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Vadim Paka and His Inventions

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Abstract

The article provides an overview of the main innovations that were developed and implemented in the practice of in situ hydrophysical measurements in the ocean by Vadim Timofeevich Paka. Among them are the thermochain, the thermotrawl, the loosely tethered microstructure probe “Baklan”, the undulating towed fine-structure system “Rybka” with undulation control by a high-speed winch, and the current velocity meter based on the inclination angles of a body with positive buoyancy suspended in the oncoming flow (Tilt Current Meter — TCM). Special attention is paid to the “Baklan” probe and the “Rybka” system, since they had the greatest influence on the development of modern methods of in situ measurements in the ocean and had the largest number of followers. The general idea of the “Baklan” probe was a quasi-free immersion of the carrier of turbulence sensors on a flexible, unloaded, free-falling cable with near-neutral buoyancy. This made it possible to quickly perform multiple measurements of turbulence in the upper layer of the ocean at a low level of noise, which was impossible when using both ordinary cable probes and autonomous free-falling probes. The article presents the history of the development of V.T. Paka’s ideas, which formed the basis of “Baklan” and “Rybka”, and their implementation in hardware. A comparison of “Baklan” and “Rybka” with existing measurement systems such as MSS Profiler and SeaSoar is given.

Keywords: *in situ* hydrophysical measurements in the ocean, small-scale turbulence, fluctuations in water flow velocity, fine thermohaline structure, self-oscillations, thermochain, thermotrawl, loosely tethered microstructure probe “Baklan”, undulating towed fine-structure system “Rybka”

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Вадим Тимофеевич Пака и его изобретения

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Аннотация

Дается обзор основных инноваций, которые были разработаны и внедрены в практику натурных гидрофизических измерений в океане Вадимом Тимофеевичем Пакой. Среди них термокоса, термотрал, слабо-привязной микроструктурный зонд «Баклан», ундулирующий буксируемый тонкоструктурный комплекс «Рыбка» с управлением ундуляциями с помощью высокоскоростной лебедки и измеритель скорости течения по углам наклонения тела с положительной плавучестью, подвешенного в набегающем потоке (TCM). Особое внимание уделяется зонду «Баклан» и комплексу «Рыбка», так как именно они оказали наибольшее влияние на развитие современных методов натурных измерений в океане и имели наибольшее число последователей. Генеральной идеей зонда «Баклан» было квази-свободное погружение носителя датчиков турбулентности на гибком, нена-

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груженном, свободно стравливаемом кабеле с около-нейтральной плавучестью. Это позволило оперативно производить многократные измерения турбулентности в верхнем слое океана при низком уровне шумов, что было невозможным при использовании как обычных кабельных зондов, так и автономных свободно-падающих зондов. Представлена история развития идей В.Т. Паки, заложенных в основу «Баклана» и «Рыбки», и их реализации в «железе». Дается сравнение «Баклана» и «Рыбки» с существующими измерительными системами, такими как MSS Profiler и SeaSoar.

Ключевые слова: контактные гидрофизические измерения в океане, мелкомасштабная турбулентность, флуктуации скорости течения воды, тонкая термохалинная структура, автоколебания, термокоса, термотрал, слабо-привязной микроструктурный зонд «Баклан», ундулирующий буксируемый тонкоструктурный комплекс «Рыбка»

Vadim Timofeevich Paka (1936–2024) was always inventing something during his long scientific career. It can be said that invention was a form of his existence in science. By trial and error, he came up with and implemented such simple technical solutions to complex problems in the field measurements in the ocean that his followers soon forgot the name of the author and considered these inventions to be something self-evident and obvious or invented by themselves. Vadim Paka generously, free of charge shared his discoveries with all interested parties — the copyright issues did not interest him much, and he was glad that researchers were using his methods in practice.

The first developments of equipment for ocean measurements by Vadim Paka date back to the 1960s — early 1970s. At that time, the so-called Paka thermochain was well-known in the oceanographic circles of the USSR, which was a chain of thermistors suspended overboard a research vessel (R/V) on a cable, allowing for detailed recording of a 2D dependence of seawater temperature versus time and depth in a given location and depth range. This opened up new possibilities for the experimental study of internal waves in the ocean. Subsequently, the thermochain was modified into a thermotrawl: a chain of thermistors was attached to a cable-rope with fairings and a heavy deepening body at the lower end. The thermotrawl was towed while the R/V was moving, which made it possible to obtain a 2D dependence (section) of temperature versus the vertical coordinate (depth) and horizontal coordinate (distance).

