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EXPERIMENTAL STUDY OF PNEUMATIC NUMERICAL CONTROLS

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EXPERIMENTAL STUDY OF PNEUMATIC NUMERICAL CONTROLS

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In order to define the problem of numerical control, we consider its application to the control of machine tools.

In this case, the following circuits are planned:

1) Input and storage circuits, which decode the data of the punched tape and store them during the machining phase.

2) Counting and control circuits of movements, which determine and limit the movements of carriers as a function of the stored data.

3) Control circuits which compare the stored data with the data given by the counting circuits in order to generate signals to the components, such as clutches, electrical valves, etc. for the purpose of controlling various functions.

4) Speed control circuits, which control the rates of movement as a function of the data.

The insertion of data is obtained by punched tape. We are using the telex tape used in telecommunication and the tape of 1" width according to the EIA standard, with no preference between the two. The telex tape has 5 channels and the EIA punched tape has 8 channels.

The different circuits which we have mentioned make use of fluid components carrying out various logic functions. These components can be designed in the form of components with 1 moving part, called NR elements. They may be classified by function as follows:

NR1	Equality function
NR2	Contrary function
NR3	Check valve
NR4	Intercommunication valve
NR5	OR function
NR6	OR-NOR function
NR7	Delay or Sequencing function

These elements are shown schematically and symbolically in Figs. 1-14. When judiciously combined, they furnish the solution of the logical part of automatic fluid control systems.

Element NR1 constitutes a positive-action relay.

We characterize the input and output ports by the following letter symbols:

X: Orifice continuously supplied with the compressed fluid--gas or liquid; this continuous pressure plays the same role as the return spring used in directional control valves;

y: Orifice connected to the input or master control circuit. We also designate the input signal by y;

Y,Z: Orifices connected to the output or utilization circuit. We designate the corresponding output signals by Y, Z;

E: Orifice connected to the return circuit to the sump (for a liquid).

We point out that the elimination of return springs as a result of the continuous compression p_x produced by orifice X increases the operating safety and speed. There is no risk of spring breaking or weakening. Control is accomplished as soon as the limit resulting from the back-pressure is overcome.

We shall return to Fig. 1, component NR1. In the position at rest ($y = 0$), we have $Y = 0$ and the channels which utilize the output signal Y are switched to exhaust through orifice E. As soon as the input signal there becomes equal to 1, i.e. when the pressure p_y of the control fluid satisfies Relation (1):

$$\Omega_1 \cdot p_y \geq \Omega_o \cdot p_x + F_1 \qquad (1)$$

(where Ω_1 is the large useful surface of the differential piston and Ω_o is the small useful surface of the differential piston, and F_1 is the resistance due to friction), the piston moves sharply to the left and we obtain the logical relation Y - y, i.e. the equality function, the symbolic representation of which is shown in Fig. 2.

The pressure on the small surface Ω_o of the piston during its displacement to the left, i.e. under the influence of p_y, is minimum if the volume of air trapped and compressed by surface Ω_o is sufficient to cause no significant pressure rise. Consequently, a compromise which takes this factor and the importance of minimum space requirement into consideration must therefore be found by a suitable design.

Component NR2 (Fig. 3) represents the contrary function and achieves the logical relation Y = y' or $\bar{y}$. We note, in fact, that in the position at rest, i.e. piston forced to the right by the pressure p_x, the output line Y is supplied by the compressed air entering through port X. The input signal y, i.e. the pressure p_y, acting on surface Ω_1 of the piston, displaces the latter to the left and thus brings orifice Y into communication with the exhaust port E. The disappearance of control signals there, as before, results in the return of the differential piston into its initial position under the influence of pressure p_x.

Fig. 4 shows the schematic representation of component NR2.

Component NR3 (Fig. 5) is a check valve which assures free flow from

Y_1 to Y_2, but checks the transmission of the signal from Y_2 to Y_1. In the absence of signals Y, the pressure p_x forces the piston to the right and prevents all communication between ports Y_1 and Y_2.

The symbolic representation of component NR3 is shown in Fig. 6.

The intercommunication valve is obtained by component NR4 (Fig. 7). This permits the transmission of signals from output Y_1 and Y_2 to the channel line Z, but does not permit the transmission of Y_1 to Y_2 and vice versa. Port X is placed under atmospheric pressure p_a (see Fig. 7). In this manner, we obtain the logical OR function, i.e. $Z = Y_1 + Y_2$.

The schematic representation of component NR4 is shown in Fig. 8.

The addition of a free piston to components NR1 and NR2 results in components NR5 (Figs. 9 and 10) and NR6 (Figs. 11 and 12), respectively.

Component NR5 carries out the logical OR function, i.e. $Y = y_1 + y_2$ from two master control circuits y_1 and y_2.

Component MR6 provides for the OR-NOR function, i.e. $Y = \bar{y} \cdot \bar{y}_2$.

Synchronization either in opening or closing of components NR1 and NR2 is obtained by component NR7 (Figs. 13 and 14). This component is formed by replacing the differential piston by a similar piston, which, however, is perforated with calibrated holes t. This replacement of the normal piston with one of the pistons in the set distinguished by calibrated perforations provides for a well-defined sequencing in the operation of the NR components.

Thus, the arrangement of ports y_1 and y_2 in the cylinder of component NR7 provides for the establishment of direct communication between the orifices in the direction of y_1 to y_2 and the insertion of the pneumatic resistance due to the perforations t, provides for sequencing or chronization for flow in the direction of y_2 to y_1.

The schematic representation of component NR7 is shown in Fig. 14.

Thus, the cynchronized closing of relay NR1 is obtained by the introduction of component NR7 in the master circuit (Fig. 15) with the possible addition of the capacitance or sump C. In this manner, the rate of expansion of the air held in sump C is regulated.

The schematic representation of this assembly is shown in Fig. 16.

The group of components NR1-7 furnishes all of the components of the logical circuits of an automatic sequential control system.

Components NR1 and NR2 can be connected as an oscillator or flip-flop, with the output circuit $Y_i (i = 1, 2)$ of one of the elements being connected to the command circuit $y_i (i = 2, 1)$ of the other element, as shown in Fig. 17.

Thus coupled, the elements enter into auto-oscillation, for which the phase shift, frequency and the ratio of the oscillation half-periods can be regulated by means of variable resistances or adjustable throttles R_1, R_2 and capacitances C_1, C_2.

The alternating reciprocating movement of the moving part, i.e. of the free piston of components NR1, NR2 (parts A and B of Fig. 17) is transmitted to pawls M_1 and M_2 of the ratchet wheel H so as to drive the latter in an intermittent rotation (see Fig. 18).

Fig. 18 shows a design of this step-by-step control intended for a tape reader.

The free pistons P_1 and P_2 transmit their reciprocating, out-of-phase movements to the ratchets M_1 and M_2 via rods L_1 and L_2.

The pin of the ratchet wheel H is thus driven by an intermittent rotation.

This rotation is started and stopped by cutting out one of the feed circuits X or one of the command circuits y_1 or y_2.

In Fig. 18, the cutout of circuit y_1Y_2, i.e. the arrest of oscillations, is obtained by the cutout Z which is remote-controlled by circuit z.

Fig. 19 shows the relation of the control pressure variations y_1 and y_2 and of the displacements x_A and x_B of pistons P_1 and P_2. The latter are returned to the initial position by the feed pressures X. In the absence of pressures p_{y_1} and p_{y_2}, we have:

$$x_A = 0 \text{ and } x_B = 0$$

The pressure rise of the input signal y_1 causes the displacement of piston P_1 to the right when the pressure $p_{y1} = p_X \cdot s/S$ (s = small active surface of pistons P_1 and P_2; S = large active surface of pistons P_1 and P_2), i.e. in "a" at time t_1 (Fig. 19).

The displacement x_A thus takes place at time t_1. The output Y_1 is then in communication with the feed X and we have $Y_1 = 1$ and $y_2 = 1$.

The pressure rise of the input signal y_2 produces the descent of piston P_2 when the pressure $p_{y_2} = p_X \cdot s/S$, i.e. in "b" at time t_5. The displacement x_B therefore takes place at time t_5. The output Y_2 is then in communication with exhaust signal y_1, when it reaches point C, the homolog of point A, causes the return of piston P_1 to the initial poistion. The displacement x_A thus has terminated at time t_2. The ratchet M_1 rotates the ratchet wheel H by one notch. At this moment, i.e. at time t_2, the output Y_1 is connected with exhaust E and we have $Y_1 = 0$ and $y_2 = 0$.

When the pressure drop of the input signal y_2 has reached point "d", the homolog of point "b", it causes the return of piston P_2 to the initial position. The displacement x_B is thus terminated at time t_6. The ratchet M_2

stops the ratchet wheel H.

We thus have an alternating reciprocating movement of pistons P_1 and P_2, out-of-phase by about 90° in the case of Fig. 19, i.e. when $R_1 = R_2 = R_3 = R_4 = 0$ and when $C_1 = C_2 = 0$.

The frequency and dephasing of these alternating movements can be modified by adjusting the resistances R and the capacitances C.

The tape reader, built in the laboratory, is shown in the photograph of Fig. 20.

The punched tape is read by a multipurpose fluid element represented in Fig. 21 and called component NR-T3 or NR turbulence element. It consists of a cylinder 1 in which 4 lobes (4) have been milled. The center part is perforated by 8 channels have been countersunk for the compressed fluid feed, while 4 other channels Y are provided at 5 for the transmission of output signals.

Component NR-T3 was optimized for use with compressed air at an inlet pressure p_X of 155 mm H_2O. Laminar flow is obtained by 4 tubes of 25 mm length and 8/10 mm I.D. The 4 laminar jets are collected by 4 tubes (5) of 10 mm length and 8/10 mm I.D. The pressure originating from the signals Y_1 to Y_4 is about 75 mm H_2O, i.e. a pressure efficiency of about 50%. This outlet pressure drops practically to 0 in the presence of a horizontal air jet originating from signals y_i under a static pressure p_{y_i} of 15 mm H_2O.

The drive of the intermittent hydraulic motors at the output of the various circuits is obtained by means of component NR10, schematically and symbolically shown in Figs. 22 and 23. Component NR10 consists of the following:

A differential piston 1;

A hollow cylinder 2 with rectangular, annular grooves on the periphery;

A body with the ports X_2 for the feed, Z_1 and Z_2 for the output and R for return to the tank;

The two bases 3 and 4 equipped with a command port Y_1 and Y_2.

The active area S of piston 1 of component NR10 is equal to twice the active area s of the opposite end. In a specific example analyzed in the laboratory, piston 1 provided for fluid distribution under feed pressures X_2 as high as 210 atmospheres.

The output ports Z_1 and Z_2 in this case are connected to the reversible hydraulic motor and lead screw for the hydraulic control of the system under consideration.

Tests have shown that for such a drive pressure of 210 atmospheres, the distributor operates with command pressures Y_1 of 2.8 atmospheres at S and Y_2 of 5.6 atmospheres at s.

In order to prevent the influence of the elasticity of a direct pneumatic control of component NR10, it is preferable to operate it with oil at low pressure with the use of 2 components NR1 and NR2 as shown in Fig. 22.

The common control of the last 2 components takes place either by compressed air at low pressure or by a liquid.

We have operated this device with compressed air at 5 atmospheres for the control of y_1, with oil compressed to 3 atmospheres and supplied by an air-oil reservoir A for components NR1, NR2, and finally, we powered component NR10 at X_2 with oil under a pressure of 100 atmospheres.

