar. The ridges on the draw bar are done along a length corresponding to the working length of the bar. Total working length of the draw bar is 3500 mm. Lower section of the draw bar is equipped with a spring-type shock absorber for softening the motion in individual steps. The step is 20 mm and is given by the pitch of the ridges.

There are two types of latches, i.e. the fixing latches and the drawing ones. The fixing latches 2b hold the draw bar when the drawing latches 2b move freely up or down along the draw bar (without meshing with the ridges). The fixing latches are in operation also when the draw bar is motionless.

Upon a command for motion up, the drawing latches close while the fixing ones open. The draw bar is now suspended on the drawing latches which thereafter shift by one step (i.e. 20 mm) up, carrying the draw bar along. The fixing latches then close and the drawing ones open and return into their starting position in opened position, i.e. without engagement with draw bar ridges. The draw bar is held again by the fixing latches.

The downward step proceeds in such a way that the drawing latches first shift into their upper position to grip the bar, while the fixing latches open whereupon the drawing ones shift one step down together with the drawing bar. Then the draw bar is gripped again by the fixing latches, the drawing ones open and the cycle of the step is finished. It is seen that each step consists of several partial motions, i.e. opening and closing of both sets of latches, and up and down motions of the drawing latches.

Opening and closing of the latches is controlled by conical bushings connected by concentric tubes with the moving poles of corresponding electromagnets. The coils of electromagnets are situated over reactor pressure vessel cover, i.e. outside the pressure boundary. The coils are cooled by streaming air. Both the fixed end the moving pole of the electromagnet are placed in primary circuit water.

The lower coil 10a controls the fixing latches by means of the pole 5, whereas the central coil 10b controls closing and opening of the drawing latches. Their vertical movements within the range of one step is controlled by coil 9. The motion proceeds in such a way that together with pole 3 of coil 9 there move the poles 8 and 7 of the coil 10b, the drawing latches 2b being connected with poles 8 and 7 via a tube. Fixed pole of drawing coil 9 accommodates a shifting damping of a ferromagnetic material 12 whose lower end protrudes into the working air gap. This bushing enhances the drawing power of the magnet in the initial phase of motion of moving pole 3, while in the second phase of the motion the drawing power is decreased due to a contact occurring between the bushing and the moving pole, as a consequence of which the air gap is partially short-circuited. The whole motion mechanism is mounted in pressure-tight plug 19 via a spring assembly. If there occurs an emergency signal, feeding of all coils is switched off, control bushings with armatures and connecting tubes fall by gravity into their lower position, and all latches open. As a consequence, the draw bar with the cluster fall into the core.

If the upper part of the drive, e.g. the plug 19, suffered a greater leakage, an intensive upward streaming of water through the pipes would occur, the pressure difference could carry up even the draw bar with the cluster. But because the pressure gradient lifts also the tubes including the control bushings, the latches close and drawing bar with cluster stops.

The indication of position is enabled by the inductance coils accommodated in pressure tube 15 entering the opening of the draw bar carrying in its upper section a ferromagnetic tube-type shunt along a length

$$s = n \cdot x \cdot d^{-1}$$

where
- s is the length of the magnetic shunt
- x is the overall working length of the draw bar
- n is the number of indication coils (=6)
- d is the number of required indication zones (=10).

Therefore, the inductance coils are located in a dry, pressureless environment, with the working temperature being approximately 300 °C. The coils are spaced 350 mm (i.e. 10% of the working length) apart, and their total number is 6. Each coil is formed by an isolated wire capable of long-term operation in temperature environment up to 400 °C, and produces an inductance when in series with an ohmic resistance. If the current flowing through the coil is I, the active component of voltage on the coil is I.R while the inductance component will be I.ω.L, both components being vectorially perpendicular. Whereas the active component of voltage is temperature-dependent, due to a temperature dependence of the ohmic resistance the inductance component will be temperature-independent and its magnitude will depend only on the absence or presence of the magnetic shunt. The position indicator as a whole consists of 6 coils spaced 1/10 of draw bar working length apart, which, using Johnson's code, enables to evaluate 10 zones of draw bar working length and 2 end positions. The input electronics evaluates only the inductance component of the signal delivered by the coils, this component being further converted into a binary-decade code for further processing.

