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AELT-1 COMPUTER SCANNER FOR NUCLEAR PHYSICS AND RELATED APPLICATIONS

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AELT-1 computer scanner for nuclear physics and related applications

The paper describes an automatic scanning device with a computer-controlled cathode-ray tube for measuring information on 35 mm film. Scanners of this type are incorporated in a system for the processing of pictures from a wide-gap spark chamber and of test flight information. The device may be used in a wide range of scientific and technical applications.

The work was carried out at the JINR Laboratory of Computing Techniques and Automation.

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The development and application of AELT-1 computer scanners [1,2] has led to the construction of a comparatively simple and reliable CRT device for measuring 35 mm ciné film which is suitable for a wide range of scientific and technical applications. Ways of using these scanners in systems for processing film information have also been examined.

1. DESCRIPTION OF THE FUNCTIONAL DIAGRAM OF THE AELT-1 SCANNER

The functional diagram of the AELT-1 scanner is shown in fig. 1. The pictures (generally film frames) are scanned by the "flying spot" method, whereby the spot is projected on the pictures and photomultipliers record the times when the CRT light spot meets a dark area (nuclear particle track etc.). The light spot on the CRT screen moves along lines whose position (number) is controlled by computer. The co-ordinates are computed by means of a special system of reference grids whereby part of the light from the CRT [3] is separated out by means of semi-transparent mirrors. The co-ordinate codes at the beginning and end of the dark area are transferred to the control computer for processing. During the scanning process, the computer controls the discrimination level of the output signal in the film channel.

The scanner has an extensive system for operator/computer dialogue which is used when program difficulties are encountered in the measurement and recognition processes.

2. TECHNICAL CHARACTERISTICS OF THE AELT-1 SCANNER

The AELT-1 scanner is designed to measure information on 35 mm film.

Frame size - 26 x 19 mm.

Accuracy of individual measurements along the line scan - 15 μm, along the frame scan without special adjustments - 25 - 50 μm.

Resolution - 30 μm.

Control computer - BESM-4.

The computer controls the position of each line on the raster and the discrimination level of the output signals (operational scanning control).

Maximum number of lines in the raster - 512.

Number of discrimination levels - up to 256.

Facilities available for operator-computer dialogue:

- display screen;
- optical screen for projecting picture undergoing measurement;
- device for manual control of the discrimination level;
- light pen;
- functional keyboard.

3. DISTINCTIVE FEATURES IN THE DEVELOPMENT OF THE AELT-1 SCANNER AS A RESEARCH INSTRUMENT

The main distinguishing features in the development of the AELT-1 scanner as a research instrument are the following:

- development and incorporation of on-line scanning control;
- use of the monitor in the cyclical scanning mode in order to assist dialogue during measurements;
- comparatively simple technical design achieved mainly by using a special system of reference grids in the precision measuring part of the device;
- a high degree of reliability both in the apparatus and in the measurements, which is achieved by using special computing and control techniques.

3.1 On-line scanning control

In order to process the measurement results after each line scan and thus decide on the position of the next line and the discrimination level for the output signals, i.e. in order to achieve on-line scanning control, a medium-sized control computer is used. This computer has a sufficiently large memory (12 K 45 bit immediate access store, 64 K bit magnetic drum store). An appropriate logic control circuit was also built /4, 10/. This system makes for flexible scanning control and plays a major part in the process of checking the reliability of the measurement results (viz. sub-section 3.4) and in reducing the time required to prepare the automatic pattern measurement and recognition programs (viz. section 4).

3.2 The monitor as a means of dialogue

Practical experience in the development of real processing systems has shown that performance, particularly in the first stage of development of a working system (viz. section 4), is significantly determined by the amount of time required for operator/computer dialogue. A particularly large amount of time is spent on helping with the measurement of film where the image quality is poor. Displaying such sections on a monitor driven in the cyclic mode as a means of dialogue can save a considerable amount of time. The useful information measured under the operator's supervision - which is often swamped in background - may then be filtered out using a display and light pen [/5/]. This method is successfully used on the AELT-1 to measure poor-quality pictures with adequate efficiency.