A lead screw was connected to the outputs Z_1 and Z_2. The operation is quasi-instantaneous and the delay recorded in this control signal transmission stage was less than 0.1 sec.

Consequently, numerical control can be achieved as indicated by the general schematic diagram of Fig. 24.

We will successively consider the storage of the program and the decoder matrix according to the sequence to be established.

The program is contained on punched tape, for example, with 5 bits or 5 elements. Fig. 24 is a diagram of the various logic circuits necessary for the insertion of this program into the circuit of a numerical control unit.

In a first phase, input takes place in parallel from the tape reader on a 5 bit buffer and this for 5 time intervals, 1-5, respectively, then 11-15, etc. In a second phase, this buffer is transferred in series into the flip-flop storage during the following 5 advance signals, i.e. signals 6-10, then 16-20, etc.

During this transfer operation, a parity chekc is made due to the fifth bit of information, which is one parity bit. In case of error, the 11th advance signal triggers the halt circuit.

In order to check the various sequences, a counter is necessary which is automatically stopped again after the 5th advance signal.

This is a 5-pulse counter. Different circuits connected to this counter permit the first, second and sixth instructions and signals necessary for the operation of the circuits.

Once the program is inserted, it may be necessary to make an additional check in order to verify the accuracy of this program. The final check is made by performing a self-check of the storage. By comparing the data in direct form from this line with the data printed in complement form on the punched tape, an error can be detected. This direct-complement comparison permits the machine to be halted before the program is executed. This comparison is shown in Fig. 25.

Once this verfication has been made, the instruction decoder matrix is used according to the established sequences.

If we call A_1 the instructions 1-5, 11-15, 21-25, etc.

P_5 the transfer pulses during record gaps 6-10,

16-20, etc.,

we can write the different equations which govern the circuits shown schematically in Fig. 24 in the following manner:

Buffer:

$$Y_A = (y_A \cdot a_I + y_A) \cdot (\overline{R_S + 6^{TH} p})$$

$$Y_B = (y_A \cdot p_5 + y_B \cdot a_I + y_B) \cdot (\overline{R_S + \overline{y_A} \cdot p_5})$$

$$Y_C = (y_B \cdot p_5 + y_C \cdot a_I + y_C) \cdot (\overline{R_S + \overline{y_B} \cdot p_5})$$

$$Y_D = (y_C \cdot p_5 + y_D \cdot a_I + y_D) \cdot (\overline{R_S + \overline{y_C} \cdot p_5})$$

$$Y_E = (y_D \cdot p_5 + y_E \cdot a_I + y_E) \cdot (\overline{R_S + \overline{y_C} \cdot p_5})$$

$$Y_{E_{i+1}} = (y_{E_i} \cdot p_5 + y_{E_{i+1}}) \cdot (\overline{R_S + \overline{y_{E_i}}\ p_5}) \quad i = (0, \ldots, n-1)$$

Parity check:

$$Y_P = (y_E \cdot \overline{y_P} + y_P) \cdot (\overline{R_S + 2^{ND} p + y_E \cdot y_P})$$

$$STOP = Y_P \,.\, 1^{ST} p$$

5-pulse counter:

$$Y_2 = (p \cdot \overline{y_2} \cdot \overline{y_8} + y_2) \cdot (\overline{R_S + p \cdot y_2})$$

$$Y_4 = (p \cdot y_2 \cdot \overline{y_4} + y_4) \cdot (\overline{R_S + p \cdot y_4 \cdot y_2})$$

$$Y_8 = (p \cdot y_2 \cdot y_4 \cdot \overline{y_8} + y_8) \cdot (\overline{R_S + p \cdot y_8})$$

Instruction circuit:

$$A_I = [(y_2 + y_4 + y_8) . \overline{a_I} + a_I] . [\overline{R_S + (y_2 + y_4 + y_8) . a_I}]$$

$$P_5 = P . a_I$$

$$1P = Y_2 . \overline{Y_4} . \overline{Y_8} . A_I . p \qquad 2P = \overline{Y_2} . Y_4 . \overline{Y_8} . A_I . p$$

$$6P = Y_2 . \overline{Y_4} . \overline{Y_8} . \overline{A_I}$$

In a machine-tool with point-to-point control, the data inserted by the punched tape can be separated into technological data conducted to the corresponding storages, decoded and transmitted, as we have reviewed, to the units to be operated--clutch, tool turret, etc.

On the other hand, dimensional data are also stored and transferred to the comparator where the data indicating the real position arrive during the movement of the parts. This real position is read by a pneumatic device consisting either of a punched disk, which is read just as the punched tape, or a punched scale. These punched holes produce signals exactly as in the reading of a punched tape and these signals are all counted. The production of a signal indicates that movement by one measuring unit, for example, 0.01 mm, has taken place.

In this manner, an instrumental digital system is obtained, the fundamental unit of which is the counter.

We know that the principal element of the counter is the flip-flop or a scale-of-two multivibrator. Flip-flop circuits can be realized pneumatically very easily either with the NR components or with components having no moving parts.

In this manner we can design a calculator by means of a group of suitably interconnected flip-flop circuits. Thus, a calculator or counter consisting of 4 flip-flops permits the calculation or counting from 0 to 9, i.e. a decade. As is known, a calculator can be used for the positioning of a machine part. Decoded data are transmitted to the calculator, the output of which includes a switch connected into the power line of the drive motor. This switch remains closed as long as the counter has not returned to 0 and is open, i.e. the drive motor for the advance stops, when the counter is at 0.

The system operates as follows:

1. The desired dimensions of movement are inserted into the calculator.

2. The switch closes, starting the motor which drives the carriage of the machine and at the same time the transducer which measures the advance, i.e. a punched disk or system of punched motches. For each unit of length of carriage advance, the transducer sends a signal to the calculator.

3. When the calculator is at 0, the switch opens and positioning stops. The carriage will thus be displaced by one increment, for example, by 0.01 mm, equal to the number recorded in the calculator in question.

In order to obtain exact positioning, the feed rate should be reduced so that at the position end, the motor can shut down instantaneously. Thus, for example, a tool slide moves at high speed until the first approach speed is set at 5 mm from the end position. At 1 mm from this position, it changes to second approach speed, which it maintains up to the shut-down signal. These successive speed changes are controlled by pneumatic circuits called "gates" which detect the patterns corresponding to 5 mm and 1 mm in the counters; these values are only orders of magnitude.

The "gate" circuits in turn control the circuit which controls the motor speeds.

We should point out that if we are dealing only with insertion of a program which is stored on punched tape, the sequential execution of which requires no verification, the picture is considerably simplified and takes the appearance of that in Fig. 26, where we have shown the circuits for a punching system of such a type that these circuits must be repeated 5 times for a 5 bit code and below we have a simple counter with flip-flop formed of 2 components NR1 and NR2.

The NR components with free pistons have the advantage of being relatively inexpensive as a result of large-scale production by compression molding. Their switching time is in the order of 15 ms. In some cases, this switching time drops to 10 ms. However, if a higher operating speed is desired, fluid components without moving parts, based on the COANDA effect, will be used.

Fig. 27 shows a tri-stable device in which we can allow a main jet, designated by X, to oscillate, attacking along curved walls either to the left or to the right. In the absence of a control jet or input signals, the main jet is axially directed. In this case it is represented by Y_2. The control signals are designated by y_1 and y_2.

We can also realize the adherence of the divergent jet on one or the other wall. This is based on the assumption that these walls have a sufficient length and in this case it suffices to apply a control jet y_1 or y_2 (Fig. 28), which causes the deflection of the main jet to the right or left and attacks the latter at the wall. But we can also (Fig. 29) utilize a fluid amplifier equipped with a wedge providing for the decomposition of the main jet into two jets that are distributed either to the left or to the right channel, depending upon the operating mechanism of the control jet.

Thus, fluid amplifiers are constructed in which the same power jet can control several units, at least 4, with a pressure efficiency in the order of 30%. The switching times in this case are in the order of a millisecond.

However, in complex systems, it is necessary to obtain a high gain and efficiency, a rapid response, and output signals which have no influence on the other input signals.

In Fig. 27 we find that the bubble located between the main jet and the wall is in contact with the atmosphere before the jet is contacted with the opposite wall.

In Fig. 28, in contrast, there are two separate bubbles which form during the switching of the jet.

Finally, in Fig. 29, the power jet encounters the central wedge before attacking the opposite wall. As a result, the operating mechanism and the gain of these 3 types of amplifiers differ such that a modification of the parameters (for example, position of the wedge or the position of the walls or the wall angle) does not have the same effect in the 3 switching modes.

The correct operation of a bistable amplifier requires that orifices be provided to establish communication with the ambient medium at 0_1 and 0_2 (Fig. 30), particularly when this device is blocked by the head, i.e. when the head prevents the flow of the main jet. Thus, Fig. 30 shows the effect of these orifices 0_1 and 0_2, called relief channels or vents, depending upon whether they are located above or below the wedge designated by C. In Fig. 30 we note that the wedge is terminated by an acute angle or an edge.

In Fig. 31 we show a bevel on the right of wedge C, while in Fig. 32, a concavity is present at the base of wedge C.

The form of flow of the main jet is represented in Figs. 30-32, in the two following cases, respectively:

1. Absence of head: The main flow y_1 or y_2 through the output channels is free;

2. A resistance R_1 or R_2 exists at the output of these channels.

Thus, the forms of flow represented in Figs. 30-32 are obtained by modifying the structural shapes of these components and the output impedances.

Fig. 32 shows the start of an eddy at the right of the concave part of wedge C. This eddy helps in maintaining the main jet in contact with the wall, ilel it increases the stability. However, the gain is reduced as the stability is increased. In fact, when the component is charged, i.e. exhibits a resistance to the main jet flow, the excess fluid stream is directed to the vents and creates a powerful eddy in the interaction zone, resulting in a pressure increase in this zone. A pressure rise greater than the ambient pressure can result and consequently, a flow through the control orifices. By closing a control orifice, we produce a pressure increase to such an extent that the main jet can swing on the opposite wall.

This operating form is contrary to the normal operating conditions in which closing of a control orifice causes a pressure decrease due to the entrainment effect and due to the same effect creates the deflection of the jet towards this blocked control orifice.

The devices of Figs. 30-32, if correctly designed, give rise to pressure efficiencies which are 30% in Fig. 30--i.e. 30% of the pressure at the input is recovered at the output--50% in Fig. 31 and 70% in the case of Fig. 32.

Figs. 33 and 34 show bistable elements with a COANDA effect. The symbolic and schematic representations are shown simultaneously. In Fig. 33, the bistable element is sensitive to the head, i.e. to the more or less pronounced closing of the output channels. In Fig. 34, the bistable element is insensitive to the head.

Figs. 35 and 36 show proportional amplifiers. They also furnish the symbol representation. These proportional amplifiers are based on an exchange in the amount of movement.

Fig. 35 presents an amplifier with a median dead point, i.e. a possible evacuation of the fluid jet in its center position, while Fig. 36 is a proportional amplifier without median dead point.

Fig. 37 represents a gate carrying out the logical OR-NOR function, shown symbolically and schematically; i.e. Y_2 occurs if y_1 does not occur and y_2 does not occur, and Y_1 occurs if y_1 occurs or y_2 occurs.

