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Capture

INNER **VIEW**

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corporate advisor for Hamamatsu Photonics K.K.

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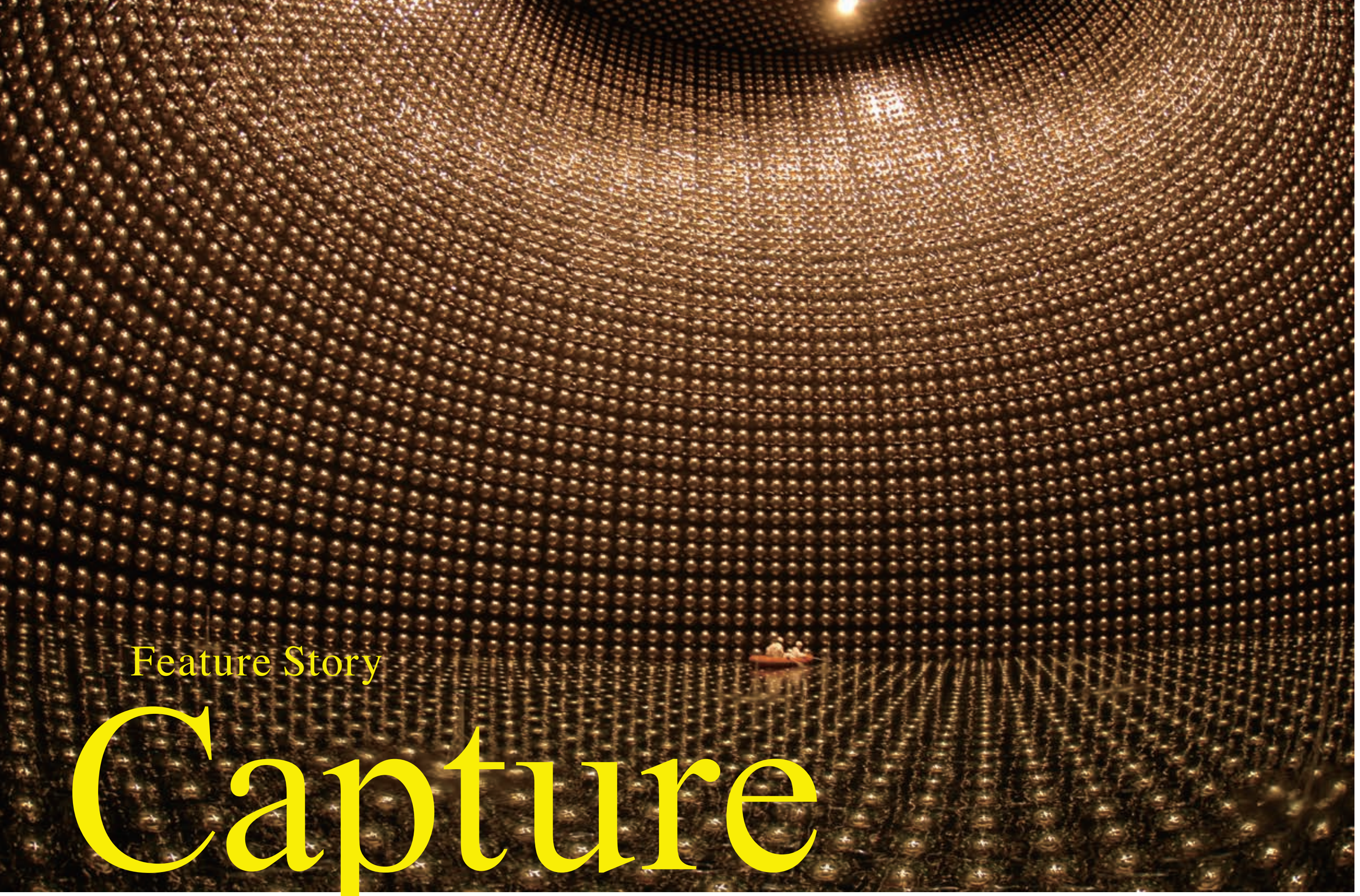

Feature Story

Capture

Inside the Super-Kamiokande detector being filled with water

Opportunity only comes to those who wait.
Observation of neutrinos began in January of 1987. The Kamiokande (The Kamioka Nucleon Decay Experiment) detected the light from the flight of neutrinos in February, just one month before Professor Masatoshi Koshiba retired from the University of Tokyo in March of that year. The neutrinos were produced as a result of a supernova explosion which was observed visually for the first time in 383 years. They lasted just 13 seconds.

Why does matter exist ?
According to Einstein's theory of relativity, mass and energy are equivalent. When energy is converted into mass, equal amounts of matter and antimatter are created. Matter consists of negatively-charged electrons orbiting around positively-charged protons. Antimatter consists of antiatoms, which are reversely charged and have positively-charged antielectrons orbiting around negatively-charged antiprotons. Of course, most of what exists today is matter, not antimatter. In the very beginning of the universe, when equal amounts of matter and antimatter should have been created, something caused asymmetrical conditions to rise, resulting in the universe we know today. Identifying what gave rise to this asymmetry might help explain how the universe began. This is why the detection of the neutrino was a discovery worthy of a Nobel Prize. In fact, capturing this one burst of light brought on a new field of learning called "neutrino astronomy", and this helps us close in on the mystery of the universe.
The Institute for Cosmic Ray Research of the University of Tokyo operates Kamioka Observatory in the mountains of Kamioka town in Hida city, Gifu prefecture. It was at this observatory in 1987 that Prof. Masatoshi Koshiba succeeded in detecting neutrinos from a supernova explosion for the first time in history. For Prof. Koshiba, this discovery led to a Nobel Prize.
Prof. Takaaki Kajita and the late Prof. Yoji Totsuka had also obtained data to support the oscillation of neutrinos, which were previously considered to have no mass. Later, data obtained by the Super Kamiokande detector proved that "neutrinos do oscillate, and hence, have mass." For this achievement, Prof. Takaaki Kajita was awarded the Nobel Prize in Physics in 2015.
The Kamiokande has fulfilled its initial purpose and has been superseded by KamLAND, a facility designed to capture lower energy neutrinos by Tohoku University. The Super-Kamiokande detector continues observation to capture the evidence for a more fundamental phenomenon, proton decay.
With us here is another individual who was instrumental in capturing evidence for the neutrino, who will enlighten us on the technology that supported the effort.

In coorporation with
The Institute for Cosmic Ray Research of the University of Tokyo, Kamioka Observatory
Hamamatsu Photonics K.K.
Organo Corporation

INNER VIEW

Toshikazu Hakamata

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Devoted to his work, but happy

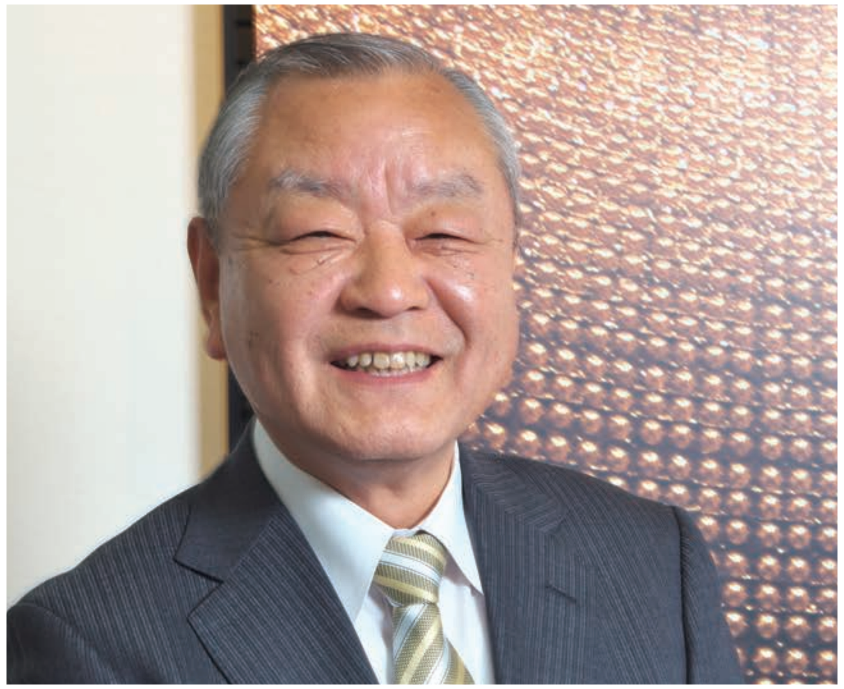
～The man whose work helped others win Nobel Prizes

Text by Michinari Okazaki / Photo by Megumi Yoshitake

When Prof. Takaaki Kajita (Institute for Cosmic Ray Research) won the Nobel Prize in Physics in 2015, one man in Hamamatsu shared the joy of the achievement. This wasn't a first for him. He was also the man who supported, behind the scenes, the research 13 years ago that led to a Nobel Prize for Prof. Masatoshi Koshiba. Let's find out a bit more about Hakamata, a self-confessed workaholic, and about his work.