In the last decade (2015–2024), Vadim Timofeevich became interested in developing cheap and practical autonomous current velocity meters in the bottom layer of the sea and in shallow water by recording the tilt angles of a cylindrical body with positive buoyancy in the oncoming flow (the so-called Tilt Current Meter (TCM), see Fig. 1).

Without the possibility to even mention all innovations developed by Vadim Paka for hydrophysical measurements in the ocean within the framework of this article, I decided to focus on two developments — the microstructure probe “Baklan” [1] and the fine-structure towed undulating complex «Rybka» («Small Fish»)

Fig. 1. A photograph of the TCM. Its shape is formed by a cylindrical perforated plastic pipe. The perforation prevents the development of self-oscillations of the body in the oncoming flow. Inside, in addition to the buoyancy modules, there is a device for measuring and recording tilt angles. The entire buoyant package is attached to a lead plate by a piece of chain [4]. What is original here is the specific technical solution, and the physical idea of measuring the velocity of the oncoming flow by the inclination of a suspended body with positive buoyancy was previously implemented by Vitaly Sheremet at the Woods Hole Oceanographic Institution

[2, 3], the creation and improvement of which took place before my eyes during sea expeditions and in the process of long-term cooperation with V.T. Paka starting from the 23rd cruise of R/V "Dmitry Mendeleyev" in 1980. In my opinion, it was these two inventions of V.T. Paka that had the greatest influence on the development of modern methods of hydrophysical measurements in the ocean.

Microstructure probe «Baklan» («Cormorant»)

In the 1960s, interest arose in the study of small-scale turbulence in the ocean — fluctuations in velocity, temperature, salinity and other hydrophysical parameters in the frequency range of 1–100 Hz and the length range from 1 mm to 10 m. The interest was associated both with the understanding the fundamental role of small-scale turbulence in the processes of water mixing and heat exchange in the ocean, and with applied problems of submarine detection. The subjective driver for the development of small-scale turbulence research at the Shirshov Institute of Oceanology was the appointment of A.S. Monin, a student of the discoverer of the theory of locally isotropic turbulence A.N. Kolmogorov and the author of the similarity theory for a stratified turbulent boundary layer in atmosphere, as director of the Institute in 1965. Soon after the Monin's appointment, the Laboratory of Oceanological Instruments in Kaliningrad headed by V.T. Paka and the Laboratory of Marine Turbulence in Moscow headed by R.V. Ozmidov were established in 1967 and 1968, respectively.

One of the greatest objective difficulties in in situ measuring turbulent velocity fluctuations in the ocean is the problem of ensuring uniform movement of the probe carrying the velocity sensor: when towing or diving on a loaded cable-rope, the body of the probe is subject to high-frequency vibrations, introducing noise into the measurements. A free-falling probe (not tied to a vessel) allows noise-free measurements of turbulent velocity fluctuations. However, it has a significant drawback: its ascent to the surface, detection in the open sea, delivery on board, and preparation for the next dive takes a long time, which makes multiple dives to obtain 2D and 3D distributions of ocean turbulence characteristics practically impossible.

Vadim Paka's goal was to find a compromise: to «marry» a noisy tethered probe, which can be quickly recovered aboard and prepared for the next dive, with a noiseless free-falling probe which cannot be quickly recovered aboard and prepared for the next dive. The solution turned out to be a loosely tethered probe, quasi-free-falling on a flexible, unloaded, free-flowing, and neutral-buoyant cable.

Work on the creation of the loosely tethered microstructure probe "Baklan" («Cormorant»), which was named after a long-necked seabird diving for fish, began in 1980 during the 23rd cruise of the R/V "Dmitry Mendeleyev". Over the next 8 years of trial and error, the loosely tethered probe "Baklan" turned into a fully functional instrument for measuring small-scale turbulence in the ocean (see Fig. 2 with a photograph of the probe on the deck during the 13th cruise of the R/V "Akademik Mstislav Keldysh").