Fig. 38 shows a pneumatic clock and Fig. 39 is a symbolic and schematic representation of a gate carrying out the logical AND function, i.e. Y_2 occurs if y_1 occurs and if y_2 occurs.

The various fluid elements which we have discussed operate at nominal feed pressures of about 35/100 of an atmosphere bar. The response frequencies are in the order of 1000 cps per element.

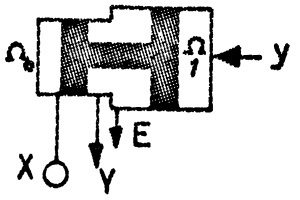
The device of Fig. 38 is the main part of the pneumatic clock, which must be completed as shown in Fig. 39.

This assembly can be constructed with free-piston elements. We have seen earlier in the schematic of Fig. 24 how a counter is constructed by means of elements with one moving part.

By means of COANDA-effect elements, bistable elements, we can also construct counters (see schematic Fig. 40 which shows the combination of bistable elements with a monostable element).

In conclusion, we can say that the fluid components NR1 to 10 with one moving part, the fluid turbulence components NR-T and the fluid COANDA-effect components NR-C, when in judicious combination, permit us to solve all problems of logical automation circuits and especially, the realization of a pneumatic numerical control.

Fig.1



NR 1 $Y = y$

Fig.2

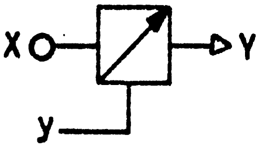
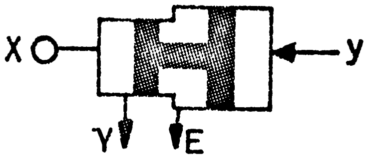


Fig.3



NR 2 $Y = \overline{y}$

Fig.4

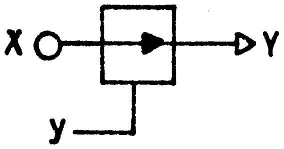
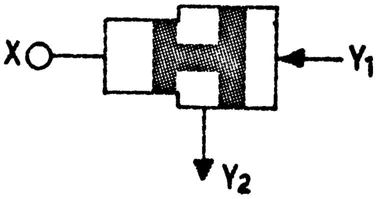


Fig.5



NR 3

Fig.6

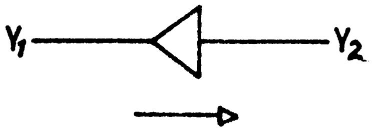
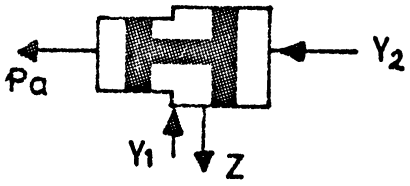


Fig.7



NR 4

$Z = Y_1 + Y_2$

Fig.8

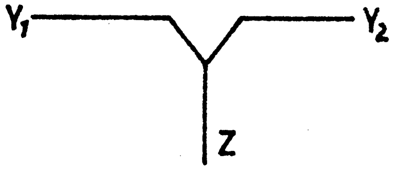
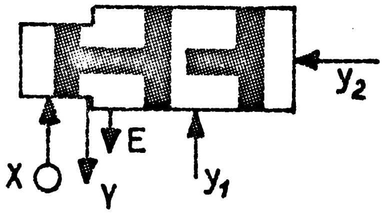


Fig.9



NR 5

$Y = y_1 + y_2$

Fig.10

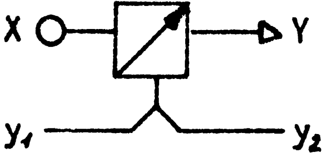
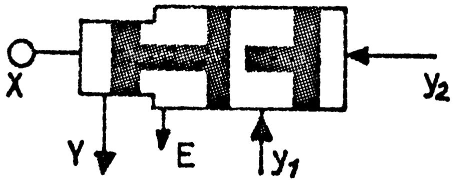


Fig.11



NR 6

$Y = \overline{y}_1 \cdot \overline{y}_2$

Fig.12

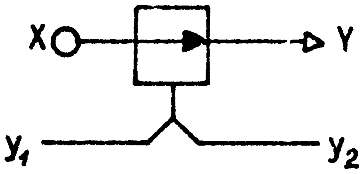
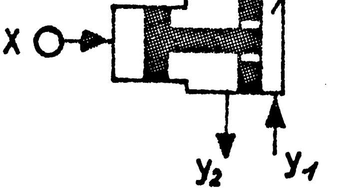


Fig.13



NR 7

Fig.14

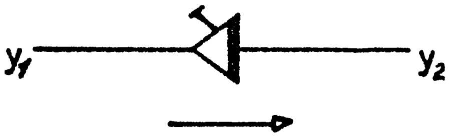


Fig.15

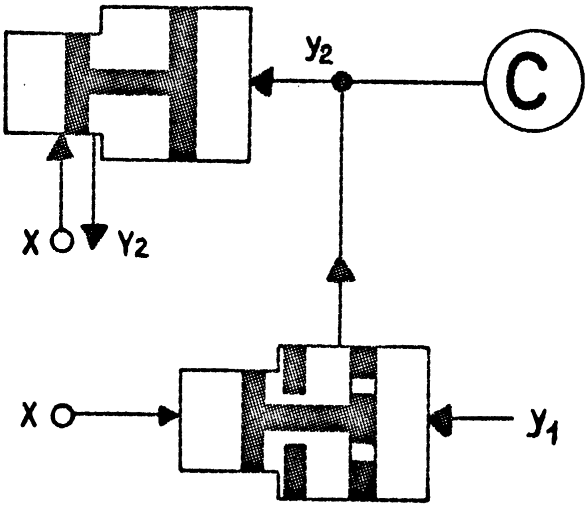
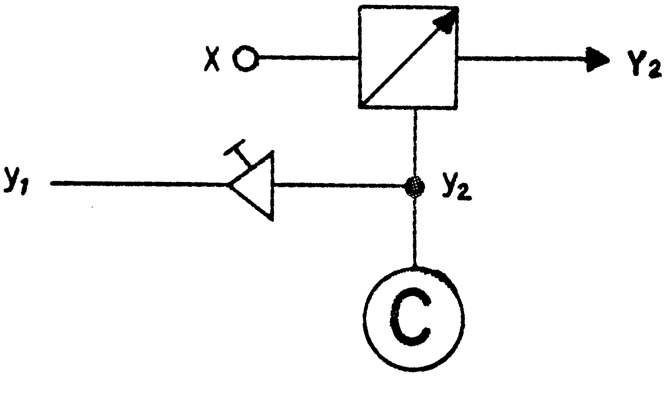


Fig.16



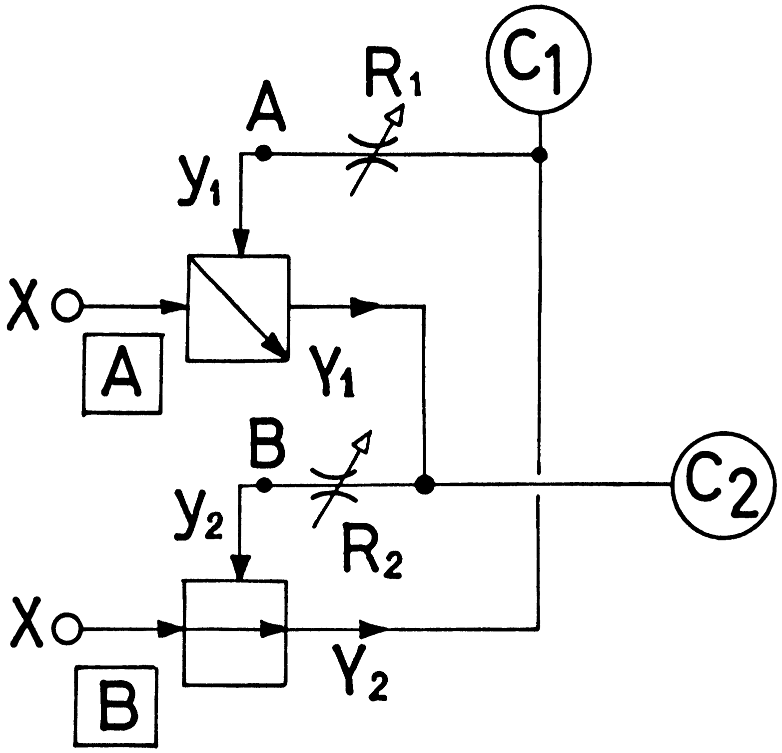


FIG. 17.

FIG. 19.

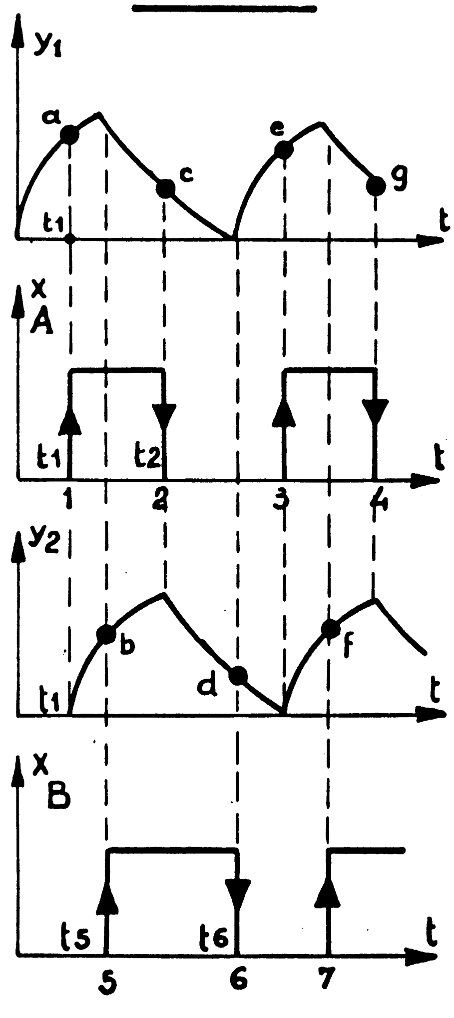
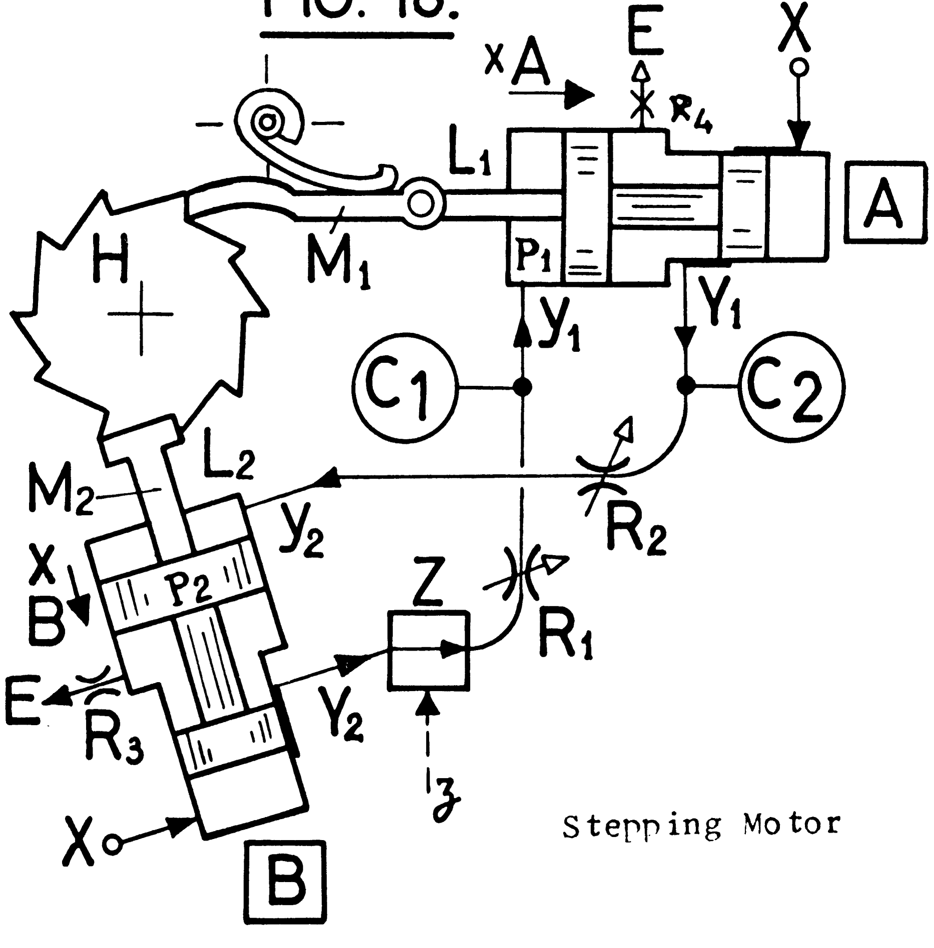


FIG. 18.



