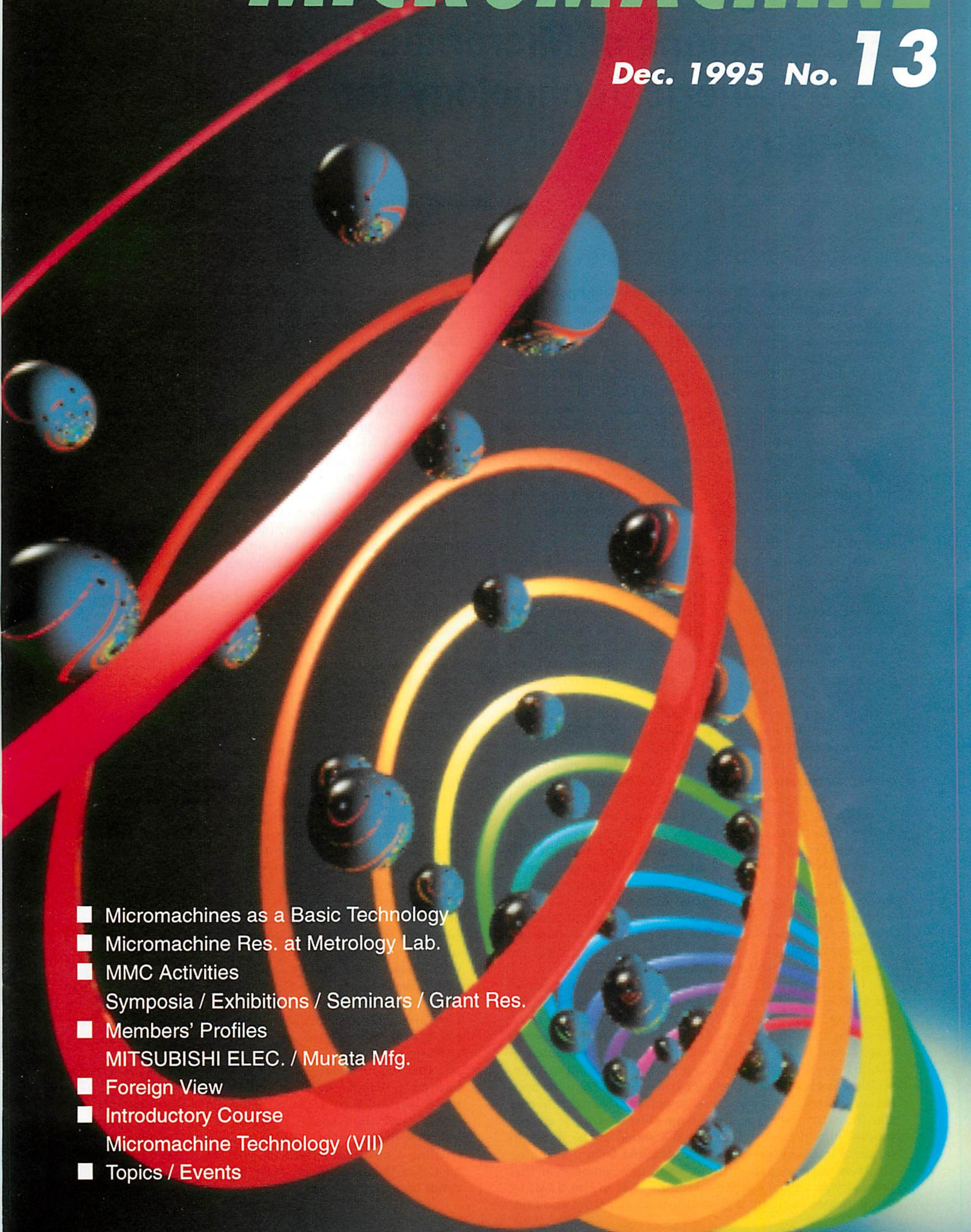
MMC MICROMACHINE

Dec. 1995 No. 13



Micromachine Center

Expectations of Micromachines as a Generic Technology for Industry

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Faculty of Science and Engineering, Chuo University

As a researcher interested in the relationship between the stiffness and accuracy of machine tools, my point of contact with micromachines was the variable of surface roughness. Whenever I have attended a conference on production engineering, the topics of discussion have been the determination of the stability limits of self-excited vibration accompanying cutting operations, and the identification of the characteristics of structural vibration. My own participation in the field of vibration and its control has been the identification of the dynamic characteristics of oscillating systems from the relationship between the input and output data of the systems. Taking all the relevant research into consideration, I realized that while there was a relationship between vibration and surface roughness, this relationship was not clear; consequently, I set out to research this matter.

In 1967, while I was at MIT, I attempted to measure the relationship between structural vibration and surface roughness in lathes. Unfortunately, my experiments showed no clear results. Oscillation is a high-speed phenomenon, whereas surface roughness has to be measured carefully by tracing the surface carefully at low speeds. It was clear that a method for measuring vibration and surface roughness simultaneously would have to be developed.

Professor K. Mitsui of Keio University as a graduate student in my laboratory at The University of Tokyo, solved the problem by developing a method by which surface roughness could be measured at high speeds. As a result, the effects of structural vibration on surface roughness, already understood in a common-sense fashion, were quantified, as were the relative displacement of the tool and object being worked on and the transfer characteristics of surface roughness. Professor Mitsui's high-speed method involved the skillful use of a charge-coupled device (CCD) in the system of an optical microscope, but measurement and analysis were possible only down to the micrometer level. Consequently, evaluation of the surface profile of compact disks and ultraprecise cutting and processing methods for the mirror surface of magnetic disks emerged as the next areas of interest, which implied a need for studying such surfaces on the nanometer level.

