The new measuring system of Cherenkov water detector NEVOD

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***Abstract*. The description of the new measuring system of Cerenkov water detector NEVOD and results of tests of the prototypes of its elements with specialized facilities are presented.**

***Keywords*: cherenkov water detector, detection sistem, cosmic ray muons**

I. Introduction

The Cherenkov water detector (CWD) NEVOD (2000 m^3 volume) was constructed for investigations of basic cosmic ray components on the Earth's surface [1]. The quasispherical module (QSM) was designed for the solution of this problem. QSM is the autonomous detector of Cherenkov radiation in water and consists of six PMT FEU-49B with the flat photocathodes and inner-module electronics, placed in the watertight housing. Photomultipliers are oriented along the axes of the orthogonal coordinate system (Fig. 1). This module has a quasispherical response, since the sum of the squares of amplitudes of triggered PMTs does not depend on the angles of incidence of Cherenkov radiation on photocathodes. On the other hand, the radiation arrival direction and the distance to its generation point can be estimated by the amplitudes of the triggered PMTs.

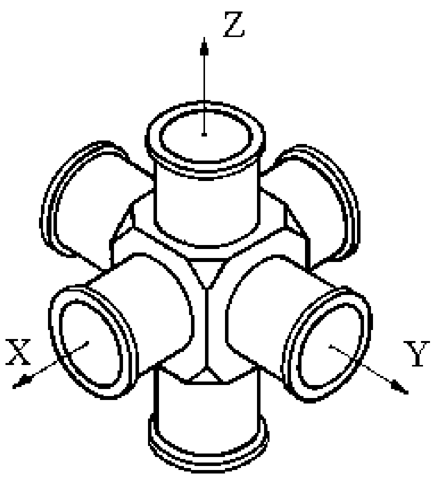

Fig. 1: QSM.

The detecting system developed for the effective registration of the events from any direction is formed by a spatial lattice of QSM (Fig. 2). Modules are combined into the strings of 3 or 4 QSM in each. The distances between the modules are 2.5 m along the detector and 2.0 m across it and in the depth. This system makes it possible to reconstruct particle track parameters in 4π-geometry.

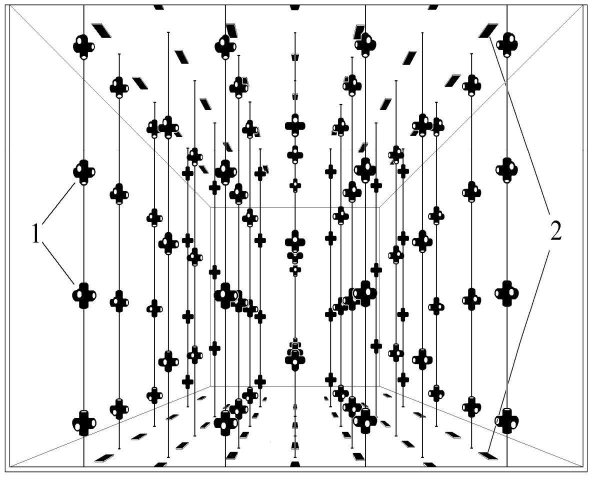

Fig. 2: Detecting system of CWD NEVOD. 1 – quasispherical modules, 2 – scintillation telescopes.

For the solution of the first priority problem – the proof of the possibility of upward-going neutrino detection on the Earth's surface under conditions of very high background of atmospheric muons [2], the information was read only from one dynode PMT in the dynamic range of 10^3 photoelectrons (p.e.). This range is insufficient however for detection of events generated by very-high and ultra-high energy particles (EAS cores, muon bundles with large multiplicity, etc.). At the same time, studies of groups of muons in a wide range of zenith angles by means of the coordinate detector DECOR [3] showed that for the generation of these groups the primary particles with energies up to $10^{18} - 10^{19}$ eV were responsible. For the analysis of energy characteristics of muons in such groups the new measuring system of CWD NEVOD was designed. The system provides the range of PMT signal detection from 1 to 10^5 p.e.

II. Measuring system of CWD NEVOD

The original measuring system (MS) consisted of inner-module electronics, cable communications and the interface block for data exchange with the external systems. Measuring, digitizing of signals from PMTs and formation of the first level triggers were accomplished inside the module. As a fact of the QSM triggering, the requirement of double coincidence of the signals of any two adjacent PMTs was used. This choice of trigger was caused by a large dark noise of used FEU-49B PMT, and as a result it decreased the effective area of QSM registration. The dynamic range of the analyzed signals did not exceed 10^3 p.e. This circumstance did not allow measure the large energy deposits in events. Many elements of the system physically aged after 15 years of operation, and some cable communications in water lost their watertightness.

