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**ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ**

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**SYSTEM OF AUTOMIZED DETERMINATION OF CHARGED PARTICLE  
TRAJECTORIES IN MAGNETIC FIELDS OF LARGER EXTENTS**

**ԵՐԵՎԱՆ 1981 ԵՐԵՎԱՆ**

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А.Р.ТУЛАНЯН

СИСТЕМА АВТОМАТИЗИРОВАННОГО ОПРЕДЕЛЕНИЯ ТРАСС  
ЗАРЯЖЕННЫХ ЧАСТИЦ В МАГНИТНЫХ ПОЛЯХ БОЛЬШИХ  
ПРОТЯЖЕННОСТЕЙ

Описана созданная автоматизированная система определения траекторий частиц методом гибкой нити с током. Система обеспечивает определение траекторий частиц с энергиями выше 100 МэВ в магнитных трактах любой конфигурации и с протяженностью трасс до нескольких десятков метров с разрешением по импульсам до  $3 \cdot 10^{-4}$ . Производительность системы составляет в среднем 1500 трасс/час.

Ереванский физический институт

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SYSTEM OF AUTOMIZED DETERMINATION OF CHARGED PARTICLE  
TRAJECTORIES IN MAGNETIC FIELDS OF LARGER EXTENTS

An automatized system for the determination of particle trajectories by the floating current-carrying wire method is described. The system is able to determine the charged particle trajectories with the energy above 100 MeV in magnetic systems of any configuration and with track extent up to several tens metres with momentum resolution up to  $3 \cdot 10^{-4}$ . The system efficiency makes 1500 tracks/hour on the average.

Yerevan Physics Institute

Yerevan 1981

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YEREVAN PHYSICS INSTITUTE

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At present the floating current-carrying wire method for the determination of charged particle trajectories in magnetic fields of larger extents has found a wide-spread application in transportation or acceleration of the high-energy beams. It is conditioned, first, by the fact that the modelling or imitation accuracy of the particle motion provided by this method becomes acceptable only for high-energy beams. Second, such advantages of the method as the possibility of the field investigation and tuning in the completely assembled magnetic system with account of influences of all metallic constructions and geodesic errors accompanying the system as well as the substantial decrease of the volume of necessary measurements and data handling due to the integrational measurement as compared to the point measuring method of the magnetic field topography, make the floating wire method highly attractive.

The modelling method of charged particle motion by means of the floating wire is known to be based on the coincidence of the position of the conductor with current  $I$  in the magnetic field with the particle trajectory whose momentum is connected with the current and tension  $T$  of the wire through the following relation [1-3]:

$$P = cgT/J = 2.9426 T/J \quad (1)$$

where  $C$  is light velocity,  $g$  is gravity acceleration (if  $T$  is in grams and  $J$  in amperes, then  $P$  is to be in MeV/c). Here the average value of the radius of the circle along which the wire is placed can be calculated by the expression

$$\bar{\rho} = 9820 \frac{T}{J\bar{H}} \quad (2)$$

where  $\bar{H}$  is field intensity in oersteds, the value of  $\rho$  is in cm.

The wire tension is usually provided by a load suspended to the conductor and thrown over the turning block. That is why the value of the error of the momentum determined by relation (1) depends on the current measurement error the flexibility and weightlessness of the wire and the friction value of the bearing axis of the turning block.

It is evident now that when using the method for the small momentum particles, the difficulties will arise caused by the necessity for creation of weak wire strain at high current. At the same time the strain minimum value must be substantially higher than the wire weight in order to provide the minimum wire sagging. Besides, small strains bring to the error notable increase due to the wire elasticity. One should take into account that the wire weight is proportional to its cross section; the breaking force and elasticity are inverse proportional to the square of the cross section; and permissible current density noticeably increases with the decrease of the wire diameter. Therefore the necessity of the careful selection of the wire type is evident, and it is desirable to create special wires for the method.