Stepping Motor

Fig. 20

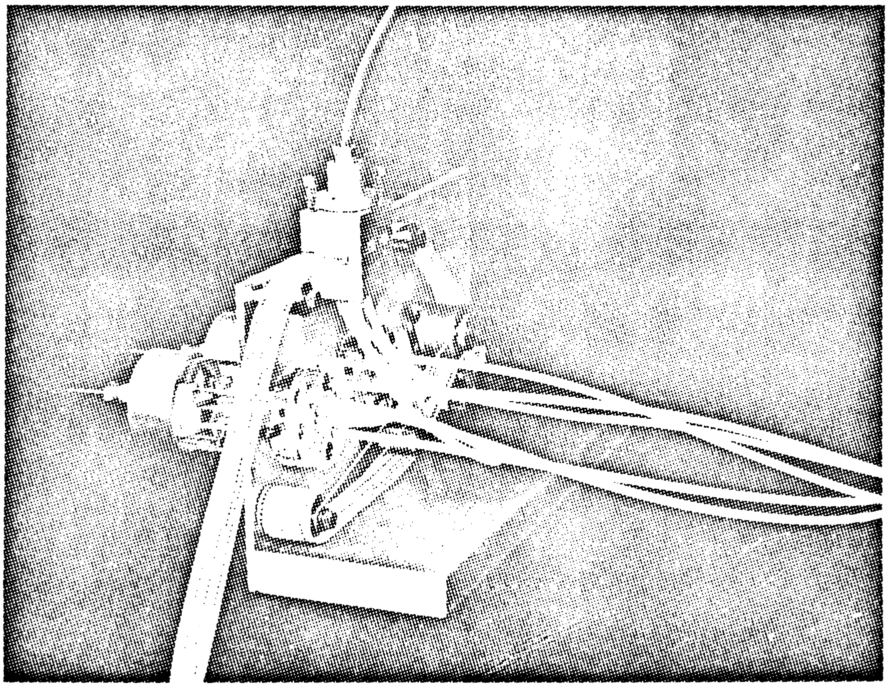
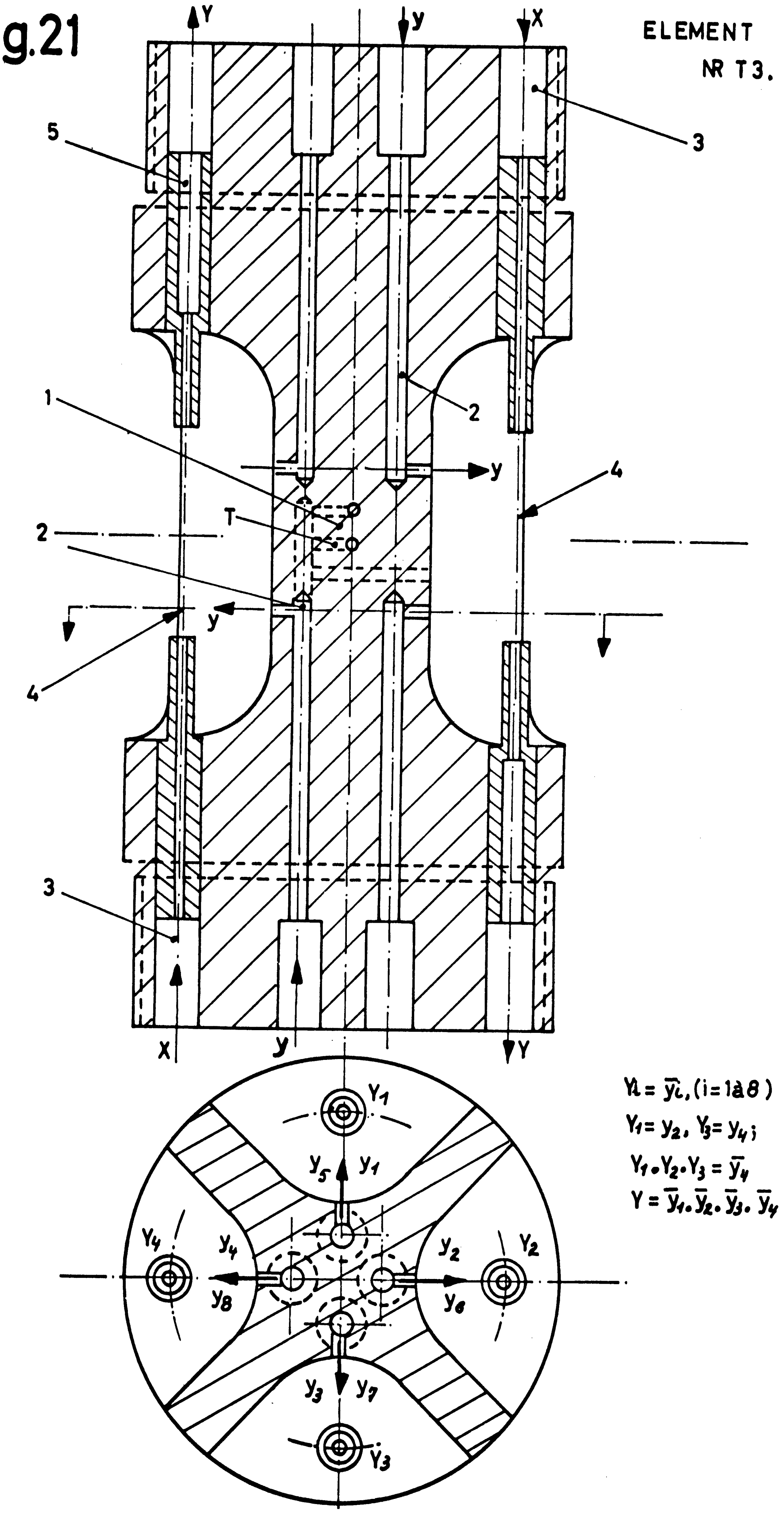