A request from Prof. Koshiba

"I first met Prof. Koshiba in 1974. He called me with a request, and I said I would come to see him the next day. He immediately lectured me for keeping a customer in need waiting a whole day, so I changed my mind and went to seen him that very day. Fortunately, he held our product in high regard, and we established a solid relationship."
Several years before the development of large aperture photomultiplier tube for Kamiokande began, Hakamata supplied 3,000 photomultiplier tubes for the JADE project, a particle physics experiment being carried out at Deutsches Elektronen-Synchrotron (DESY) research center at the request of Prof. Koshiba. The project researchers are said to have been amazed by the stable performance of the photomultiplier tubes. This success led to the request for Hamamatsu TV (as the company was called at the time, and where Hakamata worked) to develop the large-aperture photomultiplier tubes for Kamiokande.
"When our president found out the aperture was to be 20 inches (50cm) in diameter, he asked us,'Can you do this?' I replied, 'It can't be impossible.' I was pretty optimistic."
The largest aperture of any of the company's photomultiplier tube at the time was 20 cm in diameter. Taking the job meant they had to develop a product



Toshikazu Hakamata

Born December 1948 in Shizuoka, Toshikazu Hakamata graduated from the Department of Electrical Engineering of Hamamatsu Technical High School in 1967. He began working for Hamamatsu TV Co., Ltd. (currently Hamamatsu Photonics K. K.) the same year. In 1997, he became the chief of the Electron Tube Sales Department; in 2012, deputy chief of the Electron Tube Division; and, in 2014, corporate advisor, the position which he holds to this day. He is also director of the Research Division at the Research Foundation for Opto-Science and Technology. Since joining the company, he has consistently remained involved in the development of photomultiplier tubes. Ever since research began at the University of Tokyo's Kamioka Observatory, he has acted as liaison to relay technological needs to the company. Outside work, a major interest is collecting photographs of aircraft.

Website of Hamamatsu Photonics K. K.
http://www.hamamatsu.com/jp/en/

with an aperture more than double the size of their current product within one year. Why was such a large aperture necessary? And what's a photomultiplier tube, anyway?

"Strong light can be converted into electrical signals using photodiodes. Weak light has to be detected by converting photons into electrons, then sending the electrons to a sensor incorporating an internal amplification mechanism. In other words, this takes two functions: photoelectric conversion and multiplication. And since we have to capture as many photons to measure a single photon, we needed a photomultiplier tube with a large aperture. The multiplication in this case doesn't mean a factor of two or three: it means a factor of several tens of thousands.

"With small apertures, not enough photons enter the photomultiplier tube. For example, if only one photon entered the tube, the resulting signal would be indistinguishable from the self-noise produced by the sensor. If we double the aperture, two photons might enter the tube and produce a signal peak with twice the height, which we can then distinguish from noise. The larger the aperture, the better the result. In reality, even a diameter of 20 inches is enough to capture just one photon at best. Observation is a battle against noise."

Sales representative or developer?

Hakamata, who is telling us about photomultiplier tubes, is also quite knowledgeable on its technical aspects. However, since those days, he has always belonged to the sales department. What's his actual role?

"Our company wasn't large. Since we're a highly specialized company, and even though I was a sales representative by title, I've always acted as both a sales and engineering person, or as a liaison between customers in the engineering field and the sales staff. Being a sales representative was never really my choice. All I tried to do was to solve whatever issue presented to me. I did my best, and the people around me worked with me."

Hakamata joined Hamamatsu TV, the predecessor of Hamamatsu Photonics, in 1967. He was about to graduate from a local technical high school and was looking for a job when he first heard of the company.

"I wanted to have a job in the electrical field, so I got a qualification to repair televisions. I didn't want to transfer out of my hometown. I was looking for a local company. That's when I heard about Hamamatsu TV from my older brother. I applied for the job and got it."

Hamamatsu TV was founded in the footsteps of Prof. Kenjiro Takayanagi, the first to succeed in producing a Japanese character on the world's first electronic television screen in 1926. The spirit of its founder carries on to this day, and the company is renowned for fearlessly tackling new challenges.

"Everyone at Hamamatsu Photonics is a researcher. We're basically given a free hand to do anything. You're free to focus on sales or development. We earn money so that we can fund our next development. Money itself isn't the goal. Our profits allow us to pursue new knowledge and challenges. The development of the large-aperture photomultiplier tube wouldn't have been possible if it weren't for the profits made from other products."

The 20-inch photomultiplier tube requested by Prof. Koshiba was originally intended not for detecting neutrinos, but for documenting proton decay. It took less than one year for the company to develop the product, and 1,050 photomultiplier tubes were delivered by 1982. The development proceeded at an amazing pace.

"There was a clear purpose, to observe proton decay. To add to this was the fact that if successful, the discovery would certainly lead to a Nobel prize. Those were great motivational factors. Our company has a tradition of being the first to tackle the unknown and unexplored areas. This was a good theme, and everyone gave it their best. It was a tough year, but very rewarding."

Being called a workaholic

Hakamata enjoys his work. So much that people around him call him a workaholic. Although he loves to drink, if forced to choose between working and enjoying his drink, he says he would quit drinking.

"I enjoy finding out things that aren't known. I hated my studies at school, and I had no intentions of going to college. I wanted to learn about electricity and go to work as soon as possible. That's why I enrolled in the department of electrical engineering at a technical high school.

"The first four years at my company, I was in charge of inspecting the photomultiplier tubes. But, at the time, the practical applications for photomultiplier tubes were still pretty limited. So there was really no one who had mastered the technology or who could mentor me. So I worked outside my range of duties as an inspector and began studying the mechanism on my own. I learned the characteristics of photomultiplier tubes by performing actual measurements. But that was the fun part. I lost track of time, and I was totally immersed. It became a hobby."

His workplace is where Hakamata "feels the most relaxed." His office has office desk and cabinets on both sides, but he says he loves to come to his office even on Saturdays and Sundays to bury himself in the pile of documents.

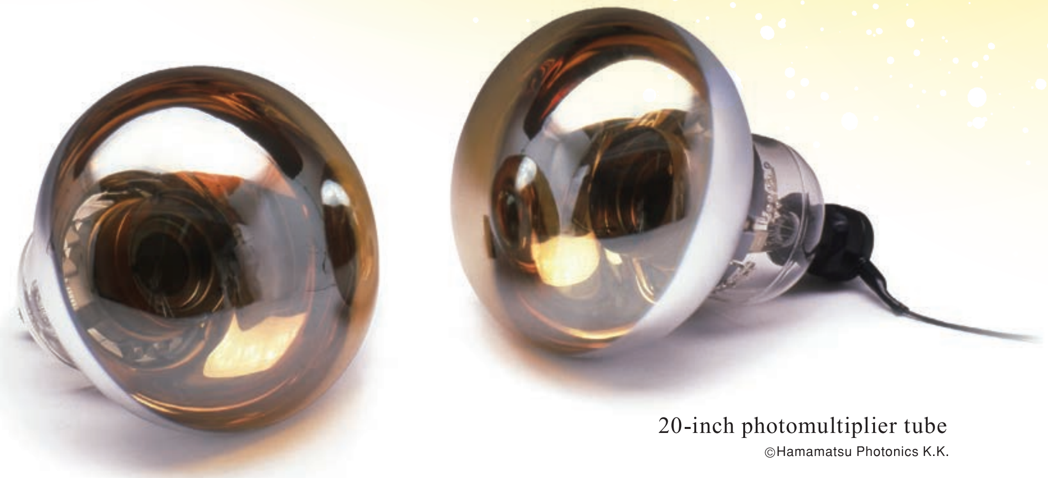
"On weekends and holidays, when no one else is around at the company, I can do whatever I want. There's no noise to distract me. I have all the time in the world to think. I also feel a sense of accomplishment whenever I complete a backlogged job."

For Hakamata, work remains his hobby. His best hours have always been work hours. It goes counter to current views on labor practices and efforts to change work styles, but in Hakamata's case, there's no hint of the misery associated with long working hours.

"After being in charge of inspections, I was assigned to the sales department. The job appealed to me because I could talk to my customers based on four years of experience in inspecting tubes. Whenever a customer asked about something he couldn't understand, I'd explain, drawing on my experience. I didn't need to relay the question to an engineer. I was giving an answer on the spot and allowing things to proceed smoothly. I felt incredibly happy I could resolve a problem my customer was experiencing based on what I said. I'm normally not the socializing type, but I kind of liked talking about technical matters. I think this is why I was able to continue with my job for 40 long years. I really experienced no stress."

However, not everybody enjoys working. What would be Hakamata's advice to such people?