At present, the accuracies practically achieved by the floating wire method (taking into account the wire coordinates measurements error) can be

specified by the following figures. For the particles with momenta in the region of tens MeV the errors are of order of  $5 \times 10^{-3}$ , while in the region of more than 10 GeV they reduce to  $10^{-5}$ .

The improved automatized system for charged particle trajectory determination in the extended magnetic fields using the wire method is worked out in Yerevan Physics Institute. This system has been successfully exploited for some years, being constantly improved [4, 5]. The automatization of all the basic processes of the trajectories determination using the wire method allows one to increase the measurement accuracy as well as noticeably reduce the time and labour expenditure of the researches, thus creating the possibility to define about 1500 trajectories per hour. This is achieved by the automatic coordinate measurements of the constantly moving wire with the discrete step control in the measurement region as well as by the variation of the wire current within a wide range according to the given program. The system is connected with a computer for the simultaneous registration and handling of the values of the coordinates and wire current as well as of the magnetic field intensity in the reference point of the investigated electromagnetic system.

The functional scheme of the main system is shown in Fig.1, where the floating wire is stretched between A and B points in the investigated magnetic system. The wire A end is fastened on the support of the moving carriage of the driving coordinate mechanism (ЗКП). The B end is thrown over the block and the load T is fastened on it creating constant wire strain. The interaction of the wire with the magnetic field is provided by the d.c. of wire feeding by means of the code handling supply source. The induction monitors  $\Delta_1 \div \Delta_5$  of the beam type are used in the resonance mode as a wire position zero indicators. To provide the use of induction monitors the

wire is additionally fed with high-frequency current (100 kHz frequency). The choice of such frequency is stipulated by two causes. First, the frequency must be sufficiently high, so that the a.c. passing through the wire in the magnetic field would not oscillate it. Second, the frequency is desirable to be no more than  $\sim 500$  kHz as in this case the choice of apparatus simple design is possible, the problems of the hindrance defence are simplified etc. The induction monitors are mounted on the coordinate following mechanisms  $K\Lambda_1 \div K\Lambda_4$ . The follow-up units  $BC_1 \div BC_5$  provide the uninterrupted following of wire position by the corresponding carriage with the induction monitor. Running coordinates of each carriage is counted by the corresponding reversible counter (counters  $C_1 \div C_4$ ) and registered in the buffer register (BP).

The control system (YY) yields the command for the information readout from all the registration systems at the beforehand given step of the moving point A [4] as well as for discrete current values setting in the wire and for stopping the moving carriage ( $3K\Lambda$ ) after the measurement program is completed.

The lock circuit (C3) provides the information input into the buffer register from the reversible counters without the information loss.

The outside view of the coordinate following mechanism is shown in Fig. 1. The induction monitor 1 is set on the special support in the centre of the carriage. The slave electric motor 3 controlled by the corresponding following unit provides the coincidence of the monitor axis with the floating wire direction with the accuracy no worse than  $\pm 20$  mK. The carriage linear movements with the induction monitors transform into periodic voltage pulses by means of the angle diffractive transformer. Such long (about 1 m) coordinate following mechanisms are usually used for investigating the wide-apertured magnetic channels, e.g. different spectrometers or analyzing mag-

nets. While investigating small-apertured magnets (smaller than 20 cm), e.g. the magnets of high-energy circular accelerators, it is more expedient to use semiconductor-type fixed monitors in order to register the wire coordinates [6].

The turning block uninterrupted angular following the wire position is performed by means of the monitor  $\Delta_5$ , so that the wire would not touch the block groove walls that will give additional measurement error. The special duraluminium turning block with diameter 100 mm and thickness 2 mm with small friction has been manufactured. The magnetic suspensions are used for friction lessening of the rotation axis [7].

However, the described system is able to provide the determination of the trajectory only with the angle no more than  $\pi$ -radian and the track extension no more than 15 m. The particle trajectory imitation by means of the wire in the uniform magnetic field along the arc  $\theta \geq \pi$  or in magnetic lenses in case the wire is stretched out of their focal distance is impossible due to the rise of wire instable position. To provide the wire stable position the wire strain  $T$  must depend on the measured trajectory length  $L$ .