In 1987, Hartmut Prandke from the Institute of Oceanography in Warnemünde (IOW), the East Germany, took part in the 13th cruise of the R/V "Akademik Mstislav Keldysh". He was interested in the Soviet experience in in situ measuring small-scale turbulence in the ocean, since he himself had recently developed a quasi-free-falling probe, which actually slid down two loaded vertical nylon threads [5]. It was obvious that sliding on loaded threads, which inevitably experienced self-oscillations in the oncoming flow, made the Prandke's probe unsuitable for measuring turbulent velocity fluctuations. Getting to know the «Baklan» probe was like winning the jackpot in the lottery for Hartmut Prandke. After the reunification of Germany, Hartmut Prandke founded his own company ISW Wassermesstechnik, which flooded the market with loosely tethered microstructure probes, MSS Profilers, built on the principle of the «Baklan» probe (compare Fig. 2 and 3). Hartmut Prandke subsequently sold Wassermesstechnik to Sea&Sun Technology, which manufactures and sells the MSS Profiler probe till now (https://www.sea-sun-tech.com/sea-sun-technology-buys-isw-wassermesstechnik-dr-hartmut-prandke/. Everything would be fine, but unfortunately, in the long list of people whom Hartmut Prandke thanks in the Acknowledgments of a report on the development of the MSS Profiler, the name of Vadim Paka is missing (see [6]).

The story of the «Baklan» probe could have ended there, but Vadim Paka would have ceased to be Vadim Paka if he had stopped and not continued to improve the probe. In 2008, Bert Rudels from the Finnish Meteorological Institute, Helsinki, reached me with a request to propose V.T. Paka to carry out measurements of small-scale turbulence in the Denmark Strait Overflow Plume as part of the EU project THOR (Thermohaline Overturning — at Risk?). The problem was that both «Baklan» and MSS Profiler were designed to measure turbulence in the sea surface layer of a 300–400 m thickness, but here it was necessary to carry out measurements in the bottom layer of that thickness at a sea depth of about 2 km. Despite the fact that such measurements required a major upgrade of the «Baklan» probe, Vadim Paka agreed and brilliantly coped with the task [7, 8].