"For example, if you're a sales representative, you have to learn in detail about what you're promoting. Otherwise, you'll fail to gain the customer's trust. Then, you have to establish a relationship in which both you and your customer can speak candidly to each other. That way, you come to understand what your customer really needs. I don't mean to sound pretentious, but I think it's important to let your colleagues see you work hard into the late hours and take pleasure in talking to customers. I think I've done that. My ultimate joy would be for people of future generations to say, "All he seemed to do was work. But he was a remarkable person."



20-inch photomultiplier tube
©Hamamatsu Photonics K.K.

To catch a single photon

～the 20-inch photomultiplier tube

Cherenkov radiation — that's the name of light that holds the key to elucidating the universe's beginnings.
The neutrinos that emit this light come from a long, long distance away in the universe.
The light is extremely faint, so faint it's invisible to our eyes.

Photons and the photomultiplier tube

Light exhibits the properties of both waves and particles. When we talk about the particle-like behavior of light, we talk about photons, the most fundamental unit. Viewed with an oscilloscope, the signal pulsates as light intensity falls. Below a certain intensity, the peak height of the pulses becomes constant, and we see apparent changes as changes in temporal frequency. This is the manifestation of the theoretical behavior of light as particles, seen through physical observation. The number of pulses counted per unit time indicates the amount of light.

The instrument used to measure the amount of light and convert it into electrical signals is the phototube. In the case of very weak light, we need to amplify the signal created by the captured light, or photons. That's the function performed by the photomultiplier tube, which is also referred to as a PMT or, in Japan, as a photomul. Catching a single photon is something like detecting the light of a tiny candle on the moon's surface from here on Earth.

How light is captured

A photomultiplier tube is a vacuum tube sealed inside a closed vessel. It basically consists of an input window, photoelectric surface, electron multiplier, and an anode (Fig.1). The photoelectrons emitted from the photoelectric surface in response to the incident light are collected and accelerated by the focusing electrode, then made to collide with the electron multiplier, called the dynode. The collision causes several secondary electrons to be emitted from the dynode. By repeating this process, we can multiply the number of electrons in a cascading manner. At the last dynode, the electron group that reaches the anode is multiplied by a factor of 1 million to 10 million compared to the initial group (Fig.2). We can convert the arrival of this electron group at the last anode into an electric signal.

The photomultiplier tube is used to measure ultra-weak photon emissions in applications such as high-energy physics experiments, medical instruments, instruments for the biotechnology field, petroleum exploration instruments, astronomical observation instruments, particle counters, etc. The photomultiplier tube developed for Kamiokande had an aperture of 20 inches (50cm), the world's largest. The principle of photon detection remains the same as for smaller counterparts.

Neutrinos were a noise source.

Countless neutrinos, one of the smallest elementary particles constituting matter, are all around us, moving at rates as high as several hundred trillions per second. Yet, due to their extremely small mass of less than one-millionth of an electron, they travel unimpeded through the vast atomic space without the least effect on the human body or Earth. That's why, while theory indicated neutrinos had to exist, quite some time passed before they were actually observed. Once in a great while, a neutrino collides with an atomic nucleus and produces a charged particle. When the speed of this charged particle exceeds that of light, it generates a type of shock wave. This is known as Cherenkov radiation. In water, the speed of light is suppressed to 75% of that in vacuum, making it easier for the charged particle to exceed the speed of light. Thus, more water increases the possibility of detecting Cherenkov radiation, even if it remains a rare occurrence.

The Kamiokande at the Kamioka Observatory began observations in 1983. The goal is to capture the phenomenon of proton decay to explore the state of space in the far future. Since proton decay is an extremely rare occurrence, we need to increase the frequency and deploy a mechanism capable of capturing the faint associated radiation. This requires massive volumes of water and a disturbance-free (noise-free) environment. This is why a gigantic facility with a pool containing 3,000 tons of ultrapure water was built 1,000 meters below the ground in the mountains of Kamioka. The plan was to have the approximately 1,000 photomultiplier tubes embedded in the walls to patiently wait and observe the pool.

Cherenkov radiation is emitted not just by neutrinos, but by proton decay. Kamiokande was originally designed to observe the latter. Since the Cherenkov radiation emitted by neutrinos is the source of noise in proton decay observations, it became necessary to develop a way to distinguish the noise attributable to neutrinos from the target Cherenkov radiation produced by proton decay. The method for distinguishing them eventually led to the Nobel Prize.

The most difficult aspect of developing the 20-inch photomultiplier tube was designing the tube to guide the photoelectrons precisely to the dynodes. Needless to say, efficiency was essential. But the tube also had to be designed so that the time-of-flight of photoelectrons from the photoelectric surface to the dynode would be the same, regardless of the position of the collision on the photoelectric surface. That was because this parameter would be critical in determining temporal resolution, an important performance specification for determining the direction from which a photon arrived. Rigorous electron orbit calculations were performed to design the shape of the glass tube and the electric field structure of the dynodes. As for the multiplier, a 13-stage Venetian blind structure* was adopted. The development was completed in the amazingly brief timeframe of 10 months. The first prototype was ready in October 1980.

Super-Kamiokande, the successor to Kamiokande, currently incorporates 11,129 advanced model 20-inch tubes and 1,885 8-inch tubes.

* Similar to blinds on a window, a significantly large number of narrow, reed-shaped units are aligned in rows.

Interviewer : Nobuhisa Okamoto

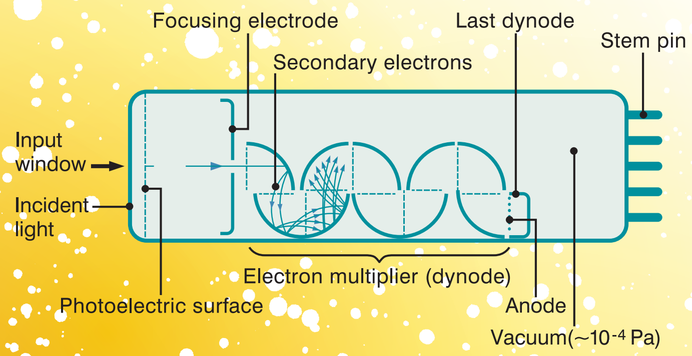


Fig. 1. Mechanism of photomultiplication by photomultiplier tube

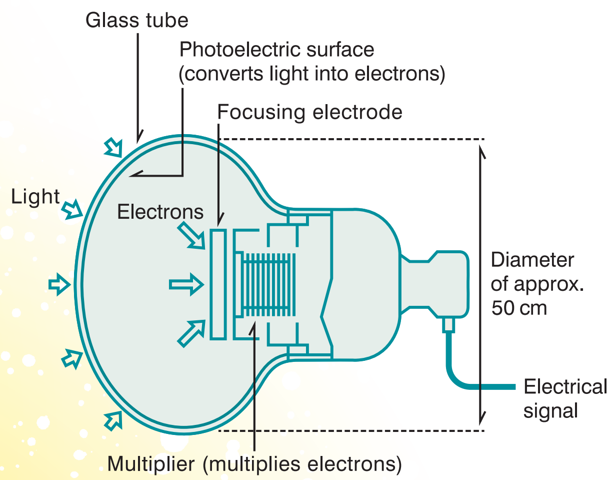
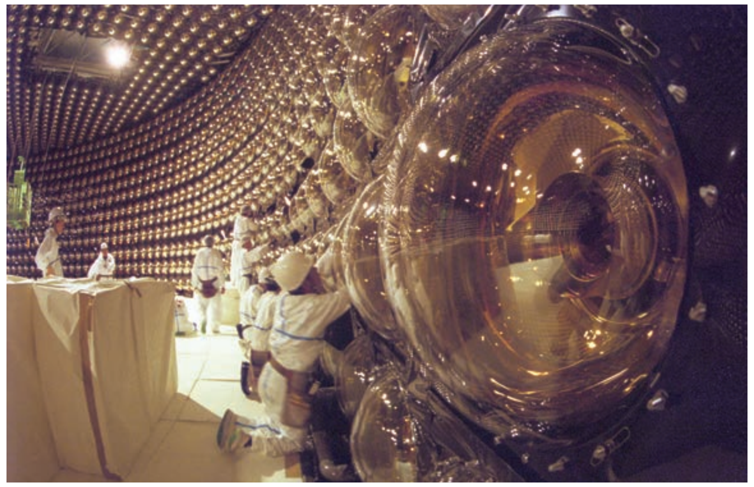


Fig. 2. Structure of a photomultiplier tube



Installation of photomultiplier tubes in Super-Kamiokande
©Kamioka Observatory, Institute for Cosmic Ray Research, The University of Tokyo

Beyond the limit
～the ultrapure water production system

To detect the extremely faint Cherenkov radiation associated with neutrino observations, Kamioka Observatory needs a massive supply of ultrapure water.
We have several interesting stories to tell about this system for water purification and water quality control, which shed light on the difficulties and technologies unique to this facility.