Fig.21



$Y_i = \bar{y}_i, (i = 1 à 8)$

$Y_1 = y_2,\ Y_3 = y_4;$

$Y_1 . Y_2 . Y_3 = \bar{y}_4$

$Y = \bar{y}_1 . \bar{y}_2 . \bar{y}_3 . \bar{y}_4$

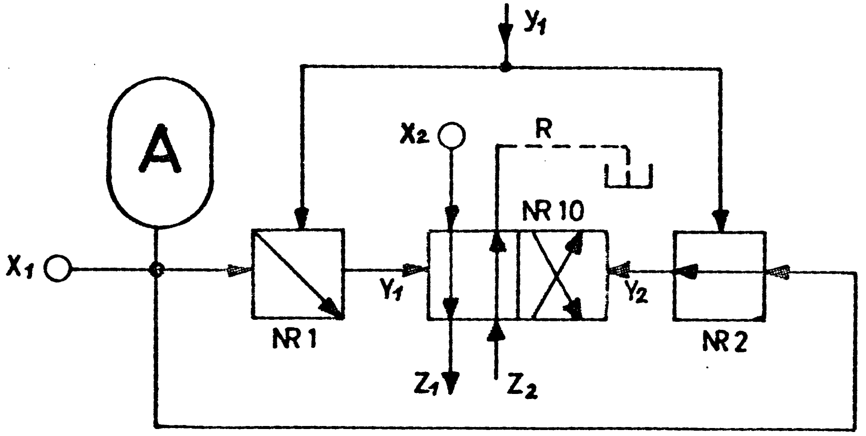


Fig.22

NR.10

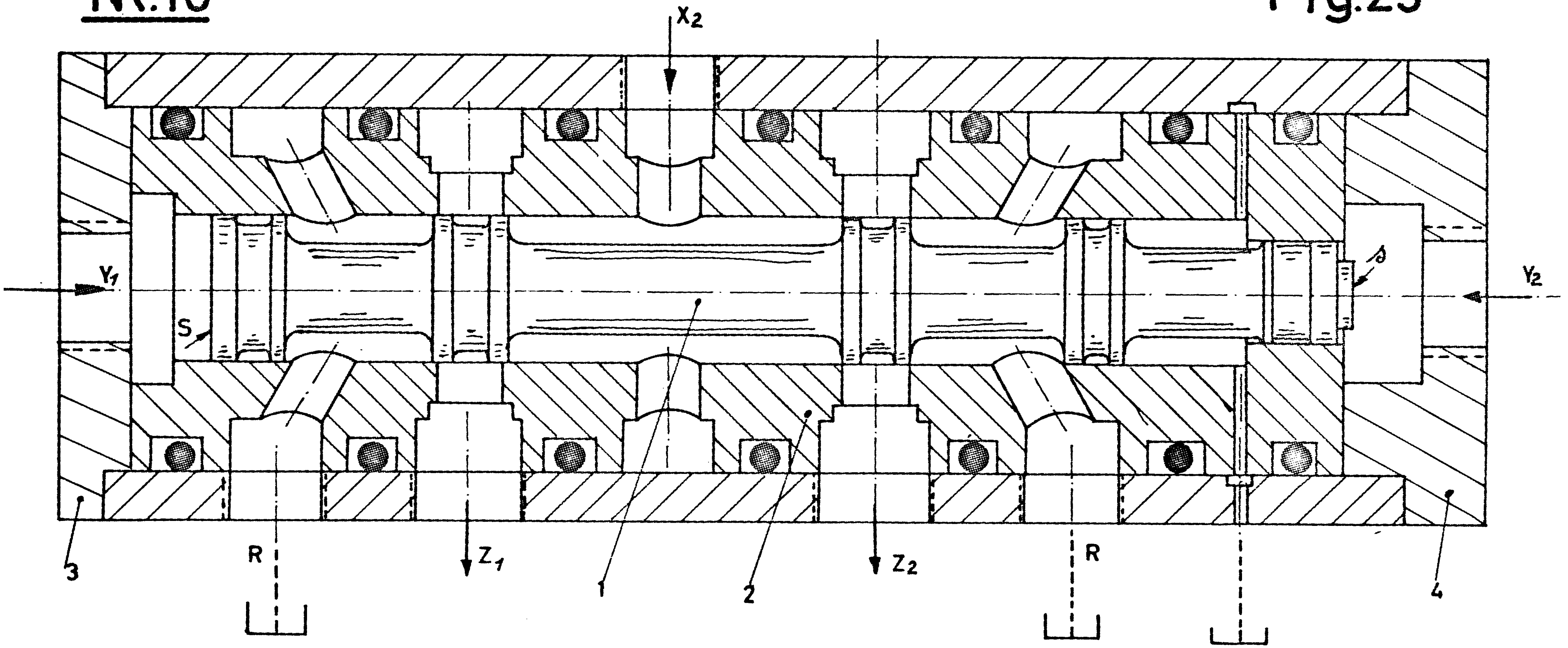


Fig.23

Fig. 24

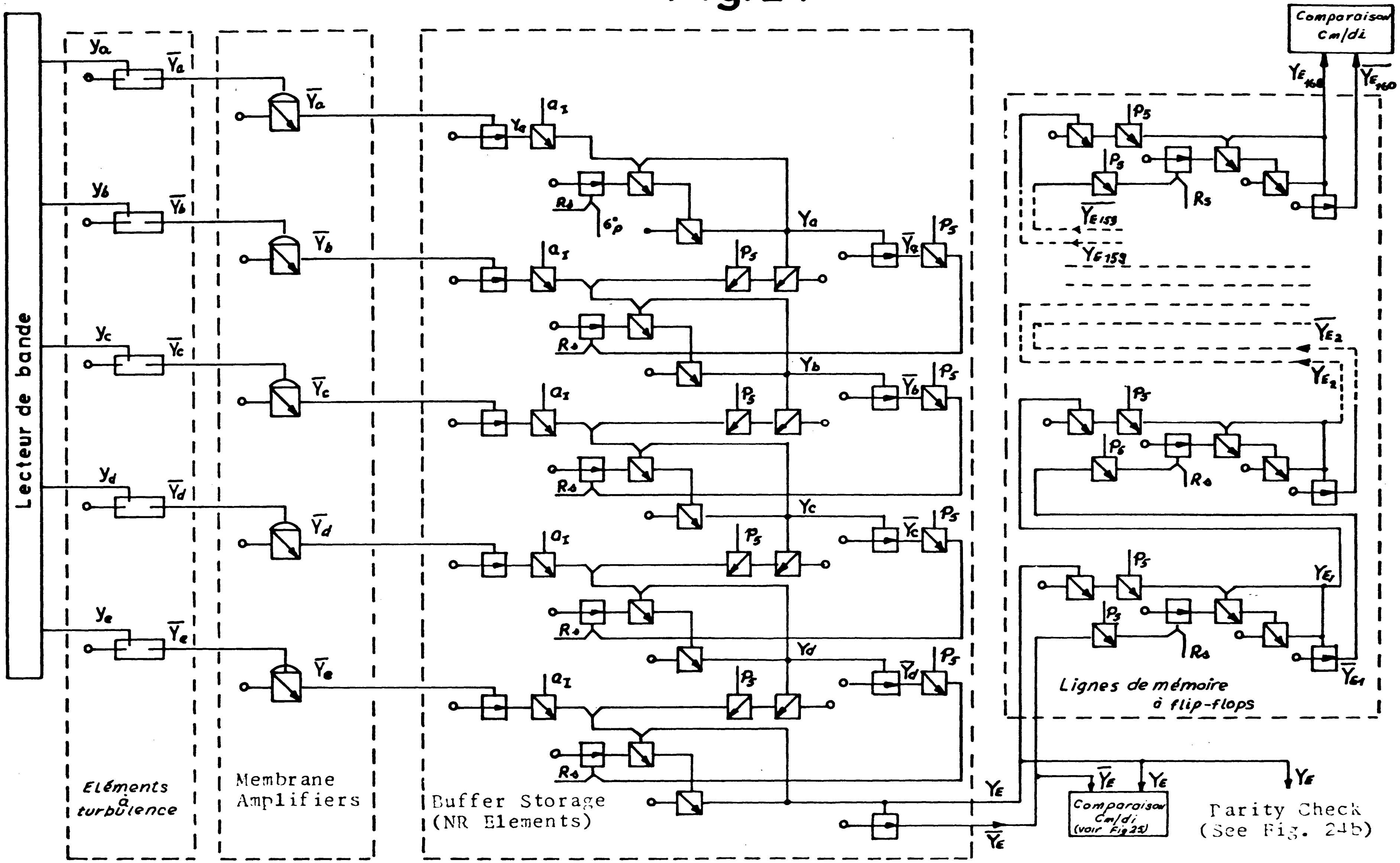
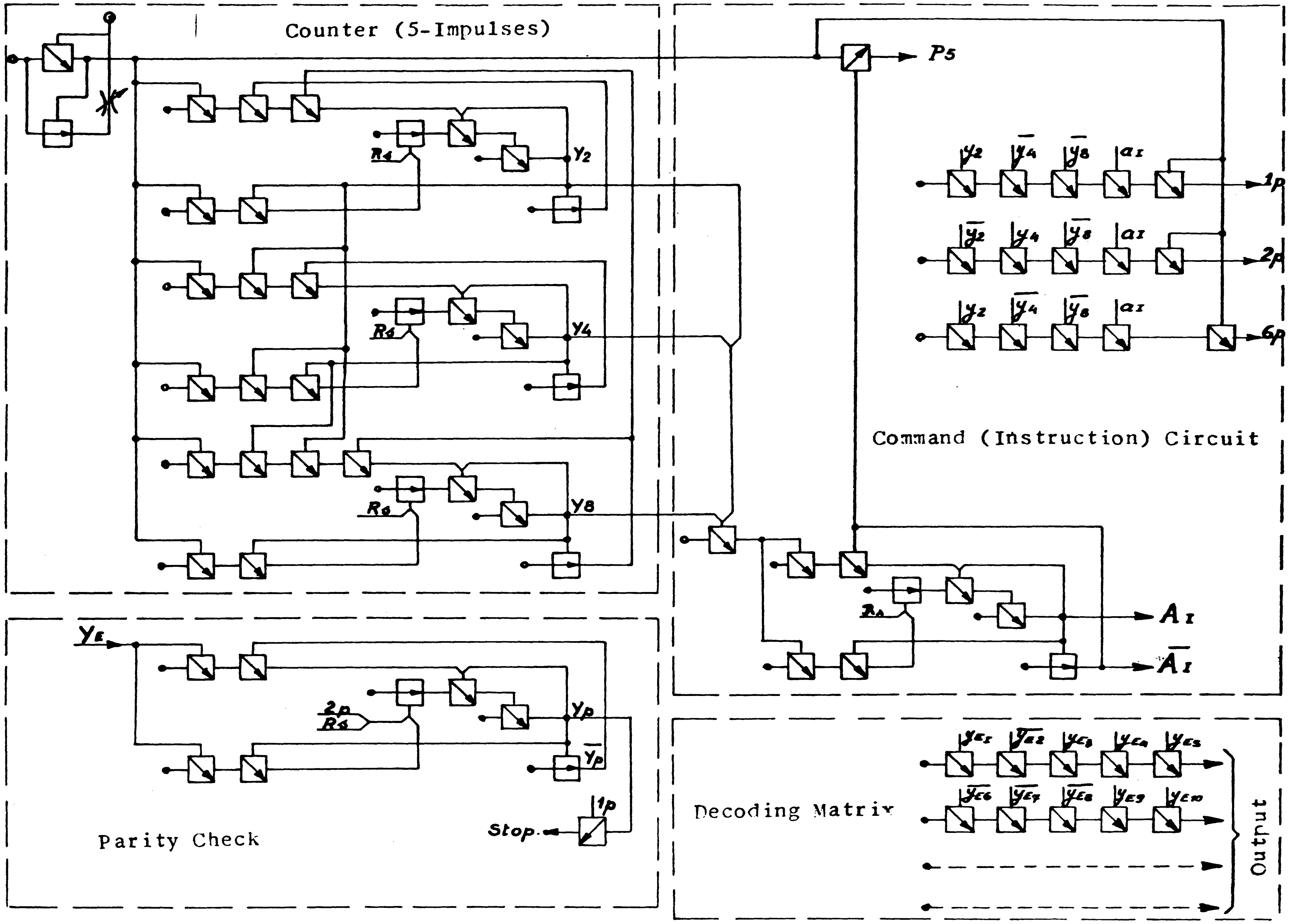
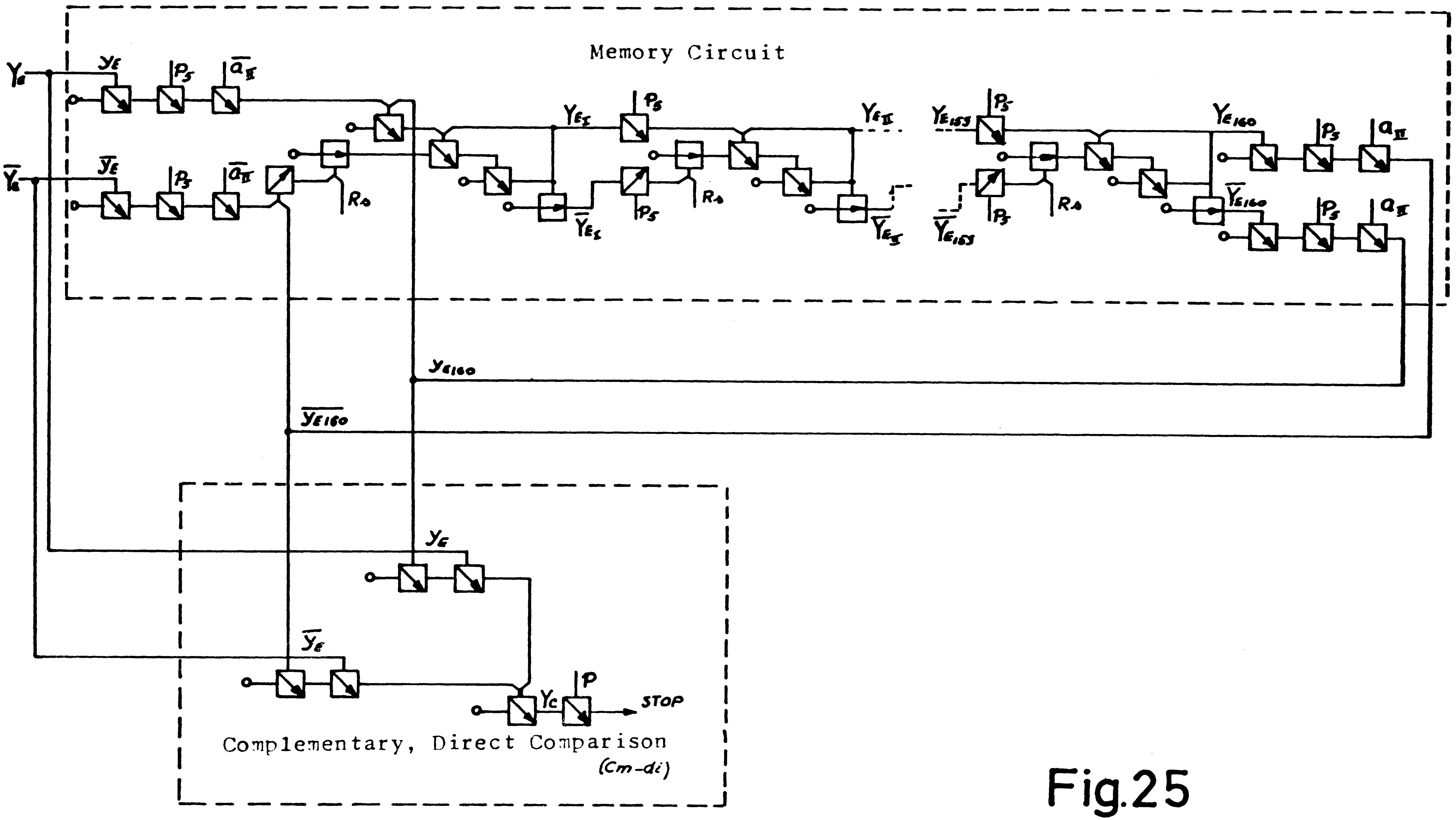