2.2.2. Control electronics

The dynamic properties of the linear step drive are given in the first place by its control unit. As a consequence, this drive needs a special feeding package which must meet also the reliability and safety requirements imposed on the control system of the whole reactor.

The power feeding package ensures the following functions:

- controls the amount and the time course of current into all 3 coils of drive electromagnets

- switching over to standby d.c. feeding in the case of an unpermissible reducing of current into the magnets when using 3x220 V mains supply

- in dependence on reactor control commands, to ensure up and down motion of the motor
- if there occurs an emergency signal, immediately to switch off current into all coils of drive electromagnets
- providing continuous self-control.

Feeding of the power package is provided from an independent 3 x 220 V, 50 Hz system, while for standby feeding serves an accumulator, 110 V.

Function of power control

Functional scheme of power control is shown in fig. 3.

The feeding voltage is fed via circuit breakers and reactance coils in thyristor modules (TM) on rectifier control. Output d.c. voltage serves for feeding individual electromagnets of the drive.

The time course of the output d.c. voltage is determined by the logic unit (LU). Instantaneous amount of current is measured by two measuring transformers (MT) on the alternating side of the rectifier and serves as an information for current controller (CC). This controller is controlled by a commanding signal delivered by the logic unit LU, the deviation signal being led to the phasing control unit (PCU). The current controller incorporates also threshold circuits which control whether the intensity and the time course of current is in conformity with preset values and, in the case of disharmony, it switches on the standby feeding, and ensures signalling of the failure.

The phasing control unit together with the synchronizing unit SYN control the angle of ignition of thyristor rectifiers in the thyristor modules. The controlling system as a whole is designed as short-circuit-proof.

The control signals from reactor control system are led on the logic unit LU via optoelectric elements of the galvanic isolation. Similarly, a galvanic isolation is done for signals between position indicator and the control unit.

One panel (1200 x 800 x 2000 mm) accommodates 4 units of power control, cooling of the panel is natural.

2.2.3. Position indicator

The position indicator ensures:

- provides the control room with a signal indicating cluster position (with an accuracy of 1% of the working length)

- delivers into computer a current analog signal whose magnitude is proportional to cluster position

- provides current signals indicating end positions and intermediate positions of the cluster

- provides a logic signal "FALL" in the case of cluster falling

- provides a logic signal "SEIZING" if there occurs a mechanical seizing of the draw bar.

The accuracy of position indication is 1%. In the case of switching off and repeated switching on of the feeding, the position indication must be resumed with an accuracy of 10%. In the course of bar movement, this indication will automatically be corrected to reach the accuracy required.

Function of position indicator

The functional scheme of position indicator is presented in fig. 4. The 220 V, 50 Hz feeding voltage is led via a circuit breaker and the feeding transformers onto the position indicator feeding (PIF) unit. The magnitude of all voltages as well as the position indicator sensor excitation current are continuously controlled. The PIF unit serves for feeding all position indicator units, including the position indicator.

The position indicator sensor consists of 6 coils permanently operating in a temperature environment of some 330 °C. Sensor output signals are led into the input unit (IU) where the analog signal delivered by the position coils is converted into a numerical signal in binary code. This signal is further processed in the analog signal units (ASU) and the logic signal units (LSU).

ASU processes signals from IU together with signals indicating the number of drive steps, wherefrom results a current and voltage signal which is proportional within 1% to the position of the cluster. The signal delivered by IU is processed in

LSU with the aim of obtaining current signals representing the end and intermediate positions of the cluster (this serves to reactor control and safety system), and logic signals indicating the end positions (which serves to power control unit, bar falling signal and possible bar seizing).

Bar falling signal is evaluated from the time of bar motion between two adjoining zones as indicated by position indicator sensor (with a discretization of 10% of working length). If bar motion is faster, this fact is evaluated as bar falling.

The position of moving bar is indicated in two decades. Individual percents are indicated by counting command pulses for bar motion from power control unit, while tens of percent are given as zone signals from indicator position sensor, as mentioned above. If the state of the counter of individual percents is to be changed from 9 to 0 or vice versa, there must simultaneously come a zone-transition signal from position indicator sensor. If the zone-transition signal does not occur and the power control unit delivers commands for bar motion, this situation is evaluated as "bar seizing".