Why water? What kind of water?

The Cherenkov radiation observed at this facility is attributed to proton decay and neutrinos. The task of the photomultiplier tubes aligned on the walls is to capture this light. The water, on the other hand, has the important task of generating the light and transporting it to the tubes. When a neutrino collides with a water molecule, it triggers the release of a charged particle, which is responsible for generating Cherenkov radiation. The chances of this collision occurring are vanishingly small, so the volume of water needs to be made as large as possible to ensure a reasonable chance of observation. To allow the feeble Cherenkov radiation, once generated, to reach the photomultiplier tube without attenuation, the water has to be ultrapure, with as close to all impurities removed as possible.

Production of ultrapure water

The Kamioka Observatory uses groundwater that streams out from the Kamioka Mine.The groundwater is treated using an ultrapure water production system and fed to the measurement tank from the top. Since this is a cyclic treatment system, the water is returned to the purification system from the bottom of the tank. The tank capacity of Super-Kamiokande is 50,000 m^3. The system treats 60 m^3 per hour; it takes about one month for the water inside the tank to turn over completely.
The water purification system removes ions, particles, gas, and bacteria thoroughly. Impurities like metals and other ions can absorb Cherenkov radiation or change its wavelength and need to be removed using ion exchange resins and other technologies. Water purity is measured by its electrical resistance.
In addition, bacteria, a major factor in increasing the turbidity of water, is removed using a UV sterilizer to levels of one count per 1cm 3 or less.

Radioactive materials, water temperatures, and water levels

In practice, the greatest obstacle to observing Cherenkov radiation is naturally-occurring radioactive materials. The radioactive materials found in rocks are dissolved into groundwater, and the radiation emitted by these materials generates noise. In particular, the tunnel of the mine in which the Kamioka Observatory is installed exhibits extremely high concentrations of radon, which, dissolved in small quantities in groundwater, inhibits Cherenkov radiation observations. Thorough removal of the radon dissolved in water is done with a RO (reverse osmosis) membrane unit and a degasification tower. Radon is removed from air coming into contact with the water using active carbon.
It's worth noting that radioactive materials are eluted from materials of tank, pipe etc., although in trace amounts. The ultrapure water inside the tank is subjected to cyclic water treatment in order to maintain high purity.
Also,vertical temperature gradients inside the tank generate convections and affect observations, so the water is precisely controlled to 13±0.1°C. Water levels also have to be precisely maintained, since a difference of 0.1 mm in water level will result in 0.1 m^3 differences in the volume of water. High precision water level gauges are installed to control water levels. These stringent specifications are unique to the ultrapure water production and control system for Kamioka Observatory. They're in sharp contrast to the specifications that apply for other uses, including applications within the electronic or other industries.

Monitoring air and water

Radioactive materials, such as radon, are found not just in water, but in the air above the surface of the water. That can affect water quality. Although we can't measure radon directly, its concentration is believed to have a proportional relationship to concentrations of other particles and impurities. Thus, cleanliness is controlled by measuring the number of particles in water and air.
At Kamiokande, a particle counter is placed at the water intake from the ultrapure water purification unit to the tank. However, to maintain the purity of water in the Super-Kamiokande, the water used for measurements isn't returned to the tank. That means the water needs to be replenished. The downside to this approach is that the replenished water inevitably contains radioactive materials.Thus, it's important to allow the water inside the tank to circulate for as long as possible after it's supplied to the tank. Since the stability of the water quality is confirmed, monitoring is performed only during regular maintenance.
RION's liquid-borne and airborne particle counters are being used to monitor particles.

Ceaseless challenges

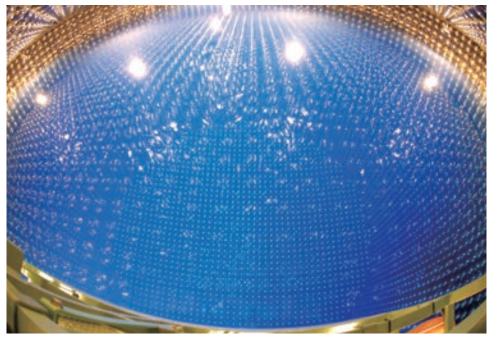
Simply maintaining the quality of the ultrapure water at the Kamioka Observatory at its current level isn't enough. In science, new discoveries always generate new questions. The system has to be upgraded continuously, something that's been true since it began operating in 1995. Kamioka Observatory requires functions, like the thorough removal of radon and precise water temperature controls, rarely required by other water treatment plants. It's hard, but at Kamioka today, the challenges continue to take us beyond the limit.

Interviewer : Nobuhisa Okamoto

(Reference)
[1] Definite specifications of the Organo Corporation
[2] "Welcome to the Space Theater" at the Organo Corporation's website
http://www.organo.co.jp/uchu-gekijyo/index.html

Table 1. Quality of circulating water treated with the purification system [1]

Specific resistance	≥17.5 MΩ·cm
Particles	≤10/cm^3 (particle size ≥ 0.2 μm) ≤100/cm^3 (particle size ≥ 0.1 μm)
Bacteria	≤1/cm^3
Dissolved oxygen	≤1 ppm
Uranium	≤1 mBq/m^3
Radium	≤1 mBq/m^3
Thorium	≤0.1 mBq/m^3
Radon	≤10 mBq/m^3



Super-Kamiokande near its full water capacity
©Kamioka Observatory, Institute for Cosmic Ray Research, University of Tokyo

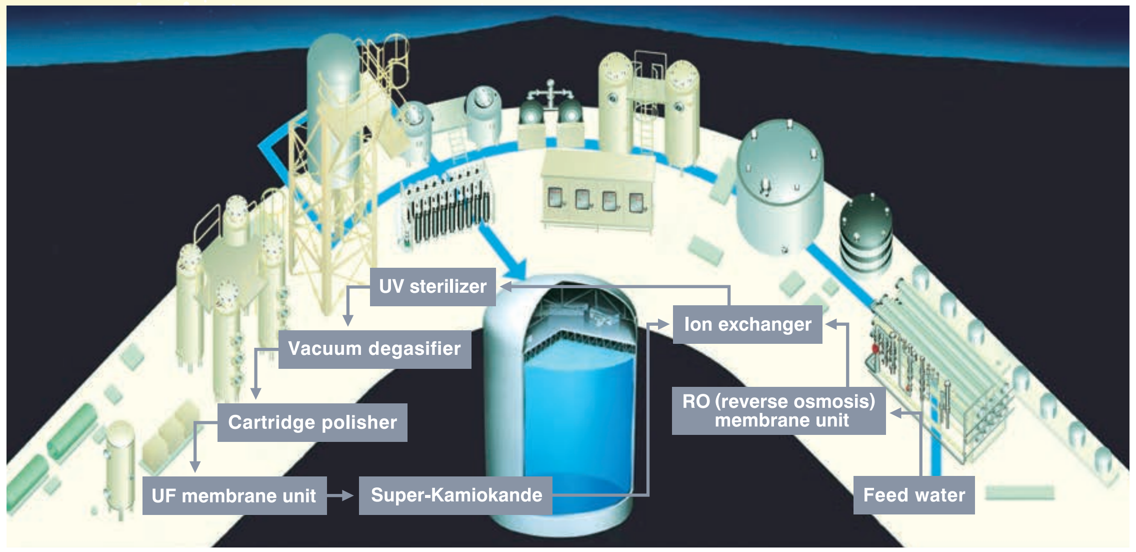


Fig.1. Ultrapure water purification system at Super-Kamiokande [2]

Road Traffic Vibration Measurement

Here we’ll introduce a case study on vibration measurement using RION’s vibration level meter that makes it easy to meet the requirements specified in the vibration measurement manual of 2014.

The Vibration Measurement Manual

Road traffic vibrations are measured using a vibration level meter. But the data obtained can’ t be correctly evaluated and compared if there are variations in the measurement instrument or method. In Japan, the Vibration Regulation Act stipulates vibration standards. A vibration measurement manual presenting measurement methods was implemented in 2014. The manual proposes methods for vibration measurement and evaluation to solve persistent issues with vibration that can’t be addressed based solely on measures presented in the Vibration Regulation Act. The measurements involve taking vibration levels along the vertical and two horizontals. The evaluation includes 1/3 octave band analysis, which corresponds to the characteristics of human perception.
Note that vibration level is a value of assessment unique to Japan and corresponds to vibration acceleration levels adjusted for vibration perception, as set forth in JIS C 1510 “Vibration level meters.”*

* See p. 16 for an explanation of vibration levels.

The VM-55 Vibration Level Meter

Conventionally, in order to perform 1/3 octave band analysis of vibration levels, waveform recording by a data recorder and then analysis by computer software were necessary (Fig.1).
RION is currently manufacturing and marketing the new VM-55 vibration level meter, which is capable of simultaneously performing vibration level measurements and vibration waveform recording, as well as 1/3 octave band analysis (Fig.2).
The main features of the VM-55 are listed below.