Lecteur de bande
Eléments à turbulence
Membrane Amplifiers
Buffer Storage (NR Elements)
Lignes de mémoire à flip-flops
Comparaison Cm/di
Comparaison Cm/di (voir Fig 25)
Parity Check (See Fig. 24b)
Y_a
$\overline{Y_a}$
Y_b
$\overline{Y_b}$
Y_c
$\overline{Y_c}$
Y_d
$\overline{Y_d}$
Y_e
$\overline{Y_e}$
a_1
P_5
P_3
P_6
R_4
R_5
6_p^0
Y_E
$\overline{Y_E}$
Y_{E_1}
$\overline{Y_{E1}}$
Y_{E_2}
$\overline{Y_{E_2}}$
$\overline{Y_{E159}}$
Y_{E159}
Y_{E160}
$\overline{Y_{E160}}$

FIG. 24 b


Counter (5-Impulses)
P5
R4
Y2
R4
Y4
R4
Y8
Command (Instruction) Circuit
y2
y4
y8
a1
1p
2p
6p
R4
A1
Ā1
Parity Check
YE
2p
R4
Yp
Ȳp
1p
Stop
Decoding Matrix
yE1
yE2
yE3
yE4
yE5
yE6
yE7
yE8
yE9
yE10
Output



Comparaison Cm - di

Fig.25

Comparaison Cm - di

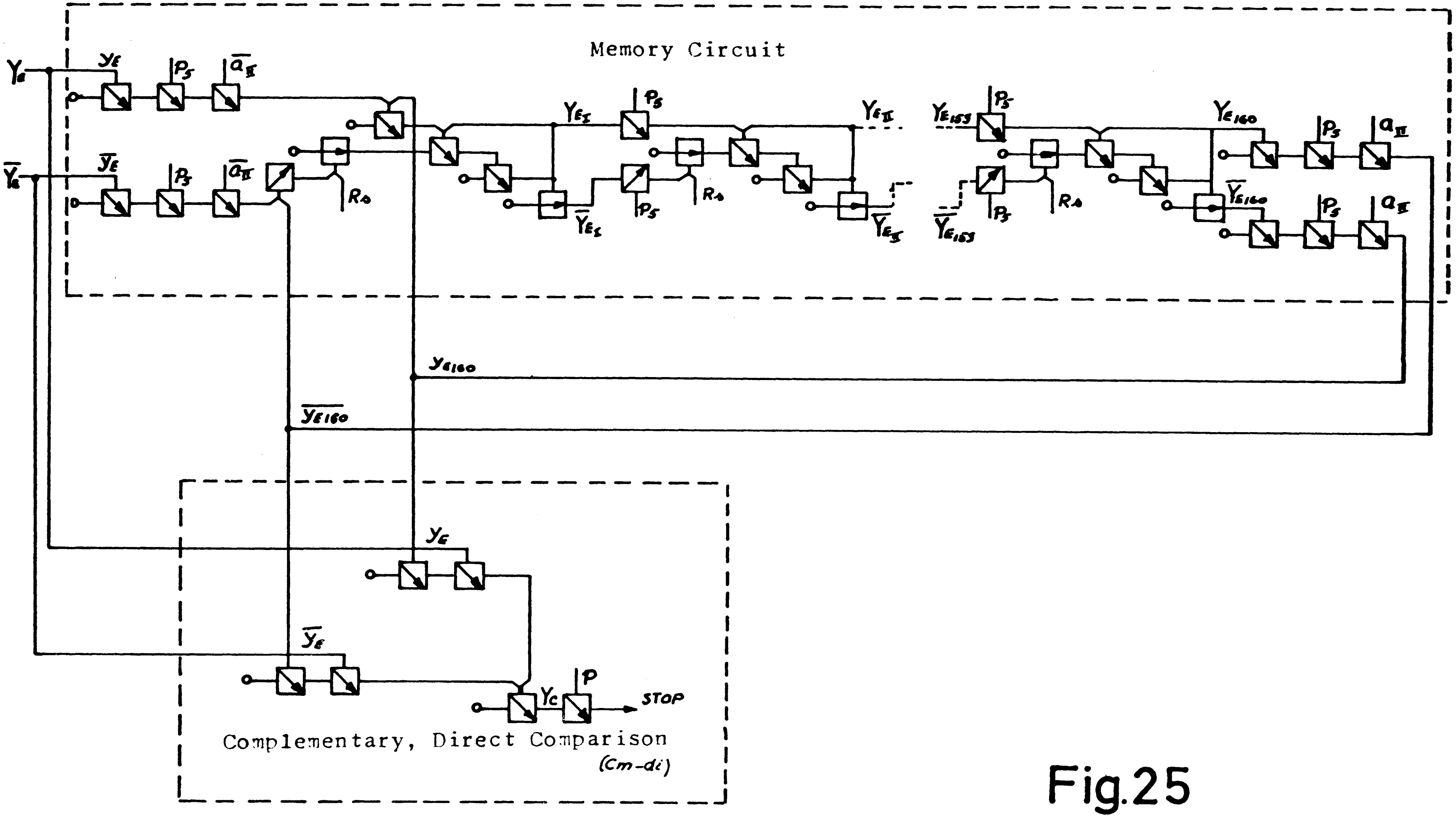


Fig.25

Program Input without verification

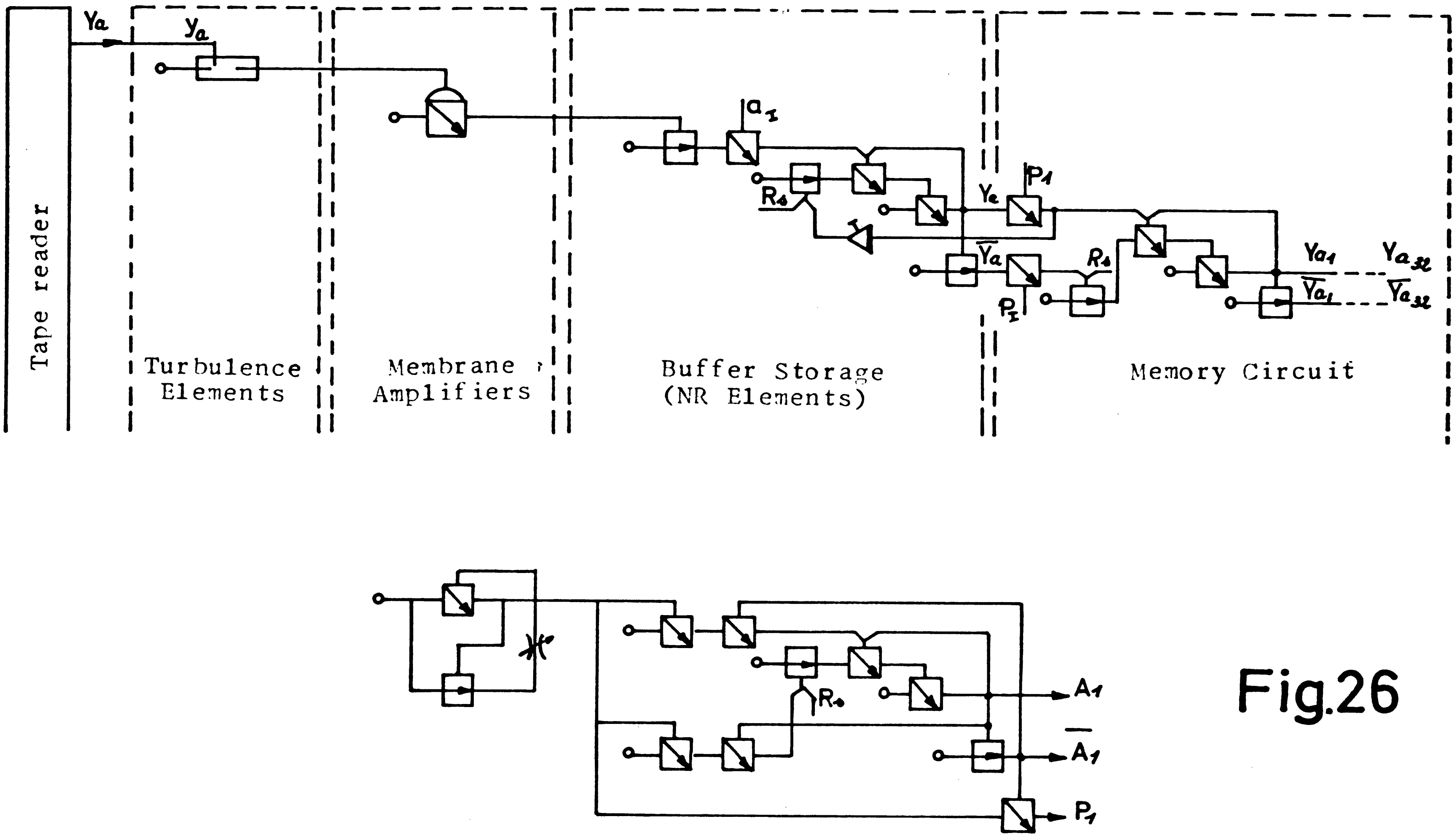
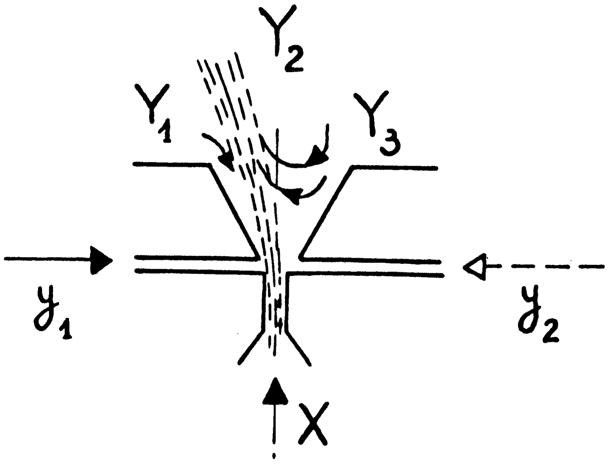


Fig.26



$Y_1 = y_2 \cdot \overline{y}_1$; $Y_2 = \overline{y}_1 \cdot \overline{y}_2$; $Y_3 = y_1 \cdot \overline{y}_2$

FIG. 27.