3.3 Simple technical design of the device

The most complicated part of any computer scanner is the precision measuring system. In the AELT-1, the design is based on the use of a special system of reference grids [/3,6/] which have significantly reduced the need for linearity and stability in the scanning process and simplified the construction of the device. The latter point also has an important bearing on the industrial production of AELT-1 scanners.

The idea behind the development of the logic control circuit was to reduce the volume of the apparatus by transposing the maximum number of scanner functions to the control computer.

3.4 Reliability of the apparatus and of the measurement results

There are two components which have a major influence on the reliability of the scanner:

- the CRT measuring device;
- the logic control circuit and the data transmission channels to the computer.

The method proposed by the author for the reliability rating of electronic circuits /7/ was successfully used in the development of a major part of the electronics for the CRT measuring device. The method is based on the calculation of the drift in the characteristics of the circuits being used (amplifier gain factors, etc.) as a function of the drift in the working conditions determining the given characteristic of the circuit's components. A characteristic is considered reliable if it is computed with a correction of (2-3)σ relative to its rated value.

Moreover, owing to competition with opto-mechanical computer scanners, designers of CRT scanners have normally sought to push the technical characteristics (resolution, etc.) close to the limit. As a result the reliability of the results is reduced, and the main characteristics have to be checked rather frequently. This problem has been overcome in the AELT-1 scanner by making a programmed check after each line scan (viz. sub-section 3.1) of the total number of read-out pulses shaped in the reference grid channel /1/, thus preventing any deterioration in the quality of the measurements as is caused both by instability of given parameters in the scanner (instability in the CRT high-voltage power supply, etc.) and by brief external interference (voltage surges in the electrical grid).

The logic control circuit and the data transmission channels are constructed from components which, after a routine efficiency inspection, can be used for sufficiently long periods (24 hours or more) without checking. In order to allow for an overall check of this part of the apparatus, it is possible to simulate the operation of the CRT measuring device by means of the computer. The special test software /8/ is used daily for a preventive check on the scanner. Only about 1% of the machine time allocation (1000 hours per year) is required in order to maintain a sufficiently high level of operation in this part of the scanner which determines the quality of the data being transferred to the computer.

Whilst the scanner is running, part of the material being processed (10%) is fed through twice in order to compare the results. In addition, periodically the same film (which is considered as a reference film) is processed twice for the same reason. This check allows an assessment to be made of the performance of the operating system as a whole, including the technical condition of the scanner and the operators' personal attitude to their assignment. The latter is proving in practice to be an important factor in ensuring good-quality results from the measurements.

4. ORGANIZATION OF THE PROCESSING SYSTEMS

In the final analysis, the purpose of picture processing systems based on a computer scanner is to reduce the costs of processing compared with semi-automatic measuring techniques. Among the host of problems which have to be solved when building a processing system, two are of particular importance:

- the need to attain high standards of efficiency and economy;
- the need to reduce software generation times.

4.1 Efficiency and economy

The efficiency of a computer scanner is determined by the ratio of the number of successfully processed pictures to the total number submitted for measurement. Many nuclear physics problems call for efficiencies approaching 100%. If the efficiency of the scanner is not high enough, semiautomatic measuring devices have to be used with the processing system (if the problem so permits). Generally, the processing operation thus becomes more expensive and the cost effectiveness of the computer scanner is reduced. Generally speaking, the cost effectiveness of a computer scanner in a processing system may be expressed as follows /9/:

$$q = \frac{b_{auto}}{S_{auto}} : \frac{b_{semiauto}}{S_{semiauto}} + (1-E_{auto}), \qquad /1/$$

where b_{auto} and $b_{semiauto}$ are the cost of the automatic and semiautomatic scanners, S_{auto} and $S_{semiauto}$ are their respective performances and E_{auto} is the efficiency factor of the automatic device. To simplify the calculations, the efficiency factor of the semiautomatic device is assumed to be 1 (i.e. 100% efficiency). The task of the system designers is to make q less than 1.