(1) Waveform recording function
Vibration acceleration waveforms are recorded using the waveform recording function of the new vibration level meter. The recorded waveform data can be reanalyzed by programs such as waveform analysis software.

(2) 1/3 octave band analysis function
This vibration level meter can perform 1/3 octave band analysis without the multiple external devices and cables required in conventional measuring.Less cables and no extra devices are needed.

(3) Electrical signal output function
The vibration acceleration waveform data can be output as AC electrical signals from the vibration level meter. This signal and the sound pressure waveform signal can be simultaneously recorded to a data recorder for synchronized processing of vibration and sound data.

(4) Serial communication function
The serial communication function allows the calculation values to be transmitted to computers. Combining this function with the 1/3 octave band analysis function, the Internet, self-developed programs, etc. enables a wide range of applications and functions, including functions that allow the display of calculation values from remote locations on the web browser.

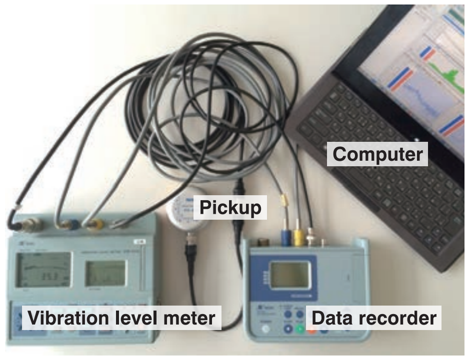


Fig.1. Set of conventional vibration meters from our company

Fig.2. VM-55 vibration level meter

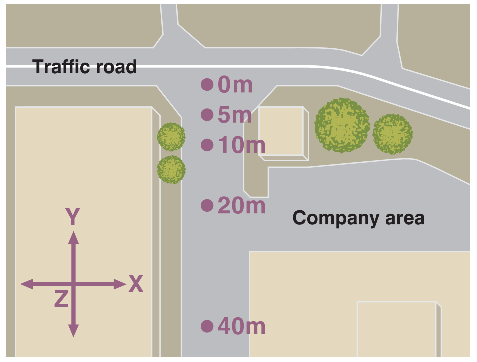


Fig.3. Measurement points

Table 1. Measurement conditions

Measurement items	Vibration levels along three directions (vertical and two horizontal axes) 1/3 octave band analysis of vibration acceleration levels along three directions
Arithmetic value	*L*max for 30 second time period
Duration of measurement	Approx.1 hour

Case Study of Measurement: Measuring the Propagation Characteristics of Ground Vibration

We report here on a measurement study undertaken in compliance with the vibration measurement manual, using only vibration level meters and function (2) introduced previous section.The study measures the propagation characteristics of ground vibration created by vehicles passing by on the road* in front of our company.

*A flat, two-lane road with lanes 3 meters wide and a 1.6-m wide sidewalk.

1. Method of measurement
Measurement points were positioned along a private road inside the premises of our company, which intersects the target road. The point where the private road intersects the target road is designated as the 0 m point. From there, one vibration level meter was installed at each point at distances of 5 m, 10 m, 20 m, and 40 m. Figure 3 shows the measurement points. Table 1 presents the measurement conditions.
Taking into consideration the conditions of road traffic vibration, the *L*max values of the 1/3 octave band in three axial directions were repeatedly recorded using the vibration level meter for a duration of 30 seconds. To allow comparisons of measurement results against the vibration events, the time at which the vibration from the passing vehicle was perceived was recorded in field notes.

2. Calculating measurement results
Based on the recorded time, the *L*max for the vibration of the passing vehicle was extracted from the *L*max of the 1/3 octave band calculation results within the 30 second time periods repeatedly recorded using the vibration level meter. In the measurement study, we were able to extract 18 vibration events during the hour of measurement.
We compared the results along the three directions for each point at the time of the vibration event to eliminate vibration events exhibiting poor correlation with our calculations. Then, we used the arithmetic mean of *L*max values corresponding to the 10 highest vibration levels (vertical direction) to calculate the propagation characteristics of the ground vibration.

3. Results of measurement
Figure 4 shows the arithmetic mean at the 0 m point and the 10 Lmax values used in the calculations. Figure 5 shows the results of measurement of the propagation characteristics of ground vibration as a plot of the arithmetic mean at each measurement point. The results for 0 m to 10 m along the vertical direction show that vibrations at 16 Hz exceed 60 dB, which is believed to be sufficiently high to be perceived by humans. Furthermore, the distance attenuation of ground vibration can be confirmed in all three directions.
Note, however, that the data obtained at the measurement points include some vibration events exhibiting poor correlation. This points to the need for collecting data on as many vibration events as possible. Depending on the frequency of vibration event occurrences, it may be necessary to adjust computing intervals to isolate individual vibration events.


Ryosuke Kazama
Development Department

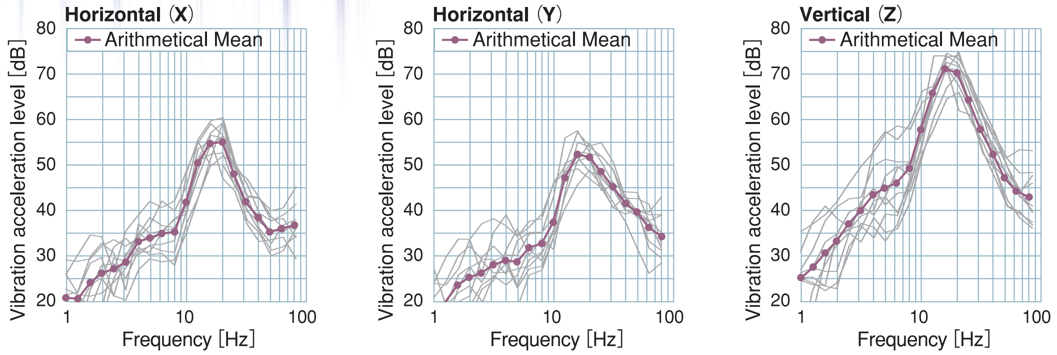


Fig.4.
Results of arithmetic mean calculations at the 0 m point and the 10 *L*max values used in the calculations (from left to right: X, Y, and Z axes)

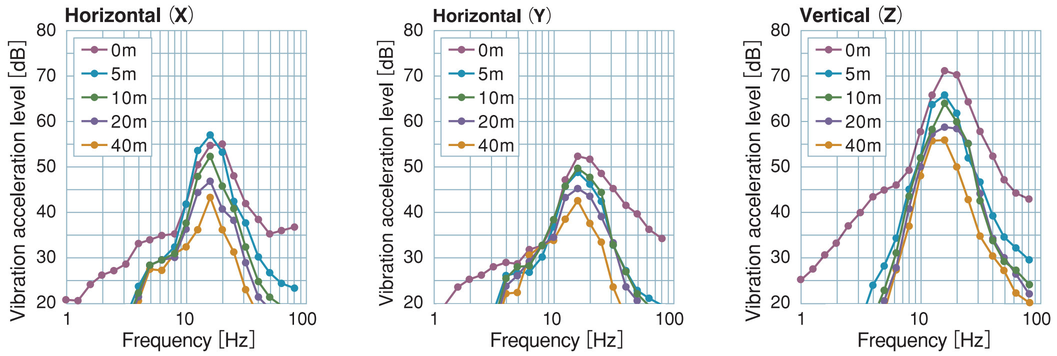


Fig.5.
Propagation characteristics of ground vibration (from left to right: X, Y, and Z axes)

Understanding Measuring Instruments

We will explain a measuring instrument from various angles in a three-part series

The seismometer (Part 2 of 3)

How a seismometer works

The previous issue showed how earthquakes are quantified.
In this issue, we'll introduce how a seismometer works—in other words, how ground motions (earthquakes) are detected and quantified.

Electric seismometers

We can group seismometers into one of two types: mechanical seismometers, which detect ground motion mechanically using balls or pendulum, like the tellurion; and electric seismometers, which convert detected ground motion into electrical signals (Fig.1). Quantification of ground motion can only be done using the latter. RION has been developing and manufacturing electric seismometers since 1980.

The electric seismometer consists mainly of three blocks: the sensing block, which converts ground motion data into analog electrical signals; the signal converting block, which converts electrical signals into digital data; and the control block, which analyzes the digital data obtained and controls the various functions of the seismometer. How these three blocks are combined can be translated into either an all-in-one model or a discrete components model (Fig.2). The all-in-one model features all three blocks in a single housing. The discrete models include analog devices with separate sensing blocks and digital devices with separate control blocks.

Sensor block

Based on the basic principle of the vibration sensor block, the pendulum (weight) is assumed to be the stationary point; the motion of the housing caused by the earthquake is assumed to be the relative displacement. The latter can be converted into electrical signals.

There are several types for sensors.Let's see them.