The new measuring system was developed for replacement of aged electronics to new apparatus and for expansion of the research capabilities of CWD NEVOD. The structure of the spatial lattice which provides the sensitivity of the detector in a whole solid angle remains the same. As a new photomultiplier for QSM, the FEU-200 whose characteristics are specially optimized for detection of the faint photon fluxes is selected. This PMT has a higher integral sensitivity compared to the existing analogs, and low noise (less than 10 kHz at the threshold of 0.25 photoelectrons). This fact made it possible to refuse from the condition of double coincidences. The dynamic range of the measured signals will be increased up to 10^5 p.e. It will allow pass to a study of the energy deposits of muon component and EAS, which are generated by particles of primary CR with energies above 10^{17} eV.

New MS (Fig. 3) has hierarchical structure of data processing with the lower trigger level on the string (cluster) of QSMs and includes inner-module electronics (IME), blocks of electronics of the cluster (BEC), system of external trigger formation and DAQ units. The reduction of IME function and refusal of the trigger formation at the QSM level simplifies installation and maintenance of the modules, provides an easy access to the main part of electronics, located now out of the water volume, and reduces a number of communication cables.

A. Inner-module electronics of QSM

The IME is located inside the QSM housing and ensures stable operation of PMTs and procedures of their monitoring. The IME includes the PMT board containing HV power supply resistive divider and two pulse-shaper-amplifiers (PSA). PSA forms signals from the $9^{\rm th}$ and $12^{\rm th}$ dynodes. The PMT boards are mounted directly on the sockets of FEU-200 photomultipliers.

To provide the linear dynamic range of spectrometric channels from 1 to 10^5 p.e. transformation coefficients of PSA of $12^{\rm th}$ and of $9^{\rm th}$ dynode were optimized: $k_{12} = 25$ mV/pC, $k_9 = 12.5$ mV/pC. Ratio of output signals of PSA from two dynodes is $A_{12}/A_9 \approx 100$. For both amplifiers, the range of linearity corresponds to 1–4000 mV and is matched with the range of the 12-bit ADC (1 count/mV sensitivity) of the module of the amplitude analysis of BEC. The ranges of the linearity of the $12^{\rm th}$ and $9^{\rm th}$ dynodes are overlapped in the interval 25–1000 p.e.

Inspection of the stability of the conversion factor of the spectrometric circuit of PMT→PSA→ADC in entire range of the measured signals in IME of QSM is provided by monitoring system on the basis of light-emitting diodes. Operation of LED drivers is ensured by a six-channel controller (see Fig. 3). Each driver represents a separate electronic plate with KingBright L -7113NBC LED ($\lambda = 470$ nm), which ensures the exposing of photocathode by short flashes (FWHM $\sim$ 5-7 ns). During MS monitoring which is to be carried out periodically in the automatic regime the amplitude spectra of signals from PMT at a standard intensity by the LED flashes will be collected. The value of the conversion factor of spectrometric circuit and the stability of its operation during the experiment will be evaluated on the basis of the characteristics of the spectra from each PMT. The power supply of electronics is provided by DC/DC converters, which convert +12 V voltage into the values of ± 12 V and into high voltage of power supply of PMT, with the possibility of its adjustment from 0 to +2000 V. Signals from QSM are sent to the BEC through two watertight deep-sea cables, via 16 screened twisted pairs. Cables are introduced into the QSM with the aid of the cable inlets of protection class IP68, and to the housings of BEC they are linked up with watertight connectors (IP67 class).

B. Block of electronics of the cluster

In the design of new measuring system the organization of registration and preliminary analysis was realized according to the cluster principle instead of the modular one. In the cluster principle, the substantial part of the functions (digitizing of the signals coming from PMT; generation of trigger signals; storage of data and asynchronous exchange with external electronic systems) was transferred into the block of electronics of the cluster. This approach makes it possible to considerably increase efficiency and operating speed of measuring system as a whole.

The blocks of electronics of the cluster are located in watertight housings, which are fastened to the beams in the space between the water level and the light-insulating cover of the detector bath. Each BEC processes the signals of IME of QSMs of one string (cluster). The existing configuration of the detecting system of CWD NEVOD includes 16 strings of 4 QSM and 9 strings of 3 QSM.

BEC contains four modules of amplitude analysis, processor plate, modules of interface with the sensor of temperature monitoring, and power units which provide necessary voltage for the elements of BEC and QSM.