In the work [8] by both the wire position potential function investigation and Fourier analysis method of the arbitrary disturbances the following expression was obtained for this dependence

$$\chi = \frac{dT}{dH} \geq \frac{T}{L(1 - \frac{\theta}{\pi} \operatorname{tg} \frac{\theta}{2})} \quad (8)$$

It is evident that to create such variable wire strain mechanically, namely by means of the spring with the variable hardness  $\chi$  or pendulum suspension of the load is practically impossible.

To fulfil the condition (8) an improvement was made in the described

system the essence of which can be understood from the functional scheme of Fig.3. Ferromagnetic load 4 is placed into the solenoid with two coils: main one 16 and correcting one 17. The wire and solenoid main coil are fed by the controlled d.c. source 10 and the correcting coil by source 11. The systems for measuring the load position in solenoid 12, for the solenoid moving in the vertical and horizontal planes 13 and for centering of load 14 provide the creation of the required variable tension of the wire with high accuracy about  $10^{-5}$ .

The results of the realization of such development are described in detail in the work [7], where they showed the possibility of the particle trajectories determination with the turning angle up to  $2\pi$  radian and also the trajectories measured out of the focal distance of the magnetic lenses.

Further on, for increasing the length of the measured tracks it is necessary to work out systems for reducing wire sagging under the action of its own weight. By the way, the sagging error may be determined experimentally with sufficient accuracy by means of the vertical wire movement. Besides, it should be taken into account that in some cases the instability in the vertical plane takes place, e.g. when investigating the lenses with double focusing; in these cases, as the practice has shown, the sagging must not exceed 1-2 mm at which the vertical stability is not disturbed.

Usually, to reduce the sagging the support glass bars are used, the friction influence of these supports being reduced by the excitation of the wire mechanical oscillations of several kHz frequency by means of the wire feeding with additional current of the corresponding frequency.

However, another device designed and manufactured in the above automatized system as its further improvement allows to reduce the sagging practically without any additional errors in the measurements. The functional scheme of

the device is shown in Fig.4, where 5 is a two-coiled small-size magnet which is placed so that the wire would be stretched in its interpolar gap, parallel to the planes of the poles. The magnet is fastened on the moving carriage of the coordinate-following mechanism 6 which provides coincidence of the wire coordinate with the magnet gap centre. One magnet coil 7 is fed by the controlled d.c. source and the second one 8 is connected in series to the wire power source in the antiphase with the first one. The number of turns in coils 7 and 8 and the current magnitude of the source 9 are chosen so that the total magnetic flux in the gap when interacting with the wire lifts the latter to the constant height within the wide ranges of the wire current variation.

Thus, the developed automatized system is able to determine the charged particle trajectories with the energy above 100 MeV in the magnetic systems of any configuration and with track extent up to 50 m within  $5 \cdot 10^{-3} \pm 3 \cdot 10^{-4}$  accuracy. Such a system may be employed not only for the investigation of large magnetic systems which usually are in the extracted beams channels, but it is also used for the adjustment and calibration works just inside of the circular tunnels of the magnetic systems of the new large cyclic accelerators, such as УНК, LEP and the others.