Practice has shown that the best results from the point of view of cost effectiveness are obtained by using computer scanners built according to the "man-computer" system. In particular, the flow of pictures can be distributed in an optimum way between automatic devices of this type and the semiautomatic devices incorporated in the system /9/. The AELT-1 is of this type and features an extensive operator/computer dialogue system.

4.2 Software generation

The main idea (aim) behind the work on the software for the computer scanner is to reduce program development time.

The introduction of on-line scanning control into the AELT-1 has led to the development and application of advanced methods of pattern recognition based on the processing of information after each line scan, i.e. searching for characteristic event points and using the 'string' method /11, 12/. The development of software for the scanner is thus considerably simplified and shortened.

A second important factor in the study of ways to reduce software generation time is the construction of the processing system in two stages /9/. The aim of the first stage is to build a highly efficient and operative processing system in the shortest possible time without, however, maximizing the performance of the system. In the second stage the performance of the system is increased.

The extensive operator/computer dialogue system forms the basis of the first stage in the case of the AELT-1. In many instances it is advisable to develop automatic recognition programs in the first stage in order to process those components of the pattern which are simple shapes (non-intersecting lines, etc.). As a working hypothesis, the author put forward and tested the assumption that each of the measured images consist to a large extent of simple shapes. It should therefore be possible to increase the performance of the scanner by developing even comparatively simple recognition programs which can be worked out in a short time during the first stage of production of the man-computer system. Fig. 2 illustrates the hypothesis that there is a critical point τ in a graph where the performance S of the system under construction is plotted against the time spent in generating the software for controlling pattern measurement and recognition. This hypothesis was verified in practice during the construction of the two above-mentioned processing systems /11, 12/. Performance levels of 30-50% of the maximum possible were thus achieved during the first stage of development of each system, thus already ensuring economy of operation.

By producing an operative processing system within the tight time limits of the first stage, it is possible to bring the scanner into operation earlier and to make more rational use of the limited manpower available for software development during the second stage when it becomes substantially more difficult to extend the software support for automatic pattern measurement and recognition.

The splitting of the development work into two stages also has an important psychological influence on the preparation of the software since faster work rates are encouraged in order to bring the system into operation within the tight time limits imposed by the first stage.

5. RESULTS

5.1 A system for processing pictures from a wide-gap spark chamber, based on the AELT-1 computer scanner, has been built at JINR and has been running since 1973. Many of the tracks in these pictures possess low contrast and short length ($\sim$1 mm), and the reference grids which are necessary for measurements with semiautomatic devices interfere with the automatic recognition process. The production of the software for controlling event measurement and recognition during the first stage of development of the system (up to point τ in fig. 2) took only 3-4 months and accounted for 10 000 instructions to the BESM-4 computer. This type of operation usually takes up to a few years and was completed in such a short time mainly as a result of the above-mentioned special features of the AELT-1 scanner - i.e. on-line scanning control during the development of the programs for event measurement and recognition and also the extensive monitoring system for operator/computer dialogue. The system was then optimized during its operation (a semi-automatic device was incorporated in the system in order to repeat the measurement of particularly poor-quality pictures) and the software was further developed in order to increase the efficiency and performance of the scanner /9/. The result was a highly efficient processing system with an output of up to 70 000 pictures per year in the single-shift mode. The cost of processing the pictures, which in turn determines the cost effectiveness of the scanner, was lower than for semiautomatic devices.

Approximately 250 000 events were measured with the system during the period 1973-1978, and new physics data were obtained as a result /13,14/.