The packages of position indication are mounted into the same panels as the power control units. One panel holds 8 assemblies of position indicator. These panels are assumed to accommodate also the circuits of grouped control of the system of control and safety of the nuclear reactor.

Conclusions

This report deals with linear step drives of the VVER-1000 reactor linear step drives of control elements.

Czechoslovak step drive is presented which has been designed in the initial stage of development. Obtained results have been used in a common Czechoslovak-Soviet alternative of VVER-1000 reactor step drives which will be produced in Škoda Concern Entreprise.

VVER 1000 LINEAR STEP DRIVE
(CZECHOSLOVAK ALTERNATIVE)

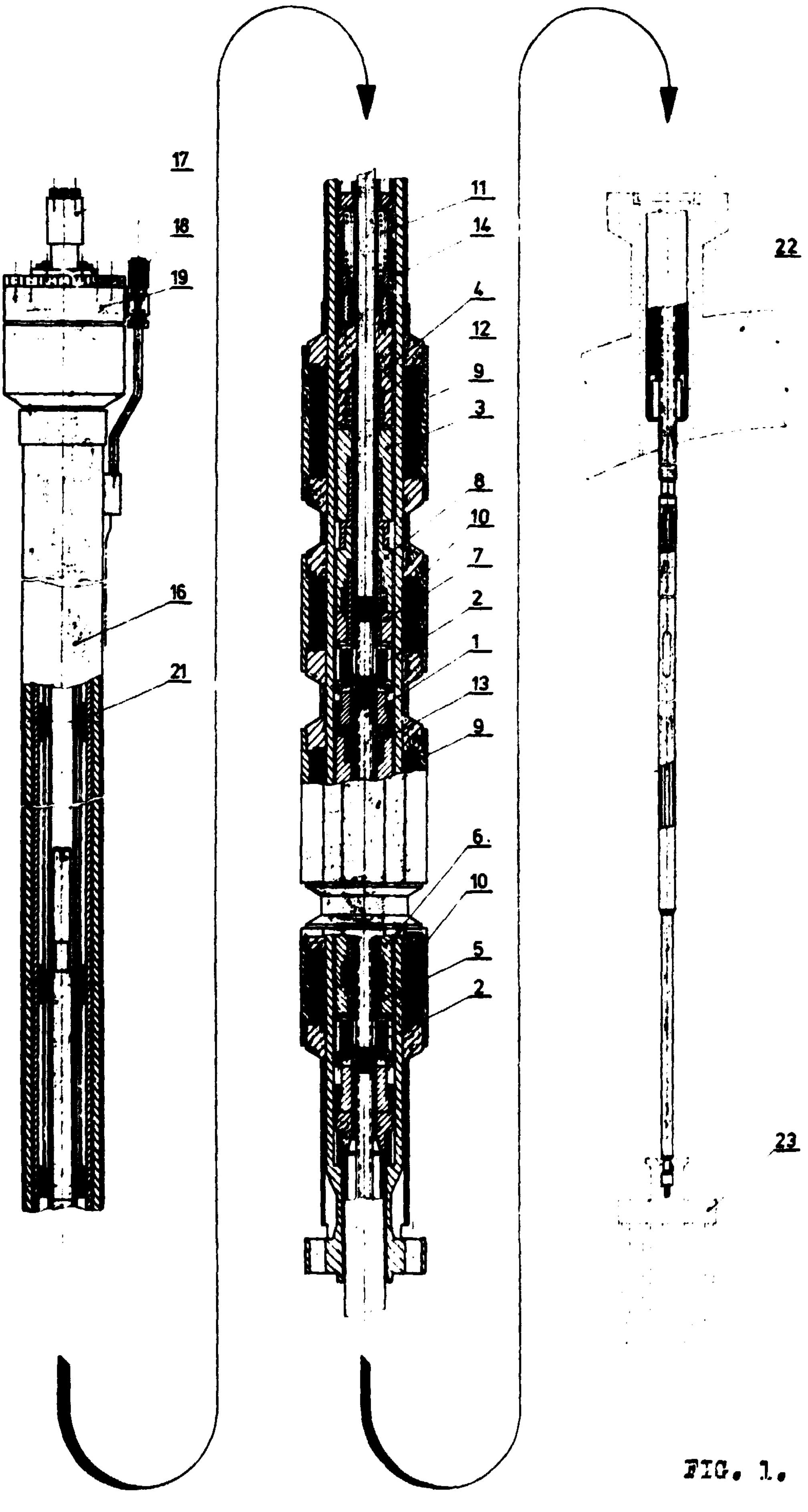

FIG. 1.