The modules of amplitude analysis perform the digitizing of analog signals with the aid of the 12-bit ADC with 25 ns sample memorization and 2 μs conversion time. Modules also contain discriminators with the program-controlled threshold and 16-bit counters for measuring PMT noise. Important function of modules is generation of three types of trigger signals for each QSM: “a”

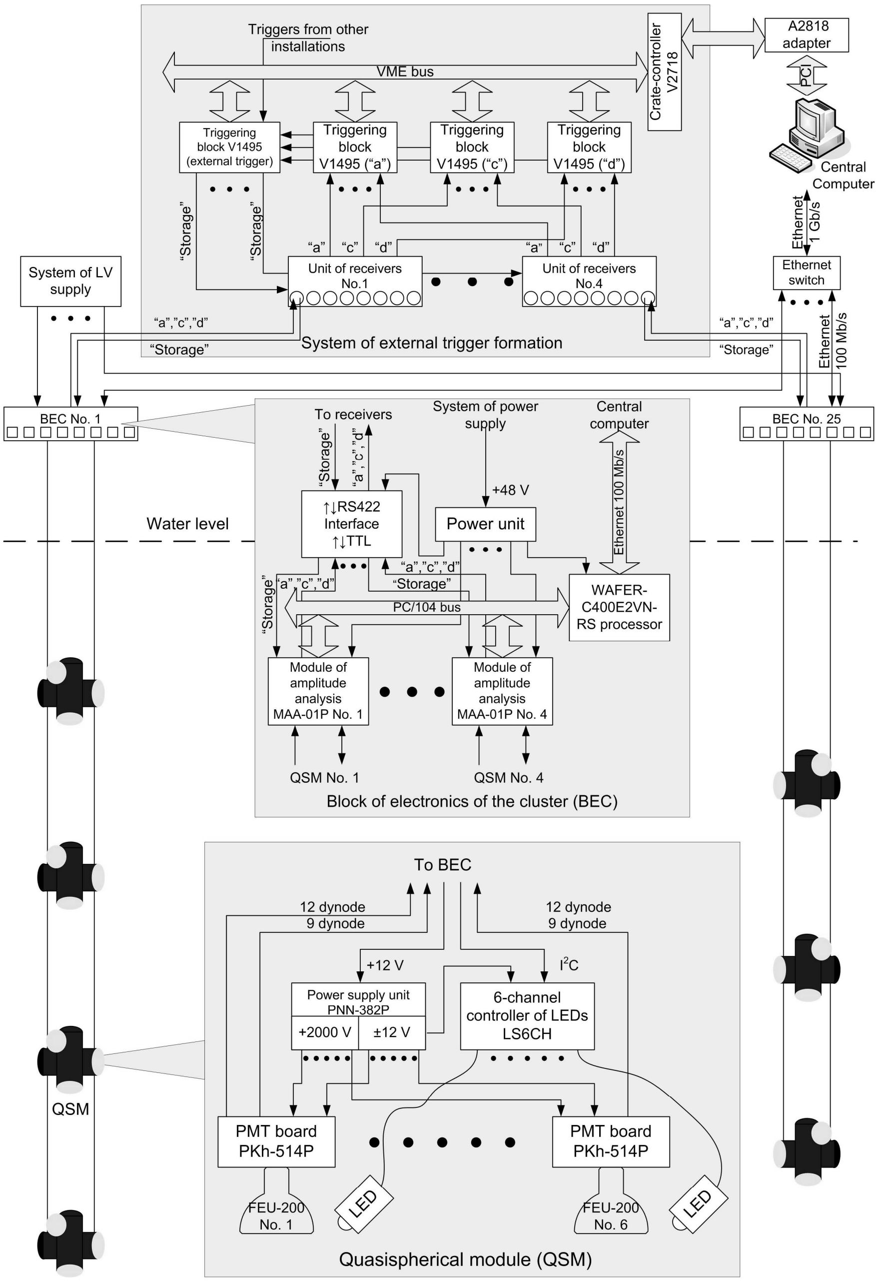

Fig. 3: Scheme of the new measuring system.

(any) logical “OR” of six signals from 12th dynodes of PMTs – is intended for detecting single muons; “c” (coincidence) – the coincidence of signals from any two PMT (except those oppositely directed) within 150 ns time gate – for detecting the events with large energy deposit in the detector volume; “d” (down) – signal from downward directed PMT – for registering muons from the lower hemisphere.

All four modules of amplitude analysis of BEC are connected with the WAFER-C400E2VN-RS Celeron 400 MHz processor by means of PC/104 bus. The processor implements the control of the measurement regime, performs the data readout from the modules of amplitude analysis in the case of the arrival of “Storage” signal, and ensures their transfer to the central PC via Ethernet.

C. System of external trigger formation

Trigger signals from BEC are transferred in the RS422 standard by means of a specialized cable to the units of the receivers at which their selection into groups (“a”, “c”, “d”) and translation into the adders of the trigger system is accomplished. The trigger system is realized on the basis of the programmable blocks CAEN V1495 on VME bus. The system provides generation of “Storage” signal, calculation of the live time of exposition and monitoring of BEC trigger signals. Each V1495 block collects signals of a certain specy (“a”, "c" or "d"). In the regime of summing up, the trigger system produces the general system signal of "Storage", if more than N trigger signals of one type have arrived within the assigned time gate. Values N are set by the program. The signal of "Storage" also can be generated with receiving trigger signal from other setups of the experimental complex. Information about the operated QSM is read via VME bus. All V1495 blocks are mounted in one VME crate and are connected with the central computer by means of VME controller.