5.2 The AELT-IM computer scanner (fig. 3) and a system for processing test flight information /2,12,15,16/ were built at Ts AGI (Moscow) during 1974-1978. The velocity, altitude and load graphs which are recorded during civil aircraft flights on 35 mm ciné film are very long (usually 1-2 km), thus virtually excluding the use of semiautomatic devices in the system for the remeasurement of specific parts of the film (where there are breaks in the graphs, scratches, etc.). The films have to be processed in this case by a single device, and the AELT-IM fits the bill simply and solely because of the operator/computer dialogue system. The software during the first stage of development of the processing system (up to point τ) amounted to 8 000 instructions to the BESM-4 computer and was completed in 5-6 months. The development of the programs for controlling graph measurement and recognition was also based on the use of on-line scanning control.

The performance and efficiency of the software was checked during the measurement of films under real conditions, and physics results were obtained.

6. CONCLUSION

The development of the AELT-1 and AELT-IM computer scanners and their associated processing systems for the measurement of pictures from a wide-gap spark chamber (nuclear physics experiment) and of graphic flight information (application) has shown that these scanners can be used to measure information on 35 mm film in various sectors of science and technology. The comparatively simple design, based on a system of reference grids for precision measurements, facilitates industrial production of the scanner.

The experience acquired with the construction of the AELT-1 scanners, including above all the development and introduction of on-line scanning control and a monitoring system for operator/computer dialogue, together with the knowledge gained with the rational two-stage production of highly efficient processing systems based on the existence, as established by means of concrete examples, of a critical point in the generation of software for controlling pattern measurement and recognition, is used in the development of the AELT-2/160 monitor-scanner and its associated picture processing systems.

The author considers that further research and development work on CRT computer scanners must be directed towards achieving even greater scanning flexibility and extending the facilities for operator/ computer dialogue. The use of reference grids (patterns) for measurement purposes should be maintained and applied to different types of scanner in their present form or in a different (modified) form. It would clearly be desirable to use modular techniques in the industrial production of these scanners. This approach will, in particular, facilitate co-operation between the various teams who are interested in developing the scanners in different directions.

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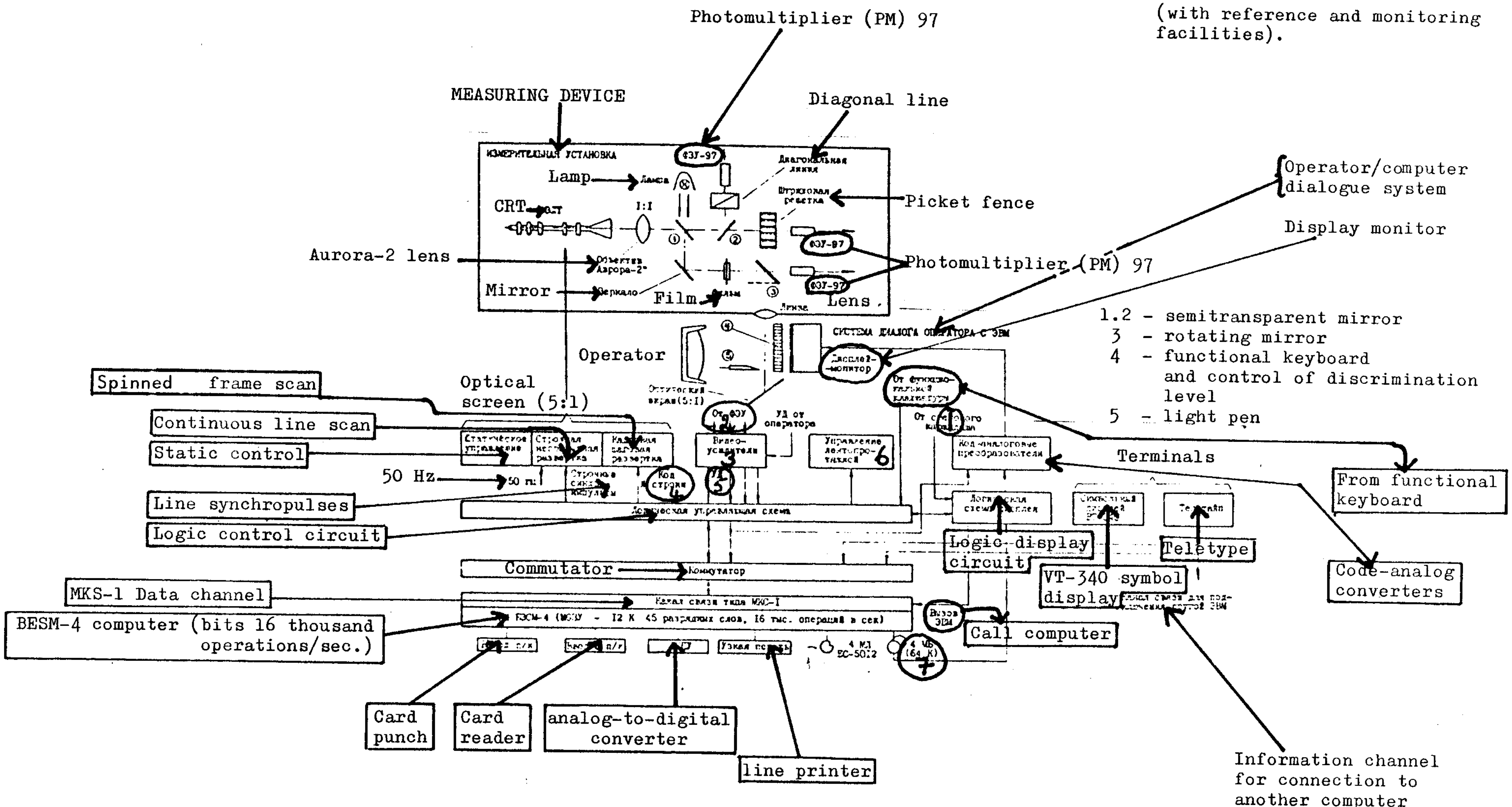
Fig. 1 - Functional block-diagram of the AELT-1 computer scanner (with reference and monitoring facilities).