VVER 1000 LINEAR STEP DRIVE (COMMON CZECHOSLOVAK-SOVIET ALTERNATIVE)

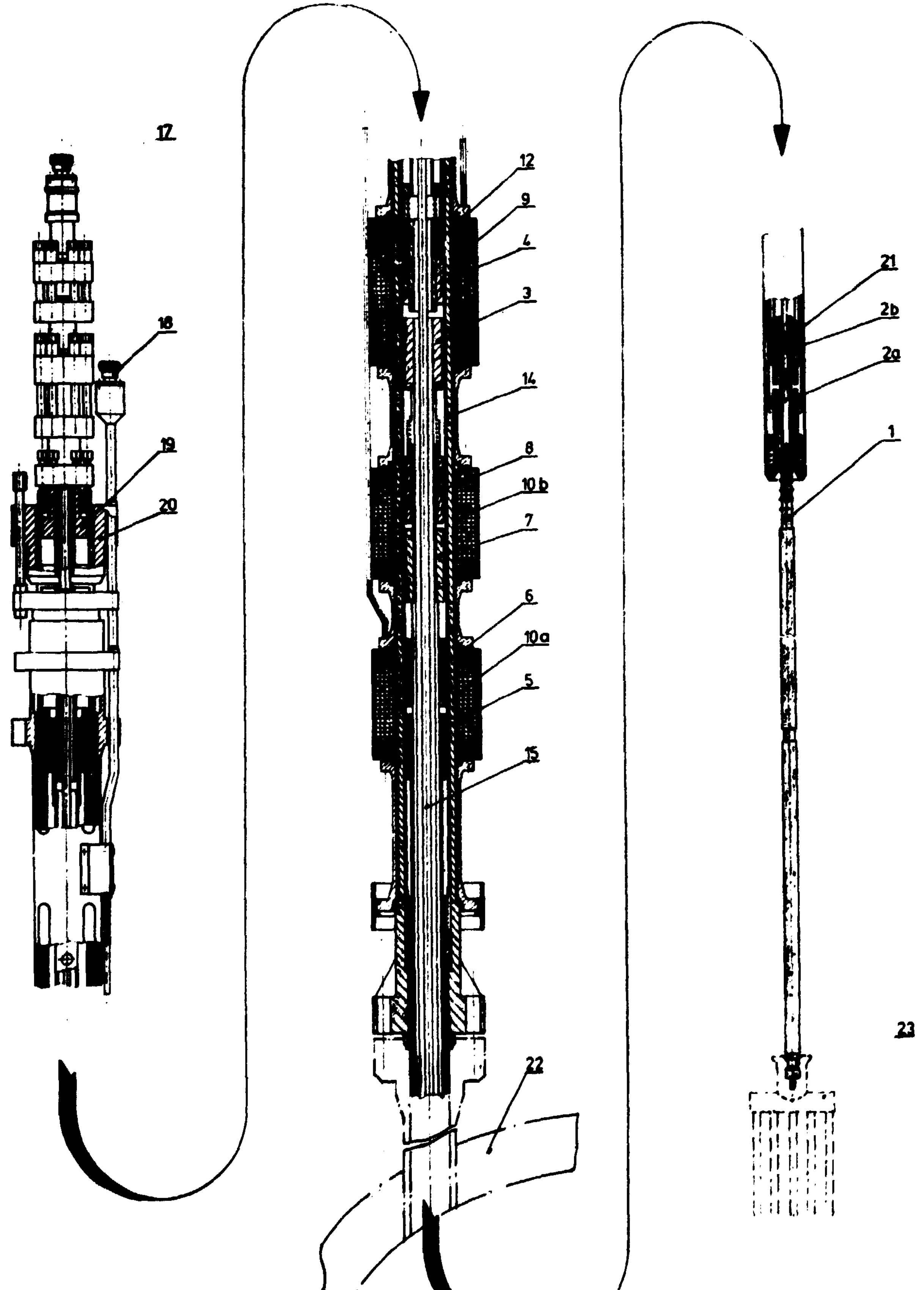

FIG. 2.