(1) Piezoelectric sensor type

This type of sensor relies on the piezoelectric effect of ceramics. When a piezoelectric element is accelerated, it becomes distorted and produces electrical signals. Since the signal intensity is proportional to the degree of the distortion (and hence acceleration), the signal gives output data for acceleration. Piezoelectric sensors offer several advantages, including low cost and compact seismometer design, but they're susceptible to the effects of occasional pyroelectric phenomena and noise generated by transient temperature changes. This makes noise reduction a critical issue for piezoelectric sensors.

(2) Electrostatic sensor type

This type of sensor relies on the characteristic change in electrostatic capacity that occurs with changing the distance between electrodes. They are based on MEMS (Micro Electro Mechanical Systems) for a compact design.

The electrostatic capacity between the mobile electrode (pendulum) and the fixed electrode #1 attached to the housing is defined as C1. The electrostatic capacity between the mobile electrode and the fixed electrode #2 is defined as C2. If there is no acceleration (i.e., when the relative displacement is zero), $C1 \fallingdotseq C2$. If the electrodes are subjected to relative displacement and acceleration, the mobile electrode will be displaced in a manner proportional to acceleration. Thus, $C1 \neq C2$ (in Fig.2, $C2 > C1$) ; this change can be converted into voltage to obtain output data for acceleration.

While electrostatic sensors are compact and lightweight, this structure leaves them susceptible to problems associated with the noise generated by micro acceleration. In response, RION adopted a design that features three sensors for each axis. In signal processing, the final output value can be determined by the "2 out of 3" majority rule, thereby ensuring high precision and high reliability.

(3) Servo sensor type

With this type, the position of the pendulum (weight) is controlled so that its displacement relative to the housing remains zero at all times. The amount controlled is used as the signal.

When the sensor is subjected to ground motion, the pendulum (weight) is displaced relative to the housing. The amount of this displacement is detected by a position sensor, and the signal is transmitted to the servo amplifier. The servo amplifier sends an electrical current through the coil to keep the pendulum stationary with respect to the housing. Since the current is proportional to the acceleration of ground motion, the current can be converted into a voltage to obtain the output data for acceleration.

While the servo sensor can detect seismic waveforms with high precision, high sensitivity, and low noise, their configuration is extremely sophisticated, making them very costly pieces of equipment.

Signal converting block

The signal converting block digitizes the electrical signals obtained by the vibration sensing block into instrumental seismic intensity and/or SI values.

The voltage signals corresponding to the electrical signals converted by the sensing block vary between sensors, even for identical ground motion. These signals also contain unwanted signals (noise). Thus, the raw voltage signals must first be modified to a specified level using signal amplifiers and attenuators. Next, before the digitization process, the unwanted signals are removed using band-limiting filters. Finally, the signal is converted into a digital signal, or numerical data, using an IC called the A/D (analog-to-digital) converter. This numerical data is transmitted to the control block.

Control block

This block houses the CPU and memory. The numerical data obtained from the signal converting block is analyzed and calculations made to determine instrumental seismic intensity, SI value, etc. This data is used to control all seismometer functions, including alarm judgment, data communication output, data recording, etc.

Seismometers have two basic functions: control and monitoring. Seismometers designed for control purposes are directly associated with human safety, like halting the operations of a facilities in factories and railways and controlling the output of infrastructures like electricity, water supply, and gas supply. Seismometers used for monitoring purposes include those installed by the Japan Meteorological Agency, which measure seismic intensity at various locations across the country in the event of an earthquake. Data like this may subsequently be reported by the media.

In the next issue, we will look into the future possibilities of seismometers.

Takeshi Sawada
Development Department

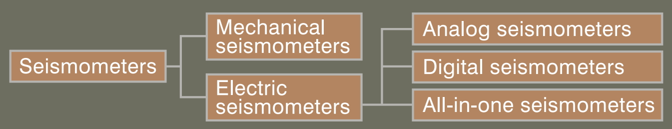


Fig.1. Classifying seismometers

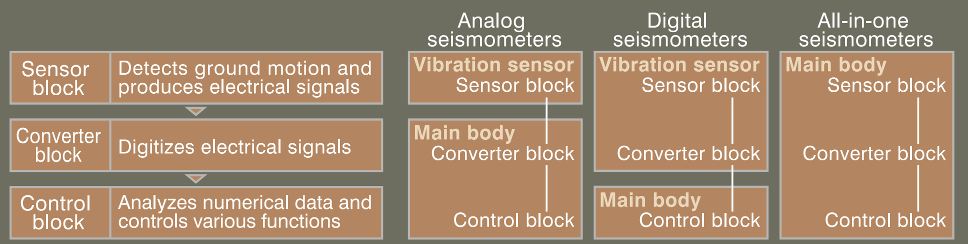


Fig.2. The three blocks of a seismometer and combinations

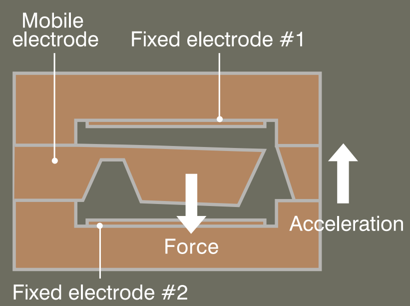


Fig. 3. Electrostatic vibration sensor

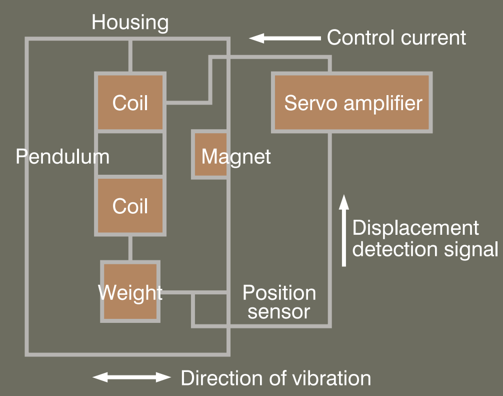


Fig.4. Servo vibration sensor

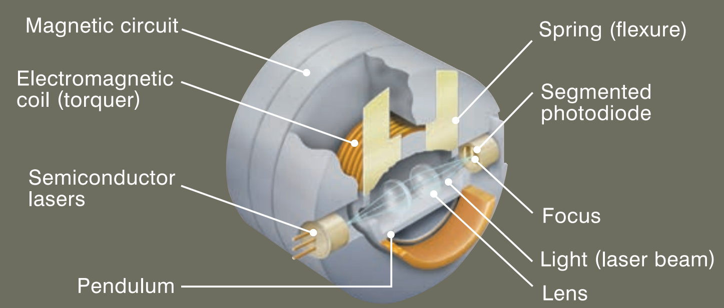


Fig.5. Schematic diagram of a pendulum-type position sensor

Rion's History of Technology

LEARNING from our Past Products

Adopting envelope processing made our vibration meter essential for equipment diagnosis

VA-10

Marketed in the latter half of the 1980s,
the VA-10 was the result of all of RION's aspirations and technologies at the time.
We'd like to interview Hidetomo Komura,* who was involved in the development of the VA-10.

* At the time the VA-10 was being developed, Komura belonged to Group 2 of the Sound Measuring Technology Department.

——Was the VA-10 RION's first vibration meter?

No, it wasn't the first. There were other vibration meters Rion manufactured and sold before the VA-10. By 1986, these included the VM-61 and VM-62, followed by the VM-63, which later became a bestseller.

——What was so epochal about the VA-10?

All of the previous models had been general-purpose vibration meters. At the time, our Sales Department held study sessions and invited specialists in vibration diagnosis, including Dr. Toshio Toyota and Mr. Tadashi Kobayashi, as lecturers. Dr. Toyota is the leading expert on equipment diagnosis. Mr. Kobayashi is an authority on gear diagnosis. Through these sessions, someone came up with the idea for a vibration meter designed specifically for anomaly diagnosis, a meter that could perform some on-site vibration frequency analysis. At the time, the popular machine checkers from other manufacturers were mostly designed for vibration frequency analysis for precision diagnoses and required optional compact data recording units. That's why we thought we could take a different approach and offer a product that performed vibration frequency analysis at a satisfactory level without a data recorder.

——Weren't microprocessors entering widespread use in the late 1980s?

Yes. Since our device was battery-operated, we used the μPD70216 microprocessor. This featured an 8-bit A/D converter, so the dynamic range was 6 dB×8 bit = 48 dB. Everyone thought this wouldn't be enough for practical use, until one of the developers proposed applying dither. Dithering is a method used to reduce quantization error by introducing white noise with an amplitude of approximately 0.5 bits. That allowed us to improve the dynamic range by around 10 dB.


Hidetomo Komura

——What was the VA-10's special feature?

It had the ability to perform simple diagnoses and precision diagnoses of vibrations.