(1) From light pen
(2) From photomultiplier
(3) Video amplifier
(4) Line code
(5) Discrimination level
(6) Tape drive control
(7) To 4 Mega bytes

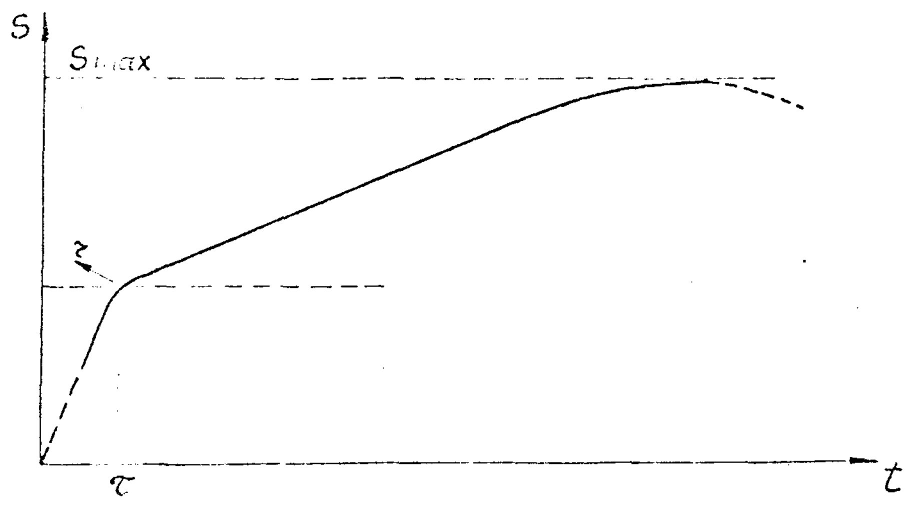


Fig. 2 caption

Illustration of the hypothesis that there is a critical point τ in the graph showing the dependence of the performance S of a processing system under development on the time t spent on generating the software for controlling pattern measurement and recognition. The slope r has a tendency to alter the point S (τ) on the graph as a function of the increase in flexibility of the scanning control and the development of the operator/computer dialogue facilities.