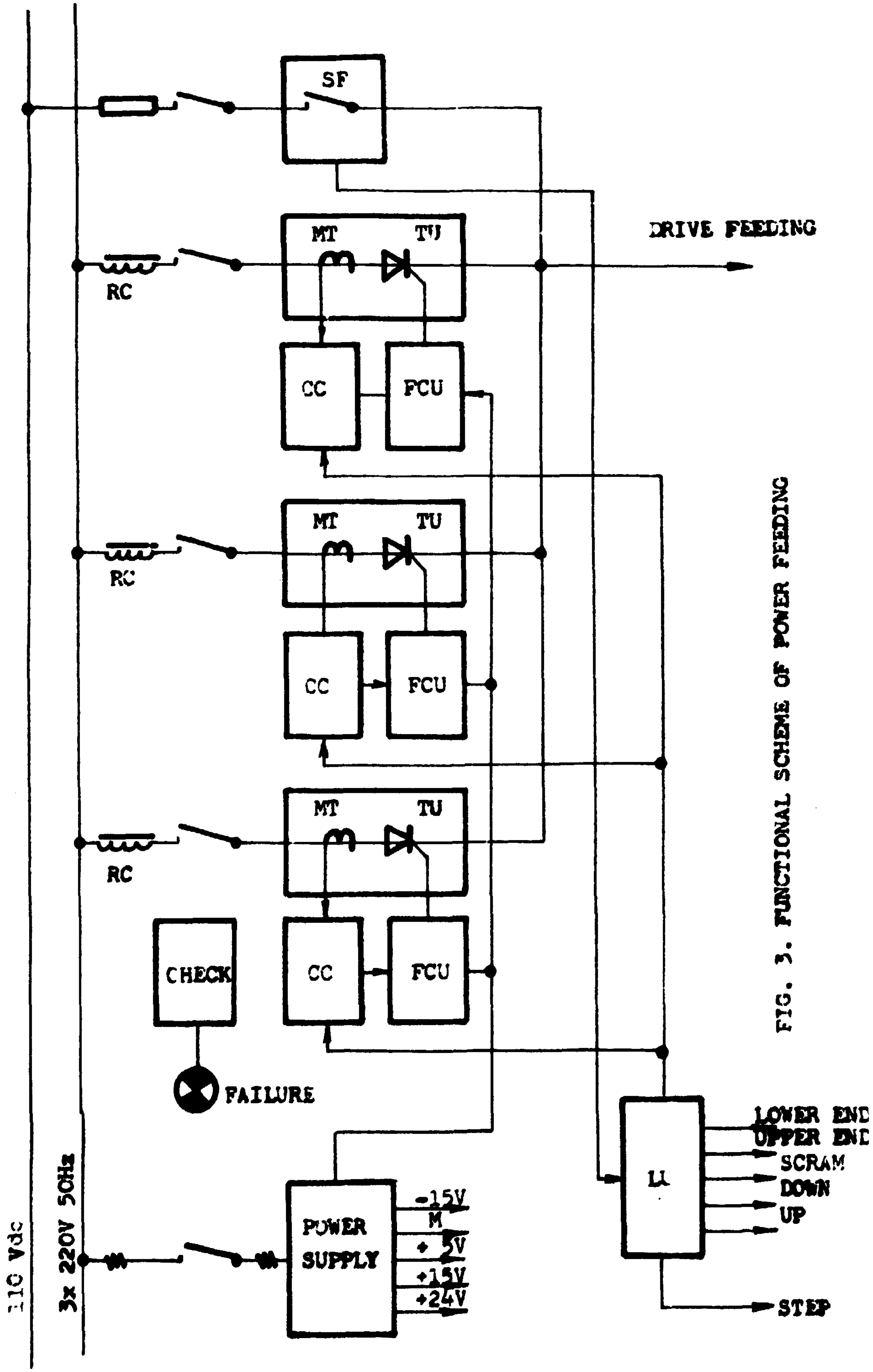

FIG. 3. FUNCTIONAL SCHEME OF POWER FEEDING