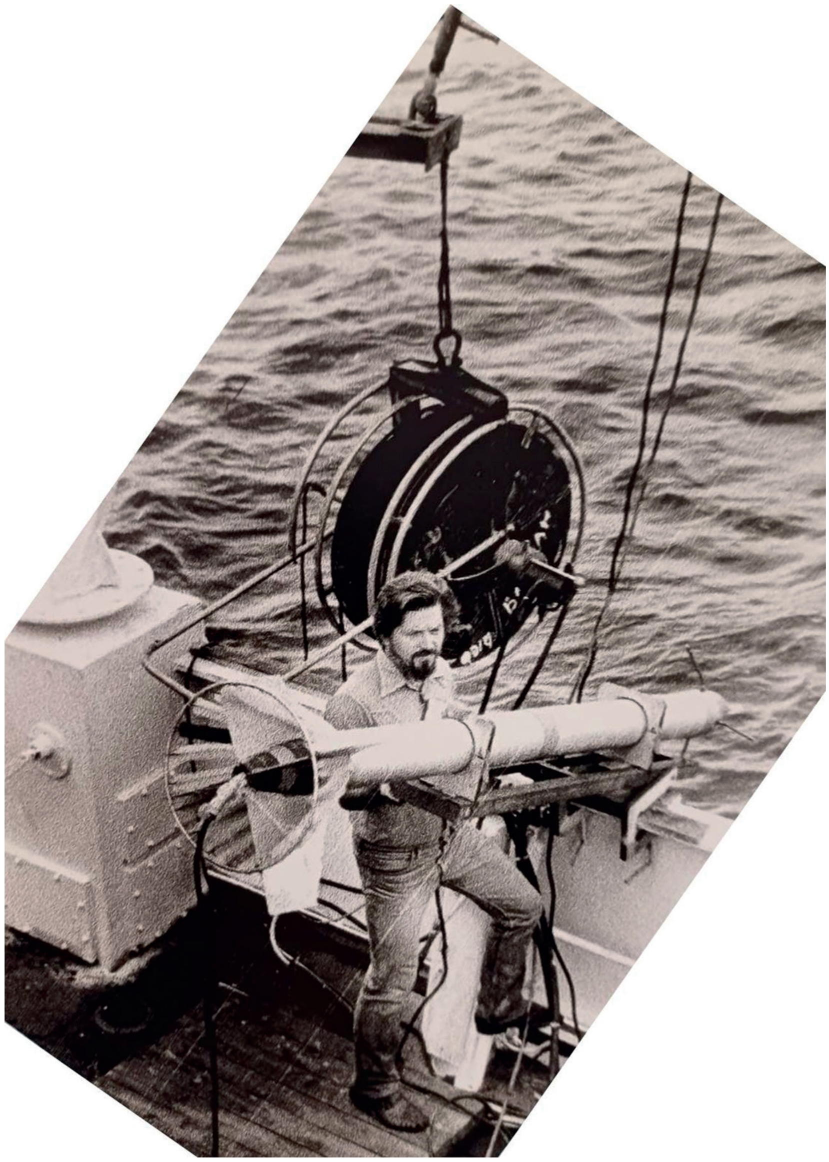

Fig. 2. Photograph of the loosely tethered microstructure probe «Baklan »
(1987, 13th cruise of R/V "Akademik Mstislav Keldysh")[1]

To use the quasi-free-falling probe «Baklan» at any depth, the tether was packed in a special magazine inside the probe, and was also partially wound onto a reel attached to the probe carrier. Only a limited amount of tether (500 m of a 4 mm thick nylon cord) could be placed. Therefore, to perform measurements at large depths, it is necessary to deliver the probe to the starting depth without using the tether. The best carrier for the «Baklan» was decided to be a standard Rosette water sampling CTD-LADCP system, which is the main instrument for hydrographic surveys. Joining measurements from a CTD and adding current velocity by

[1] Photo from the personal archive of G.A. Bambizov

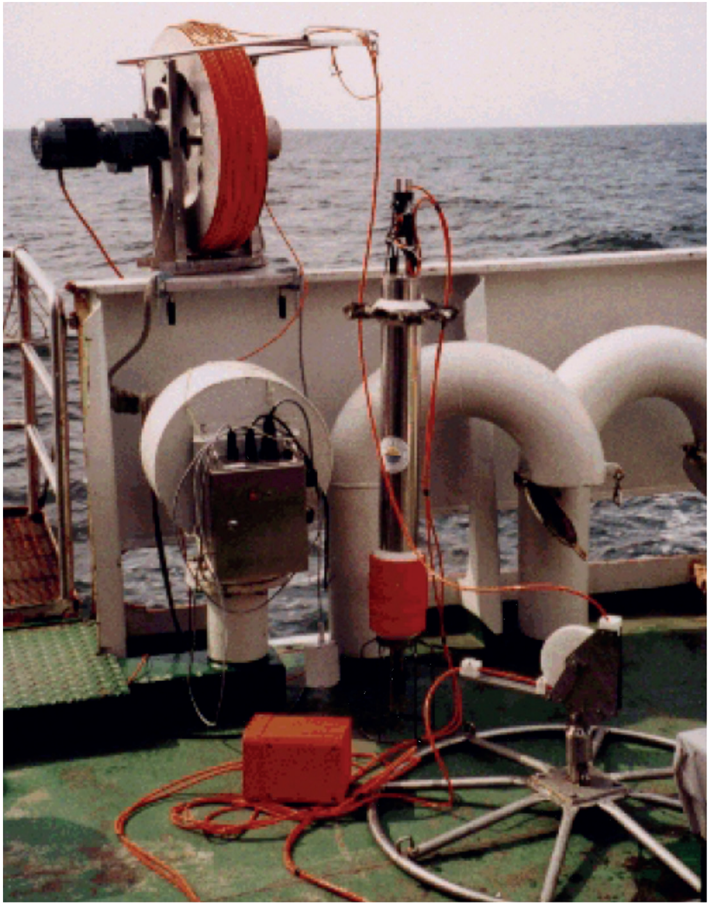

Fig. 3. Photograph of the MSS profiler by Hartmut Prandke [6].
Compare with Fig. 2 and find at least one significant difference

LADCP and microstructure measurements provides the microstructure analysis with necessary bulk parameters of the gravity current and saves expensive ship time. Fig. 4 (top) shows a photo of the measuring system ready for deployment. Fig. 4 (bottom) explains the principle of releasing the «Baklan» probe at any chosen depth [7].