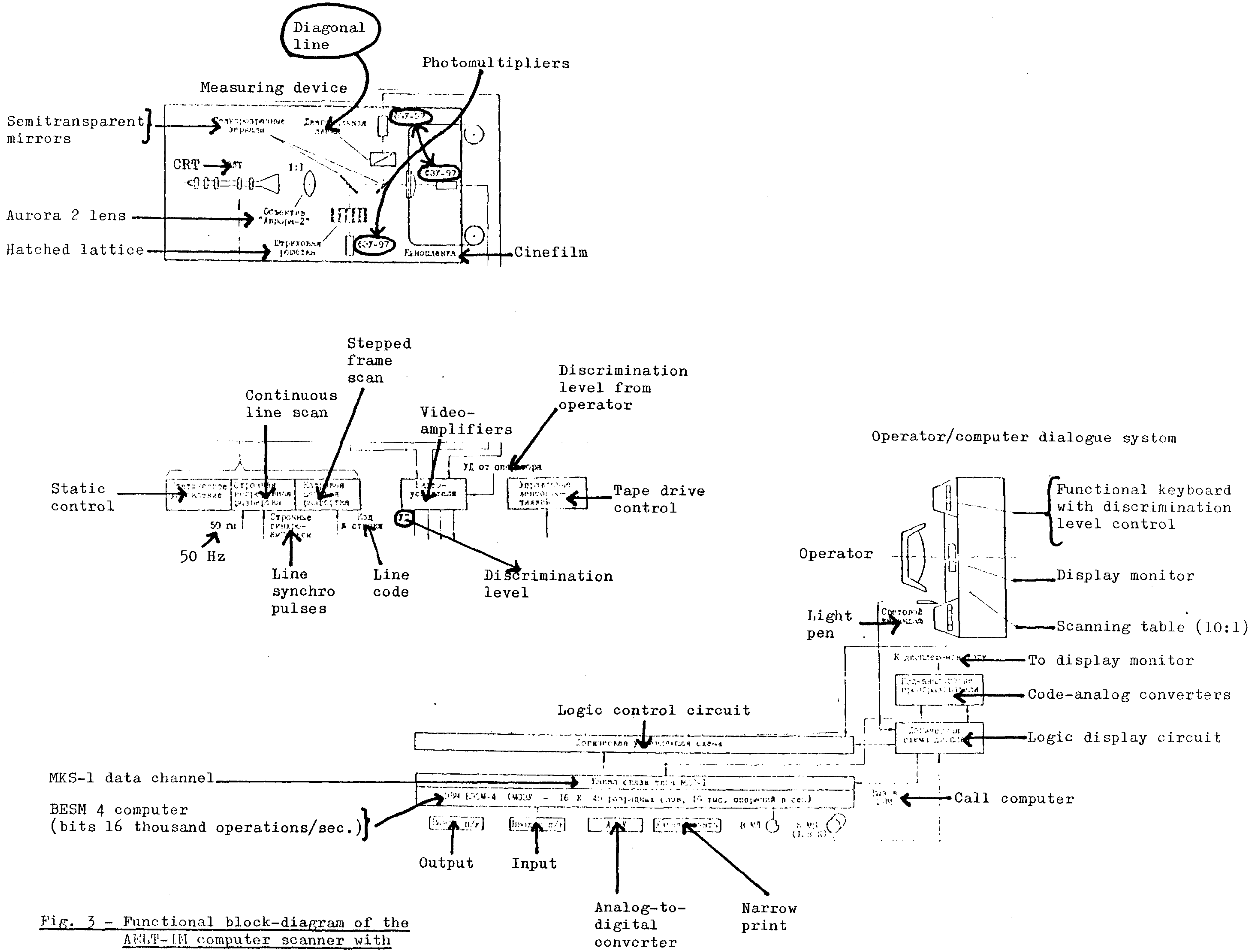


Fig. 3 - Functional block-diagram of the AELT-IM computer scanner with reference and monitoring facilities.

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