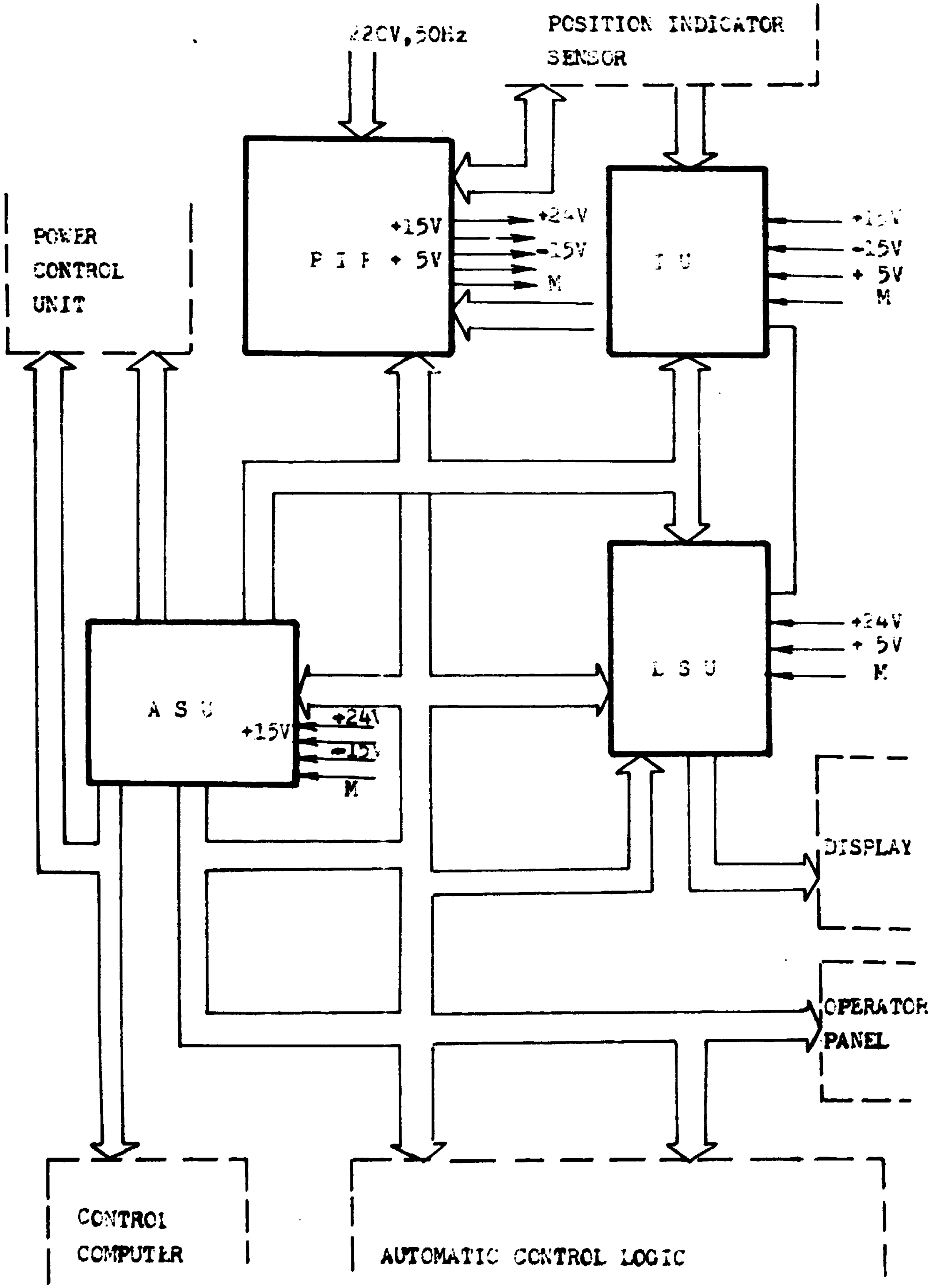

FIG. 4. FUNCTIONAL SCHEME OF POSITION INDICATOR