Finestructure towed undulating system «Rybka» («Small Fish»)

The traditional method of conducting in situ measurements of vertical profiles of temperature, salinity and other hydrophysical parameters of the ocean at drift stations involves the vessel's passage to a given point, braking the vessel to a drift state, taking measurements while drifting and accelerating the vessel to pass to the next point. Due to the high inertia of the vessel, the time spent on braking and accelerating it takes up a significant portion of expensive vessel time and significantly increases fuel consumption. To speed up the process of multiple profiling at closely spaced points of a section or area survey, since the 1960s, towed carriers of measuring instruments have been introduced, equipped with wings and aircraft-type elevators, allowing the towed carrier to undulate in the upper layer of the ocean due to hydrodynamic lift (so called undulating towed (U-tow) vehicles). Examples of the U-tow vehicles are the SeaSoar system, manufactured by Chelsea Instruments, Ltd. (https://www.chelsea.co.uk/), and a towed undulating carrier designed for CTD probe NBIS Mark 3 by Raivo Portsmouth from Estonia.

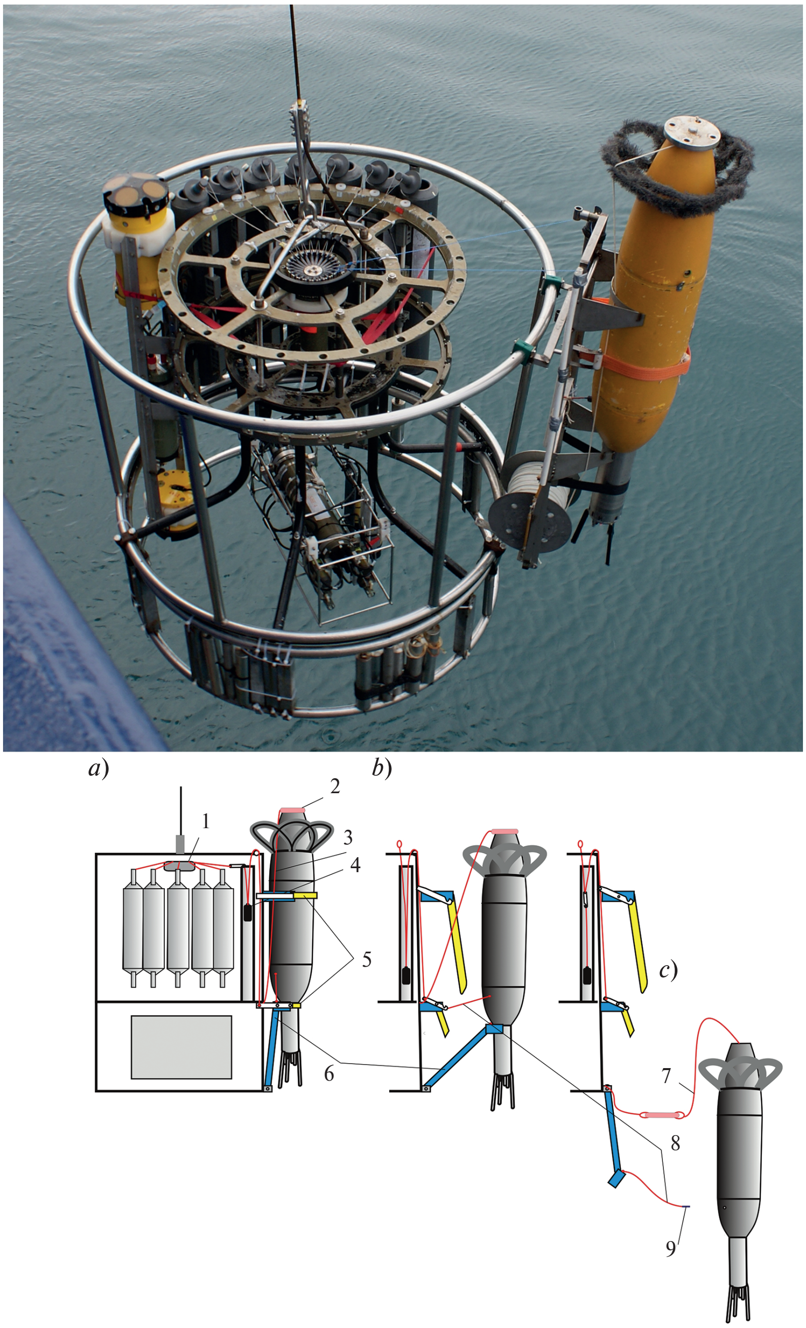

Fig. 4. (Top) Photograph of the deployed system [7]. The «Baklan» probe is the light colored object on the right. Also shown are the Rosette water samples, the RDI LADCP, and the SBE CTDO. (Bottom) Principle of releasing the «Baklan» probe from the rack at a chosen depth. 1 — the trigger assembly on the Rosette rack, 2 — attached load for accelerating the « Baklan» probe (needed due to the small negative buoyancy of the probe), 3 — rope fastening the acceleration load to the rack, 4 — trigger, 5 — belts holding the probe to the rack before release, 6 — turning support which prevents the probe from hitting the rack when released, 7 — the main tether, 8 — release cord for the magnet, 9 — magnet, which switches the «Baklan» recording on. (A) shows the configuration before releasing the «Baklan»; in this configuration the «Baklan is tightly fastened to the rack by two belts. (B) shows the beginning of the release as belts are unlocked by dropping a load and the «Baklan» moves down and aside due to the joint action of the accelerating load and the turning support. (C) shows the beginning of the free fall as the magnet is pulled out and the «Baklan» recording starts