In simple diagnosis mode, its memory was capable of storing a table of inspection itinerary consisting of up to 500 points and measurement items. The data collector function allowed users to efficiently collect and store vibration data during the course of a routine plant inspection. The measurement function was programmed to switch automatically as the user moves from point to point, based on the itinerary.

In precision diagnosis mode, the vibration meter was equipped with an FFT function. Considering the volume of information to be displayed on the screen and used for analysis, we decided to limit the number of data to 256 and the number of lines to 100. But we did incorporate a 4:1 zoom function to enable diagnosis using 400 lines.

——What were some other notable features?

I can think of three others. The first is the envelope processing spectrum, a function required for anti-friction bearing diagnosis. At the time, the VA-10 was the only product equipped with this function. I still remember how proud one of our sales representatives looked when he was demonstrating the envelope spectrum function to our customers (Fig.1). The second is the probability density function* for anomaly diagnosis. It's an indicator used in the automated diagnosis of defects in anti-friction bearings. The third is the comparator function. We incorporated this function so the instrument could be used for purposes other than maintenance—quality control, for example. The function can detect product defects by checking whether the specified spectral level falls within a certain range—in which case the product is non-defective—or falls outside that range—in which case the product is defective (Fig.2).

* Probability Density Function (PDF): the probability distribution at each vibration amplitude when the sum of probabilities is normalized to 1. Since this gives the probability of an event, it can be used for diagnosis.

——How did users respond?

Before product marketing, experts told us maintenance people didn't want to use such a complicated instrument. That really shocked me, since I was responsible for development. But when the instrument was exhibited as our main product at the Plant Maintenance Show held by the Japan Institute of Plant Maintenance in November 1987, RION's booth attracted people in droves. It was obvious people were excited and had high expectations for the product. One young engineer dropped by to see the VA-10 every day for all three days of the show.

——So it was accepted by the people on-site.

Yes. Before June 1998, when we marketed the next model, we sold nearly 3,000 units. When sales hit 1,300 units, we submitted an application for the awards held by the Japan Institute of Plant Maintenance. We ended up winning the outstanding product award for 1989. Our concept of offering a compact, lightweight, handheld vibration meter capable of performing satisfactory vibration frequency analysis had been validated.

——Did you learn some lessons in developing this instrument?

Well, how to operate an instrument! Although the VA-10 was a compact device, it had more than 30 buttons. I think this might have been a bit intimidating to some customers who'd never used it before. We learned from this and equipped our next model VA-11 with a pull-down menu and dramatically reduced the number of buttons. But for users familiar with the instruments, operations using the pull-down menu proved to be cumbersome. So for the model after that, the VA-12, we assigned frequently-used functions to buttons and others to the pull-down menu. That turned out to be a user-friendly design solution that suited most users.

——In closing, do you have a message for other developers and designers?

I'd like to ask them to actually try out the devices they've designed on site and not to finish the design process sitting at their desks. To check the functions you provide and offer a truly refined instrument to your customers, you have to take the time to use your instrument on site, making actual measurements and analyzing and processing the data before production. That's especially true in the case of real-time processing instruments.

Interviewer : Norihito Sekijima

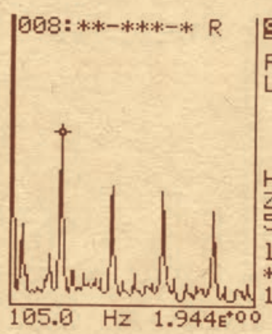


Fig.1.
Envelope spectrum of vibration acceleration created by anti-friction bearing with a defect in the outer ring

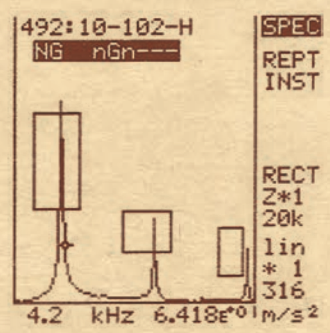


Fig.2.
Example of a comparator

Hello From the Office

An elite unit for measurement instrument sales

Kyushu Rion Co., Ltd.

The Measurement Instrument Branch of Kyushu Rion Co., Ltd., a RION group company, was launched staffed with just three sales representatives in 1980, when the Kyushu Local Office of RION was transferred to our company. In March of last year, the entire length of the Higashi-Kyushu Expressway that runs through Oita and Miyazaki prefectures was completed. All of Kyushu is now connected to a highway system, significantly reducing travel times. Currently, the number of personnel at Kyushu Rion Co., Ltd. has grown to ten, stationed at three offices : in Fukuoka, Kitakyushu, and Kagoshima. The expressway will help us respond to our customers faster, and we're committed to improving customer satisfaction still further.The greatest trait of our company is that every sales representative is knowledgeable about all the products manufactured by RION's Environmental Instrument Division, from sound and vibration measuring instruments to particle counters. That makes them capable of selling all the products on their own. In Kyushu, dubbed the "silicon island of Japan" some years ago, the automobile industry is now the major industry. Despite these dramatic changes in Kyushu's industrial environment, our sales representatives are members of an elite team of measurement instrument sales and will no doubt be fully capable of keeping up with these changes.

Hisami Ohata, Kyushu Rion Co., Ltd.

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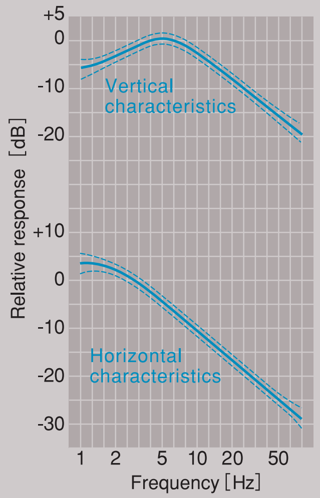
5-18 reisenmachi Fukuoka Hakata-ku,Fukuoka 812-0039,Japan
TEL:+81-92-281-5361 http://www.krion.co.jp/

Tell Me Dr.Sojun

Q.What does the 'vibration level' of Japan mean?

Vibration levels are mapped on a Japanese designed index for regulating vibration pollution, which has the goal of approximating human response.* We can use values like displacement, velocity, and acceleration to represent the magnitude of vibrations. Human response to vibration is associated with acceleration. Perceived vibration, like auditory sensations, is logarithmically proportional to the magnitude of the external stimulus (something known as the Weber–Fechner law). That means it can be expressed as the logarithm of vibration acceleration. Furthermore, since perceived vibration depends on the direction and the frequency of the vibrations, it has to be weighted by vertical and horizontal characteristics. This compensated vibration acceleration level is the vibration level used to assess environmental vibrations. It's worth noting that vibration level in the Vibration Regulation Act is assessed using vertical characteristics.The vibration level meter measures vibration levels as mentioned above, which correspond to human sensitivity. On the other hand, the "vibration meter" takes measurements of physical values like the displacement, velocity, and acceleration of the vibration.

* In JIS C 1510 "Vibration level meters," vibration levels are defined as 20 times the common logarithm of the effective value of vibration acceleration weighted by the vertical and horizontal characteristics divided by the reference vibration acceleration (10^{-5}m/s²)."



Frequency response of vibration sensitivity

Dr. Sojun Sato, Senior Advisor, former Head of Acoustics and Vibration Metrology Division, NMIJ, National Institute of Advanced Industrial Science and Technology

SCIENCE COLUMN

" Wind bends sound !? "

From ancient times, Japanese people have enjoyed the sounds made by insects, as depicted in the classic "Makura no Soshi (The Pillow Book)." I'm no exception. I love to listen to the sound of insects on a fine, windless, and quiet night while sipping a glass of cooled ginjo-grade sake and grilling mushrooms on a small hibachi (charcoal heater) out in my yard. Sometimes, on nights like this, you can hear the sound of an ambulance or a train passing in the distance. That's due to the refraction of sound waves. When the layer of air heated during the daytime remains above the layer of air near the ground, sound waves will travel faster there than near the ground. That causes the sound waves to be bent (refracted) downwards and literally makes them skip over the roofs of houses to reach distant areas (Fig.1). Under certain conditions, you can hear the sound of loudspeaker from train stations located 1 km away. Thinking about the refracted path of sound makes a glass of sake even more enjoyable for me. During the daytime, the air near the ground is heated, so sound waves travel faster near the ground. This causes sound waves to refract upwards and keeps them from reaching distant areas. Temperature gradients aren't the only factor that affects the propagation of sound waves. Wind is another. Imagine sound waves traveling in the same direction in which the wind is blowing. Near the ground, the effect of friction will lower the wind speed with respect to layers further above the ground. This bends sound waves downwards in a tailwind, but upwards in a headwind (Fig.2). When this occurs, it creates a shadow zone, where no sound waves arrive. If a person is standing in the zone, a train only 200 meters away will appear to speed by without a sound. It's a mysterious experience, but one rarely noticed in daily life.

Oops, my sake is getting warm.