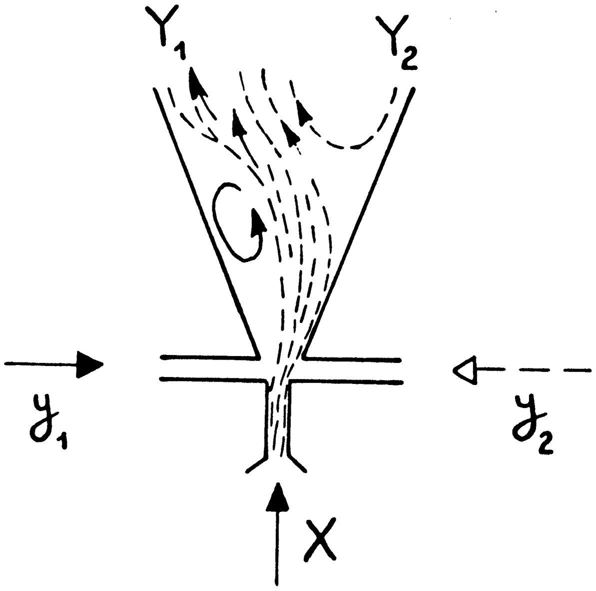


FIG. 28.

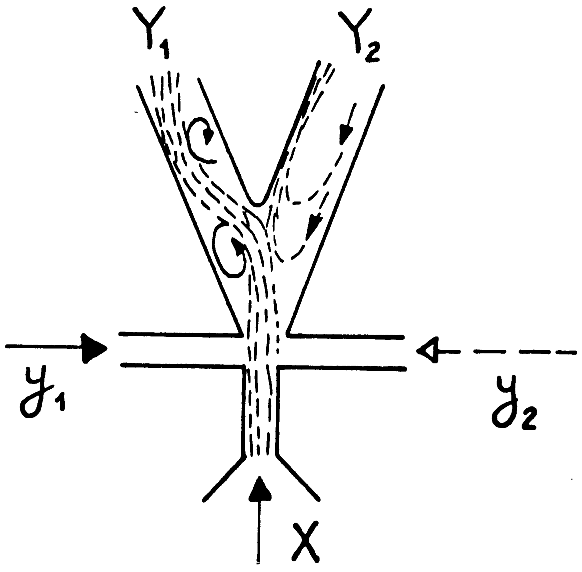
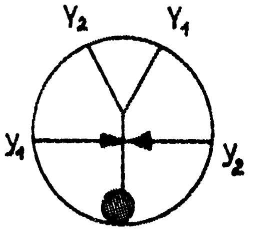
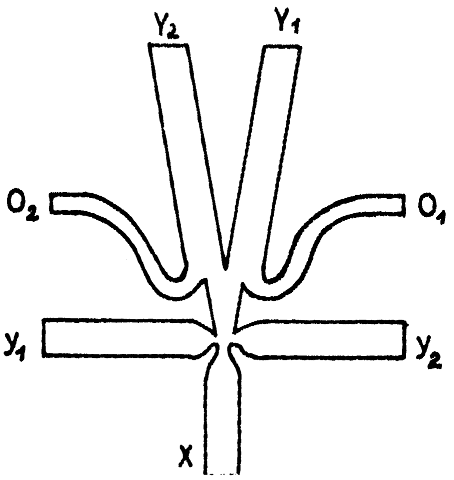


FIG. 29.

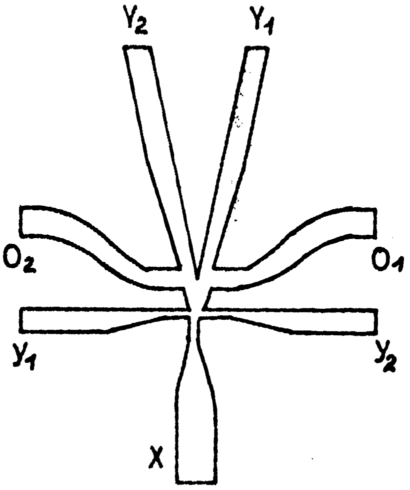


Bistable
(COANDA Effect)



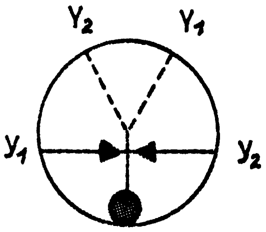
Sensitive to Load

Fig. 33

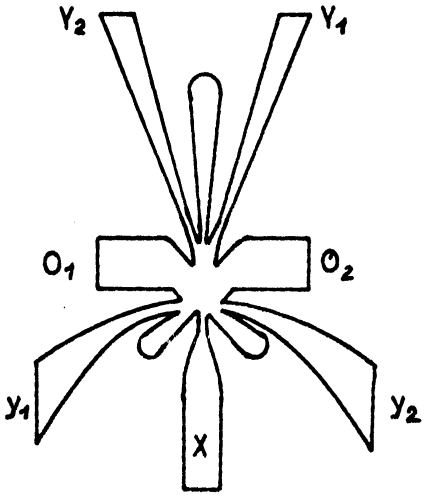


Insensitive to Load

Fig. 34



Proportional
Amplifier



with intermediate dead point

Fig.35

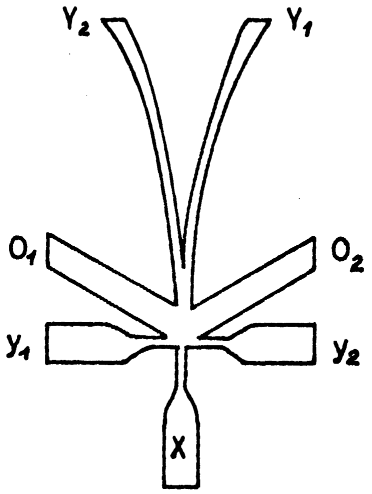
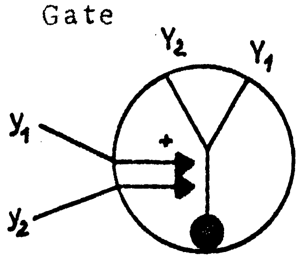


Fig. 36

OR-NR
Gate



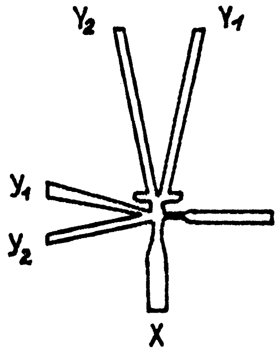


Fig. 37

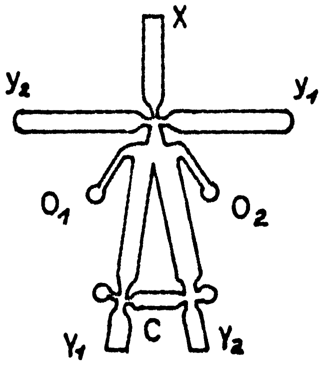
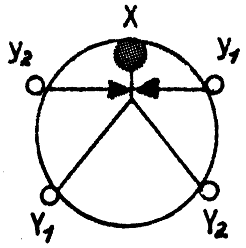
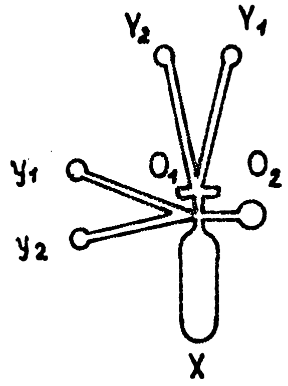


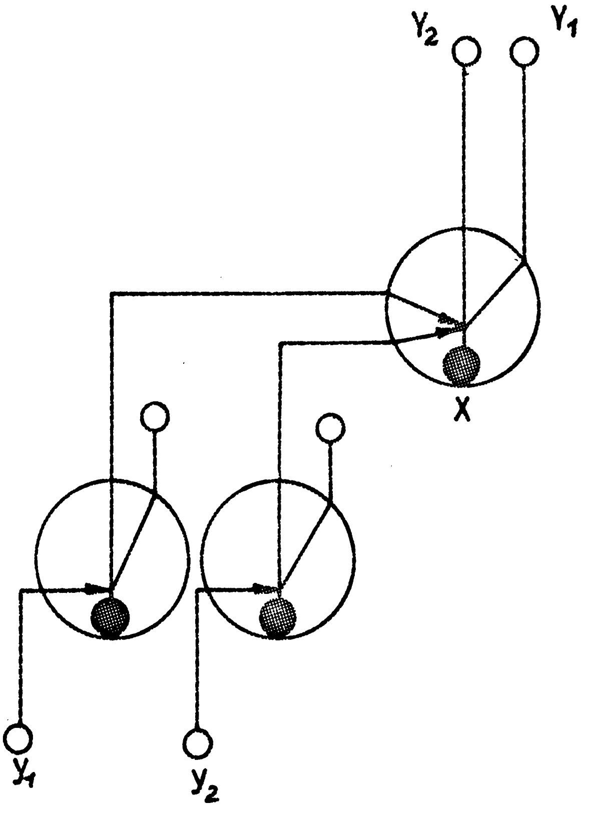
Fig. 38

Pneumatic
Clock





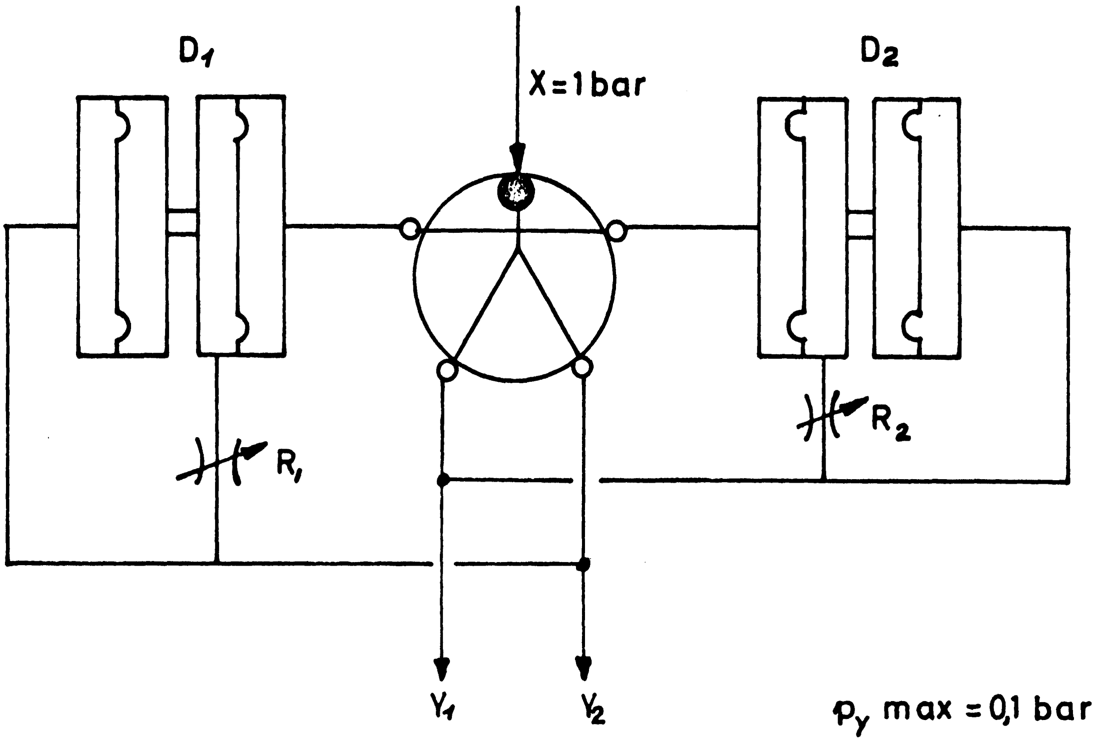
Porte ET.