Vadim Paka's goals were to (a) simplify the design and reduce the cost of the undulating towed carrier as much as possible and (b) make it suitable for operation in the bottom layer at a very close distance (up to 1 m) above the sloping bottom without the risk of losing expensive equipment installed on the carrier due to impact with the bottom. To achieve the first goal, it was proposed to control the undulation of the towed carrier with a high-speed winch by alternately paying out and taking in the cable. Technical solutions to achieve the second goal are illustrated in Fig. 5 and 6.

A heavy chain tied with a weak rope to the lower end of the towed system (see Fig. 5) ensures the safety of expensive equipment due to the following three effects. First, when the bottom is reached, the drag force increases due to friction of the lower part of the chain against the bottom, which lifts the probe located above the chain. Second, when the lower part of the chain lies on the ground, the weight of the towing line remaining above the bottom decreases accordingly, which leads to a decrease in the speed of the probe's immersion or even to the cessation of immersion. Third, if the chain gets caught on some object lying on the ground, the weak rope to which the chain is tied will break — the chain will be lost, and the probe will float up.

In 1993, during the 29th cruise of the R/V «Professor Shtokman», Vadim Paka carried out an extensive program of closely spaced CTD profiling in the Baltic Sea using the «Rybka» probe [2, 3]. Waldemar Walczowski from the Institute of Oceanology of the Polish Academy of Sciences in Sopot took part in the cruise, and Vadim Paka introduced him to the design of the «Rybka» probe in the version shown in Fig. 5, and revealed to him all the secrets and wisdom of its manufacture and operation in marine conditions. Subsequently, a towed undulating carrier for the CTD probe, similar to that shown in Fig. 5, became a standard measuring device on the Polish sailing R/V «Oceania».