Toshiya Oshima, Development Section

Fig.1. Refraction of sound waves by temperature gradients

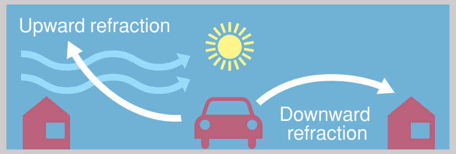
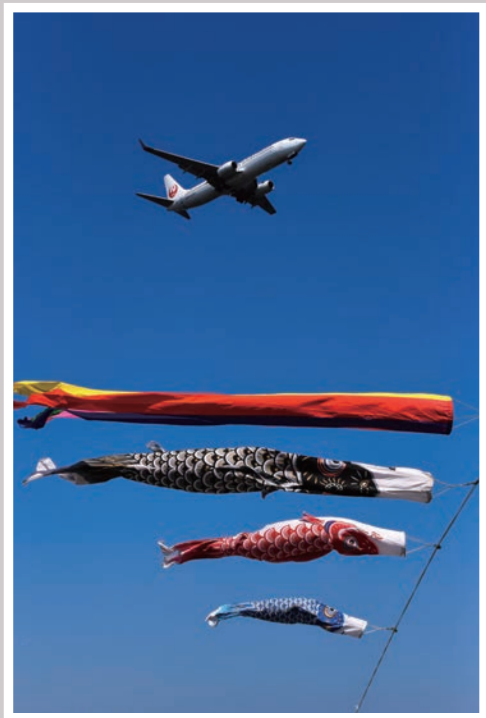


Fig.2. Refraction of sound waves by wind

Japanese scenery



On Tango no Sekku (Children's Day) celebrated on May 5, koi-nobori, carp-shaped streamers, are hurled into the air to further the healthy growth of boys. There's also the Hinamatsuri celebrated on March 3 for girls, so please don't jump any conclusions about gender discrimination. These are days of important traditional events in Japan.In the photo, from bottom to top, a kogoi (child carp), higoi (red carp), magoi (black carp), fukinagashi (banderol) and a Boeing 737-800.

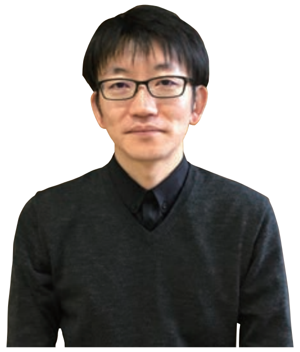
Photographer : Masahiro Oe
Hearing Aid Manufacturing Engineering Section

ShineView!

Introducing one of Rion's shine workers, someone who shines, on and off duty.

Tsutomu Hosokawa Particle Counter Manufacturing Engineering Section

Shogi ～a game of learning from your mistakes



What is shogi ?

Shogi (Japanese chess) is a game played on a 9×9 board between two players, each starting with 20 game pieces. The player who takes the opponent' s king piece first is the winner. The rule for mochigoma, which allows a player to use a piece captured from the opponent, complicates the game.

——When did you start playing shogi?

I don't remember (laugh). I've always played, as far back as I can remember. The earliest memory I have of playing shogi is when I was 5 years old and bitterly crying because I'd lost to a friend of my older brother.

——What appeals to you most about shogi?

I love many aspects of the game. Last year, I had the opportunity to play against a player in a wheelchair in a team competition. He could see the board, but since he couldn't move the pieces himself, he gave directions to an assistant using slight movements of his head and a quiet voice. I knew shogi can be played by anyone—young, old, men, women. But it was through my experience of playing a match against this man that I gained a renewed appreciation of how shogi could make anyone an equal to anyone else.

——I heard you were a participant in a study on shogi.

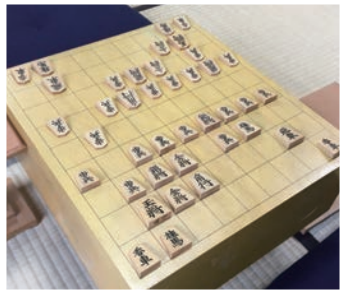
While in college, I was the captain of the shogi team. A researcher on the faculty was investigating how professional and amateur players differed in their ways of thinking and making judgments. I volunteered to participate as an amateur player. The participants wore headbands equipped with an optical line-of-sight sensor that recorded where on the board the player's eyes were focused. At the time, I had no true grasp of the purpose of this experiment, and I only noted that my eyes shifted quite a lot over the board based on the tracks of my eye motion. Later, I saw on television that while amateurs move their sight all over the board, a professional glances over the entire board just once and makes a mental note, and from that point keeps his eyes trained on a very limited area. I've seen a photo of Yoshiharu Habu wearing a similar headband. He's among the shogi players I most respect.

——The original form of shogi came from India, didn't it?

Yes. In that guise, the game appears to have had more types and numbers of pieces. But over time, the game gradually evolved into what we know today. I do believe the rule for toryo (resignation), where you admit defeat, is unique to shogi and rarely heard of in other games. This and the stress placed on etiquette and manners reflect the character of the Japanese people.

——The world of shogi appears to harbor surprising depths.

Yes, indeed. There's also a session held after the game called the kanso-sen (review of the game), in which both players explain their moves during the game to each other and look back on the game. In shogi, there's much to learn from your mistakes.



From the interviewer :
While in high school, Mr. Hosokawa was a skilled player and advanced to the national stage as one of the players representing his prefecture. He says his preferred strategy is the naka-bisha (Central Rook).
(M.Okazaki)

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TOPICS Research presentations, articles, etc.

【Related to sound and vibration measuring instruments】

◎Acoustical Society of Japan 2017 Spring Meeting
(15-17 March Meiji University)

- Development of a multipoint synchronous networked measurement system and its application to measurements of road traffic noise / R.Kazama, T.Yokota*[1], T.Matsumoto*[1] and K.Anai*[2] (in Japanese)
- Multipoint synchronous measurement of road traffic noise behind detached houses and prediction by the simplified formula F2012* based on a point sound source model / K.Anai*[2], S.Takayama*[2], T.Yokota*[1], T.Matsumoto*[1] and R.Kazama (in Japanese)
- Automatic sound source recognition using synchronized multi-point measurements by machine learning for visualization of each environmental sound / T.Naito, N.Sunago, Y.Nakajima, T.Ohshima and N,Ono*[3] (in Japanese)
- Introduction of a long-term measurement for road traffic vibration and evaluation of measurement results based on vibration measurement manual for buildings / H.Umayahara, K.Yamashita and T.Hasumi (in Japanese)

【Related to particle counters】

◎Interphex Osaka (15-17 February Intex Osaka)

- Evaluation of RO water using Viable particle counter / T.Minakami (in Japanese)

◎Earozoru Kenkyu Vol.32 No.1 (2017)

- Evaluation of counting efficiencies for optical particle counters by using inkjet aerosol generator / T.Minakami, T.Hosokawa, K.Kondo, K.Iida*[4], K.Ehara*[4] and H.Sakurai*[4] (in Japanese)

◎Clean Technology 2017 Vol.27 No.4

- Viable particle counter / T.Minakami (in Japanese)

*1 Kobayasi Institute of Physical Research *2 Kyutech *3 NII *4 AIST

Exhibitions

S Related to sound and vibration measuring instruments
P Related to particle counters

- S Manufacturing World (April 12-14 Nagoya)
- S Automotive Engineering Exposition (May 24-26 Yokohama)
- S The INSTITUTE OF NOIDE CONTROL ENGINEERING OF JAPAN 2017 Spring Meeting (April 21 Chiba Institute of Technology)
- S NOISE-CON 2017 (June12-14 Michigan, U.S.A)
- S Automotive Engineering Exposition (June 28-30 Nagoya)
- S ICSV 24 (July 23-27 London, UK)
- S Inter Noise 2017 (August 27-30 Hong Kong, China)
- P The 27th Congress of Japan Association for Clinical Engineers (May20-21 Aomori)
- P INTER PHEX JAPAN 2017 (June 28-30 Tokyo)
- P SEMICON West 2017 (July 12-14 San Francisco, U.S.A)
- P SEMICON Taiwan 2017 (September 7-9 Taipei, Taiwan)

Seminars

We conduct seminars on sound and vibration across the country. Please visit the web site (http://rion-sv.com/event/all) for dates, venues, programs and other details.

Editorial Postscript

We decided the theme for this special issue featuring the Kamiokande should be "Capture." The theme chosen is based on the content of the feature article in each issue. Previous themes included "Measure" for the first issue, "Fly" for the second, and "Resound" for the third. We hope the content we publish will continue to hold your interest. (Okamoto)

About the Front Cover

The urge to prove something that remains uncertain was the driving force that brought together the advanced technologies required to obtain solid proof for the existence of neutrinos. The clear lens in our head called curiosity will undoubtedly continue to provide us with new information and images of the universe. (Oana)

This magazine can be downloaded from the *Shake Hands* website, where you also can take part in a reader survey: http://rion-sv.com/shakehands/

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