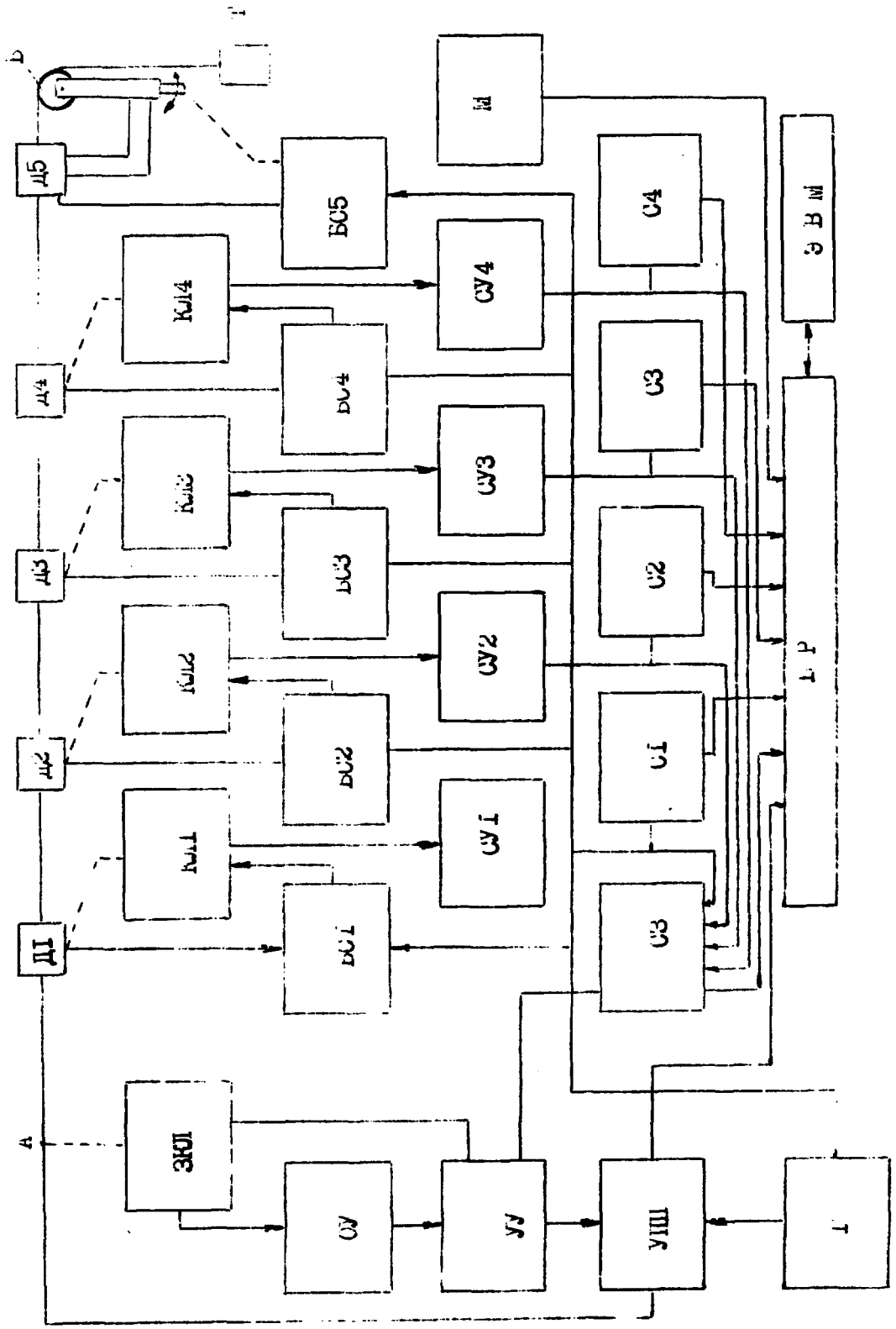


Fig. 1

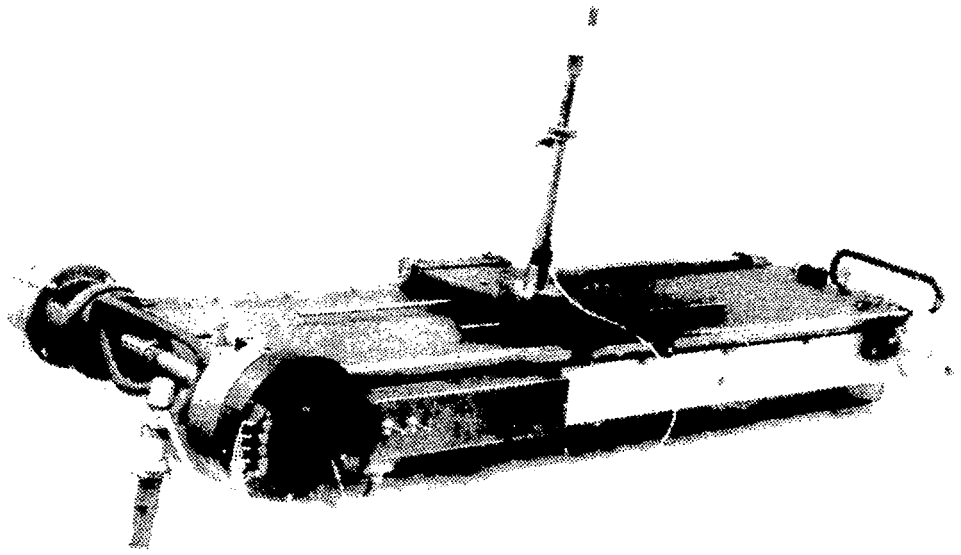


Fig. 2