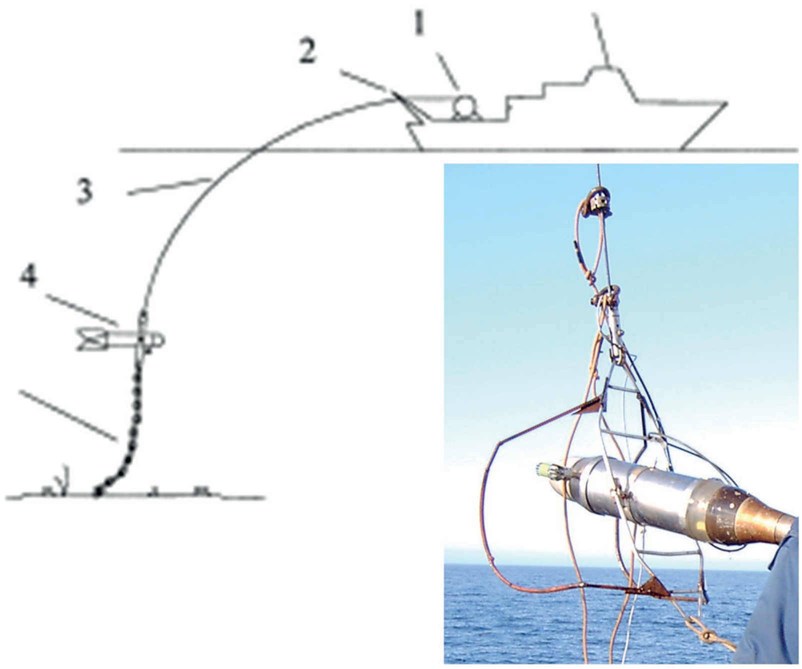

Fig. 5. Schematic and photograph of the fine-structure towed undulating complex "Rybka" [2, 3]. 1 — high-speed winch, 2 — U-frame with a canifas block, diverting the cable from the side of the vessel, 3 — reinforced cable-rope, 4 — CTD probe NBIS Mark 3, placed in a cylindrical shell with a tail, which is attached to a metal frame at the end of the cable-rope by swivels, 5 — a chain 1.5–2 m long, which weighs down the underwater vehicle and prevents the probe from coming into contact with the ground. The chain is tied to the lower end of the metal frame with a weak rope

Just as in the case of the «Baklan» microstructure probe, Vadim Paka would have ceased to be Vadim Paka if he had stopped at the «Rybka» probe and not continued to improve the arrangement for closely spaced fine-structure profiling [4] (Fig. 6). According to the new method of profiling from a moving vessel at 4–6 knots, a probe with a tether loosely coiled on the deck was released from the stern and began to sink down vertically, not perceiving the movement of the vessel. At the moment of termination of the free fall, the tether was tensioned, and the probe quickly rose to the surface. At this position, the recovery began. For recovery, a mechanism, which is a modified version of longline haulers designed for fishery, was used. It coils the tether on the deck instead of winding on the winch, and due to this allows repeating the next dive without delay due to preliminary preparation. For operation in this mode, the probe is placed between the load weighing about 5 kg and the float with a lifting force of about 2 kg, with the tether being fixed between the load and the probe, as shown in Fig. 6. The load is chosen in such a way that the steady speed of fall is 1 m/s. When the bottom is reached, the probe, held by the float at a predetermined small distance from the bottom (40 cm), stops for a short time in the vertical position with the sensors directed downward (see Fig. 6a). At the time of termination of the release, the tether is fixed on the deck, the outboard part is tensioned, and the onboard part is inserted in a hauler. Then, a recovery is implemented, ending when the probe approaches the stern. The bundle configuration during recovery is shown in Fig. 6b. Only when the probe takes off and is at a safe distance from the bottom does it perform horizontal movement. The loss of the probe with this method is possible only due to the break of the tether, which is loaded with no more than 10 % of the allowable tension.