III. Procedure of the monitoring

During continuous experimental series of measurements it is necessary to monitor the fundamental characteristics of the spectrometric channels of the QSM: gain and the dark noise rate of each PMT. The accuracy of the reconstruction of muon tracks and measurements of energy deposit depend on the gain. Dark noise of PMT influences the dead time of the detector, therefore it is necessary to measure it permanently.

The procedure of the determination of the dynode system gain M described in [4] was used for studying the stability of the spectrometric circuit conversion coefficient in the entire dynamic range. According to this procedure, the characteristics of the spectrum of PMT responses $\bar{A}$ and σ^2, obtained with the exposing of photocathode by short flashes of a certain intensity, are coupled with the gain M by formula (1):

$$M \sim \frac{\sigma^2}{\bar{A} \cdot (1 + \delta_{1e}^2)}, \tag{1}$$

where $\delta_{1e} = \sigma_{1e}/\bar{A}_{1e}$ is the relative standard deviation of charge distribution for the one-photoelectron signals from the PMT. The value δ_{1e} is nearly constant for all photomultipliers of FEU-200 type. Therefore the ratio $\sigma^2/\bar{A}$ can be used for estimating the behavior of the conversion factor of the spectrometric circuit (Fig. 4), where $\bar{A}$ is the average value of the amplitude distribution, and σ^2 is the dispersion of this distribution. This value is proportional to M.

The dependence of PMT dark noise (for one of the tested QSM) on the threshold is presented in Fig. 5. The discriminator threshold which will be used in the detector composes 0.25 p.e. In order the dead time of spectrometric circuit would not exceed 2%, the noise frequency must be less than 10 kHz. The noises of the photomultipliers in a given module do not exceed 7 kHz.

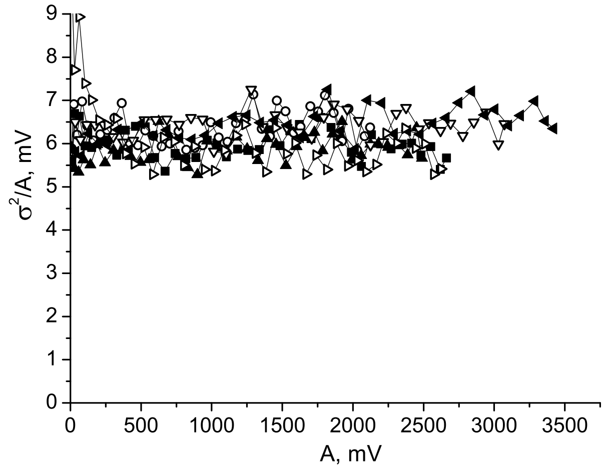

Fig. 4: Behavior of the conversion factors of six spectrometric circuits as a function of output amplitude.

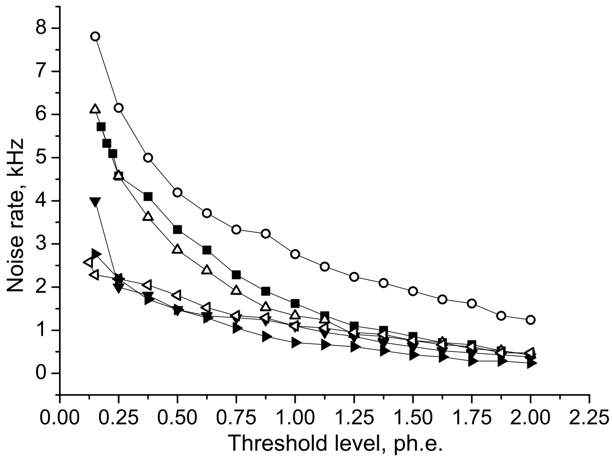

Fig. 5: Dark noise rate of six FEU-200 PMT for different thresholds of the discriminator.

Conclusions

New measuring system of the NEVOD detector ensures a wide dynamic range of detected signals (from 1 to 10^5 p.e.). It allows analyze events with large energy deposits in the CWD induced by muons of EAS with energies above 10^{17} eV. The low level of noise of FEU-200 PMT will make it possible to investigate variations in the atmospheric muon flux from all directions of the upper hemisphere with energy thresholds in the range 300 MeV–7 GeV.

Cluster organization of MS and interchangeability of its units simplifies the maintenance of reliable operation of the detector. It gives possibility to increase the effective volume of the detector and to enlarge research capabilities of experimental complex by means of addition of new clusters.

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