$Y_2 = y_1 . y_2$

Fig. 39

IMPULSE GENERATOR



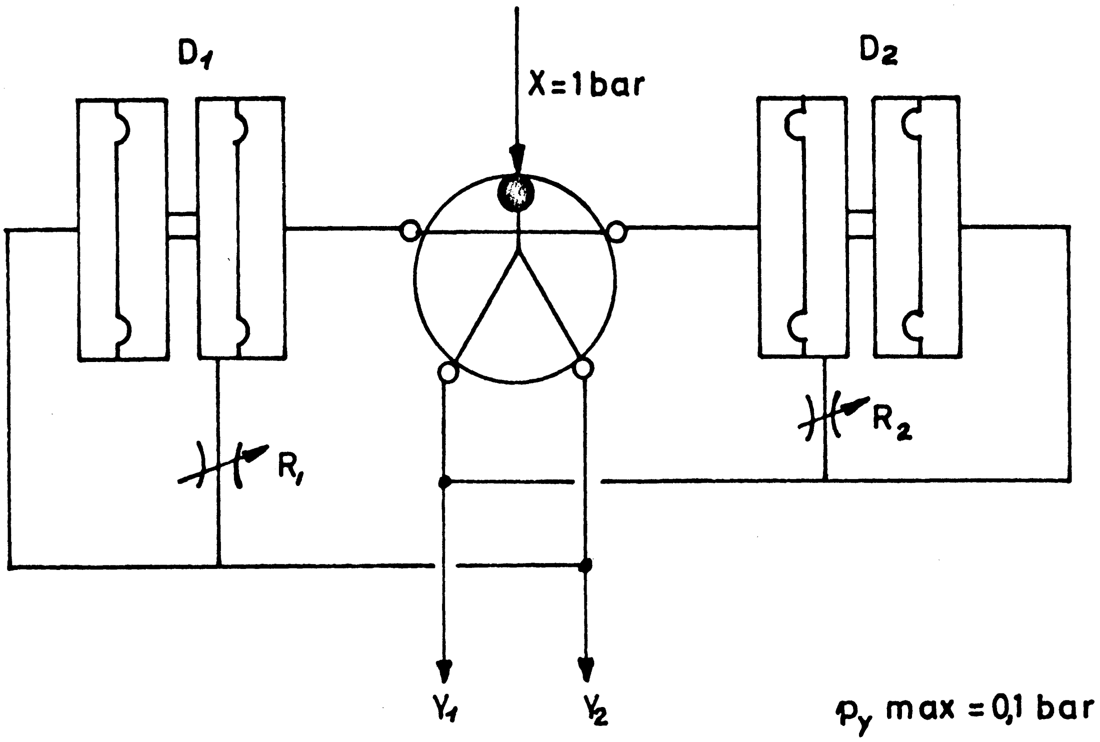
R1, R2 : Needle Valves

D1, D2 : Membrane Valves

Frequency adjustable from 4 cps to 1/20 cps
Impulse duration adjustable from 0.25 to 10 secs.

Fig.40

IMPULSE GENERATOR



R_1, R_2 : Needle Valves

D_1, D_2 : Membrane Valves

Frequency adjustable from 4 cps to 1/20 cps
Impulse duration adjustable from 0.25 to 10 secs.

Fig.40

BINARY COUNTER (COANDA Effect)

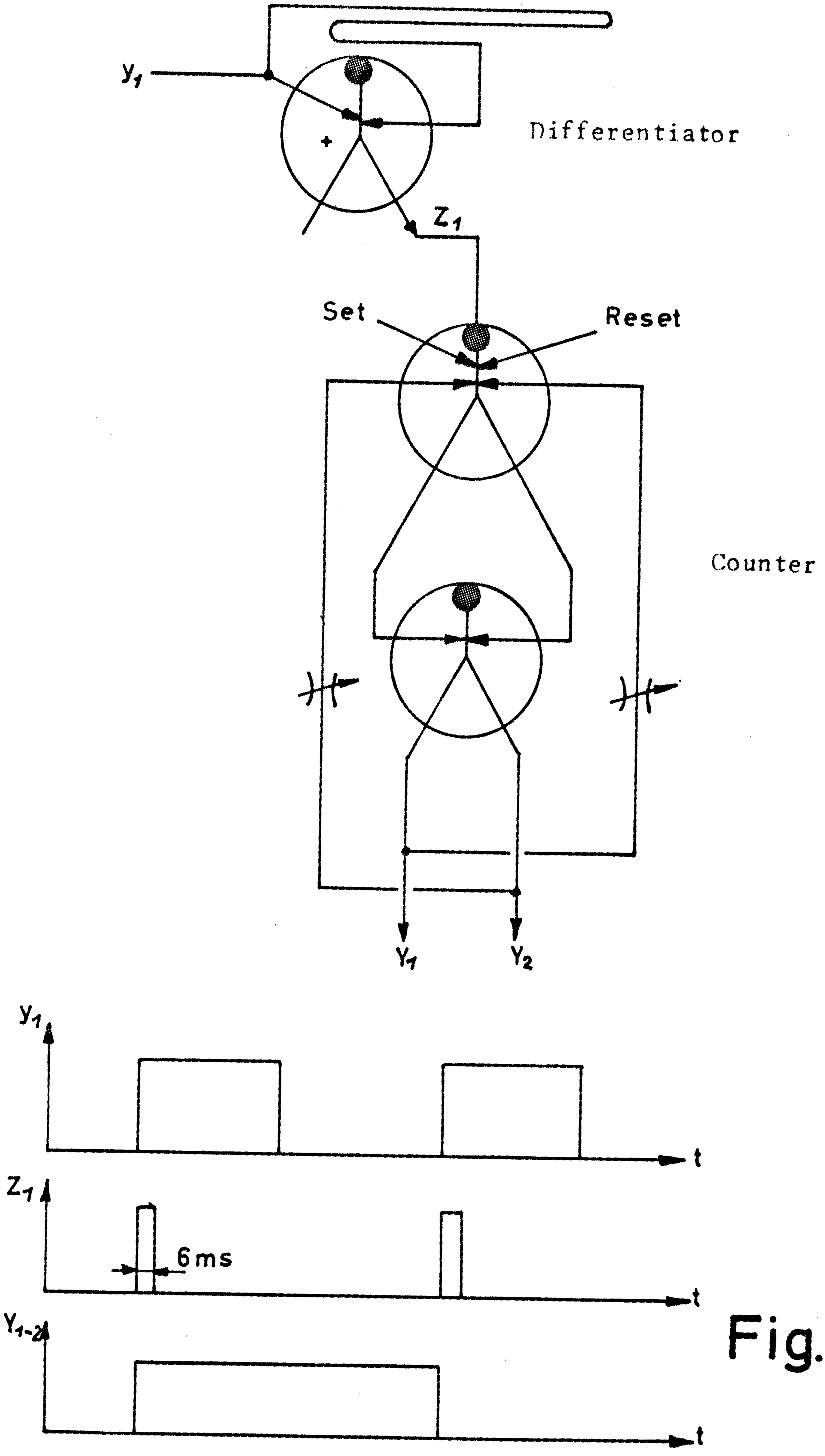


Fig. 41

BINARY COUNTER (COANDA Effect)

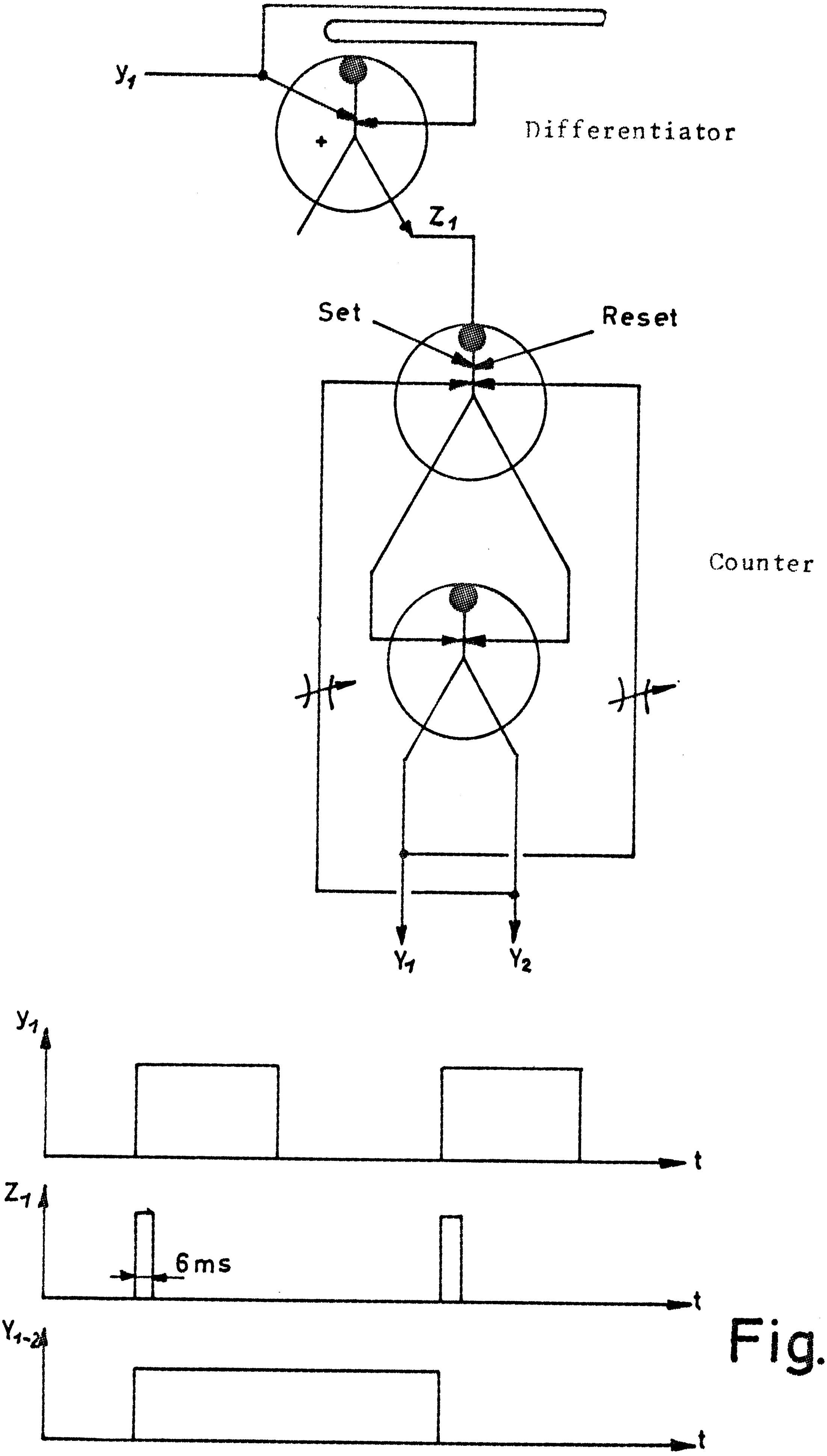


Fig. 41