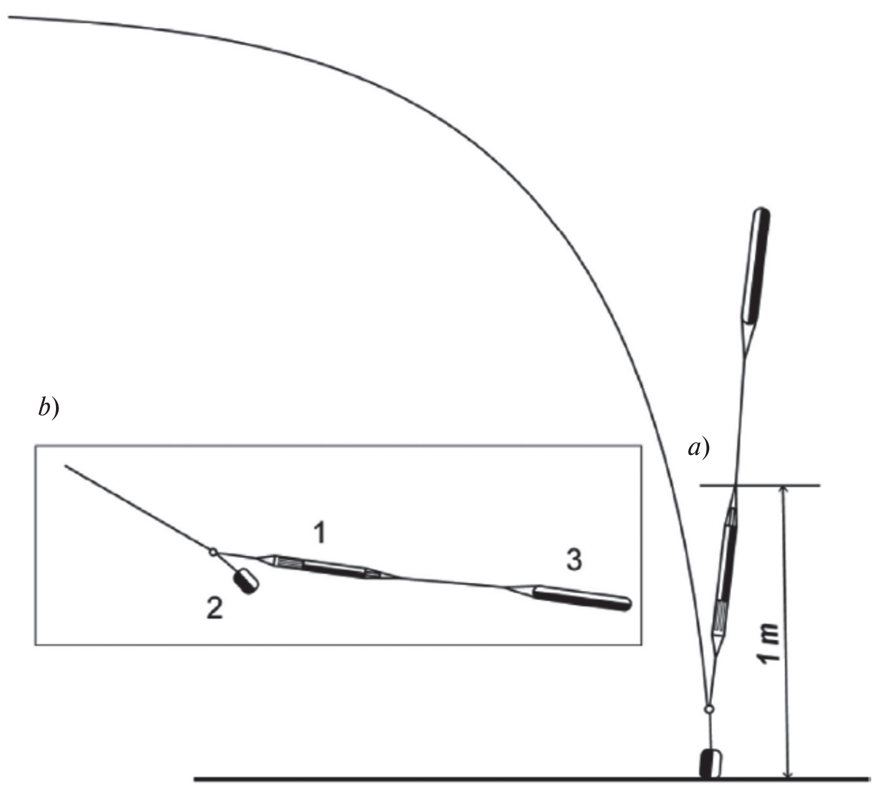

Fig. 6. An improved arrangement for the closely spaced fine-structure profiling, consisting of (1) CTD48Mc (Sea&Sun Technology), (2) load and (3) float, linked by pieces of rope. *a* —Configuration when the CTD probe reaches the bottom, *b* — configuration during recovery [4]

Vadim Paka was a talented inventor and an open, enthusiastic, optimistic person with an easy character and a subtle sense of humor. It would be symbolic to finish the story with a photograph of him flying on a crane beam above the deck against the blue sky (Fig. 7).

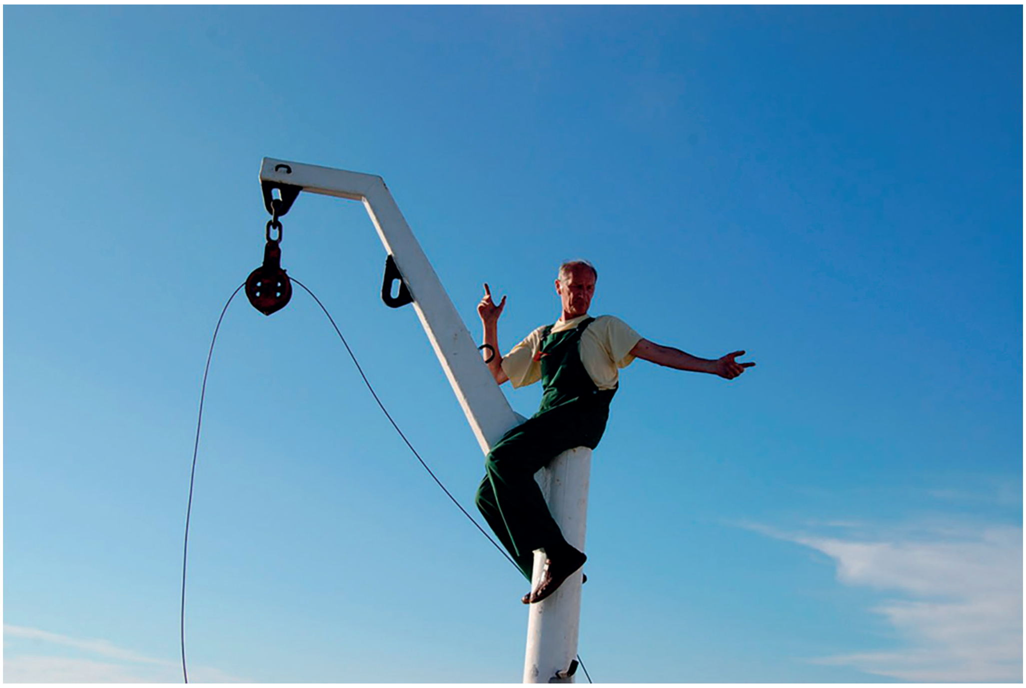

Fig. 7. Vadim Paka against the blue sky

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