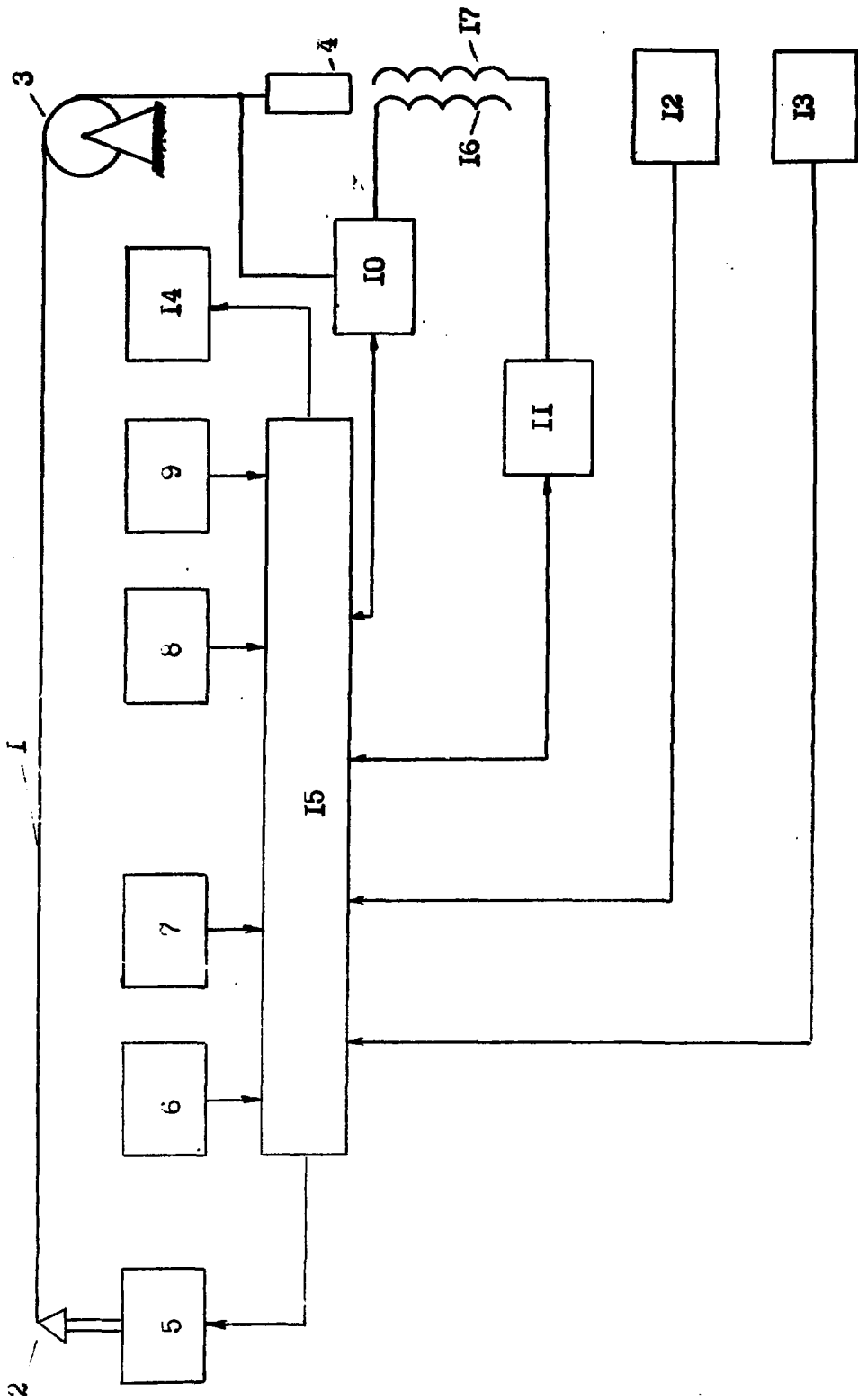


FIG. 3

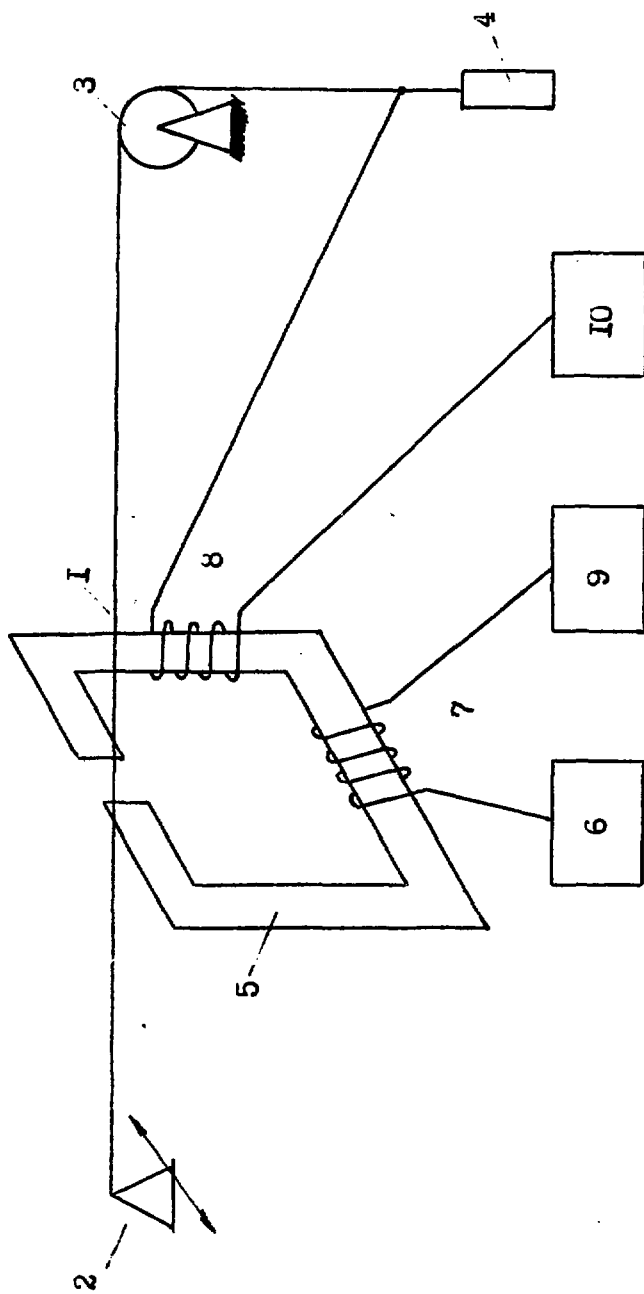
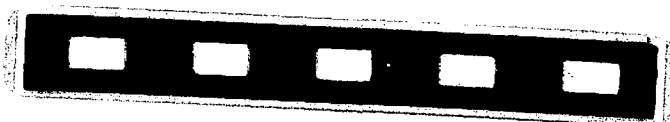


FIG. 4

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