G. Binnig and H. Rohrer made a stunning advance in the technology of visualization by developing a scanning tunneling microscope (STM), which enables things to be viewed at the atomic level. At about the same time, my colleagues and I were looking for a way to solve the problem of visualization of surfaces using the electron microscope, which was expected to have higher resolution than the optical microscope. We were able to obtain a visualization of the fine surface structure of an object using a simple process in which we integrated the signal of the image in terms of backscattered electron obtained from a scanning electron microscope. Although the development of this process was not so epoch-making as that of the STM, by using images to obtain a view of surface structure and finding a way to evaluate that structure at the 0.01μm–100μm level, we were able to show that the evaluation of the fine surface structure of "millimachines" had its own unique characteristics.

As all this was happening, the use of semiconductor fine processing was ushering in the possibility of operable micromachines. As was evident in the fact that static electricity, rather than electromagnetic force, played the primary role in providing operating power to micromachines, there was a whole new way of thinking about machines in terms of their structure and operating environment.

Although such advances as the STM and micromachines were amazing, most of the new concepts were unfortunately being developed in Europe and the United States. However, while the idea behind numerical-control machine tools was conceived in the United States, Japan took the lead in the effort toward making novel developments in the field.

The locus of Japan's industrial recovery and growth following World War II was in the mass production and supply of high-quality products at low prices. During this period, the Japanese added value to products, honed the nation's industrial technology, worked on refinement, and made various other novel developments. This was in part the result of the adoption of practices well known in advanced countries, including total quality control, just-in-time manufacturing, and concurrent engineering.

In the future we will need to combine our traditional advantages with effort great enough to result in the breakthroughs seen in the early days of micromachine development. We cannot stand around with our hands in our pockets, but must continue to come up with creative ideas that will result in the creation of new technologies and products.

Given this general tenor in the industrial world, I believe that this is the time for revolutionary thinking and original, diversified research and development in the field of micromachines in particular. We cannot rest on the laurels born from semiconductor technology, but must look into, for example, making new developments based on watchmaking technology and ultraprecision machining, adding sensor technology to existing machinery, and developing applications for medical technology. Positive results have already emerged in some of these areas, and these are likely to form the basis as generic technology for future industry.

I myself have not yet worked with micromachines, but have only touched upon the micro world in terms of the technology involved in the profile evaluation. I am excited as we enter the coming transitional period in Japanese industry, during which time research and development for creating a new industrial base will be crucial. I sincerely hope that the great efforts of the Micromachine Center will result in great successes.

Research of Micromachine Technology in National Research Laboratory of Metrology, Agency of Industrial Science and Technology

Yoshihisa Tanimura
Akira Umeda
National Research Laboratory of Metrology

1. Introduction

The National Research Laboratory of Metrology is in charge of the theme of "micromachine elements" in the Industrial Science and Technology Frontier Program entitled "Development of advanced maintenance technology for power plants".

This laboratory initially became involved in the research of micromachine technology by proposing "maintenance of machines and plants without disassembly by inserting micromachines inside them" as an application of micromachine technology.

Since maintenance is based on measurement, such micromachines have to function as a kind of measuring machines. "Non-disassembly" as a technological word is an equivalent of "non-operation" or "non-dissection" in medical terminology. The requirement exists for measurement and evaluation technologies unlike the existing technologies in order to develop technologies capable of processing and assembling small items ranging from several millimeters to 1 μm. This is basically the understanding of this laboratory, which uses the measurement and evaluation technologies and standard settings as the basis.

In the past, measurement and evaluation have been considered as important independent technologies in the machine technology system, as well as in engineering technology and control technology. We assume, however, that true progress in and development of micromachine technology will be achieved when measurement and evaluation are considered to be equally important as other technologies from the beginning and are tackled systematically. This differs from recognizing the technologies as postprocesses of robot technology based on the structure and control of motions and mechanisms, and of processing and assembly technologies that are based on robot technology. That is, systematic technology can be achieved only by considering measurement, evaluation and other technologies all as wheels of the same vehicle.

Therefore, in the area of micromachines, technology development must be carried out by intentionally and closely correlating process, assembly, and control technologies with measurement and evaluation technologies in the same ratio, even if new measurement technology and evaluation technology that were not available in the past are required.

Based on the concept described above, this laboratory is undertaking the following objectives under the theme of "evaluation of micromachine elements" with the approach of building up from the foundation over a wide range:

(1) Measurement technology for the characteristics of various types of micro sensors
(2) Development of vibration usage sensors and functional thin-film application actuator, and the requisite measurement and evaluation technologies.

2. Measurement and Evaluation Technologies for Sensors and Micro Structures

This paragraph introduces the motion generation technology for micro structures that use shock and the results of its application to measurement and evaluation technologies.

In machine dynamic measurement, generation of motion is the basis for many structures. For instance, the checking of responses to earthquakes by installing machine elements on a vibration stand or setting an earthquake resistance structure on a large vibration stand is applicable.

For various micro sensors that can be considered micromachine elements, first of all, generation of the following motions are required; (1) shaking over a wide frequency band, (2) shaking with high acceleration with quantization. The use of shock is considered the optimum method for this purpose.

Research is carried out using the shock generation method based on the principle shown in Figure 1. In Figure 1, if an airframe that was accelerated by compressed air is caused to collide with the edge of the bar, a pulse of compressed elastic wave is generated, is propagated along the axis of the bar to the other end, and reflects. In this case, micro displacement movements of high speed occur dynamically. This bar is called a "Davies' Bar", after the researcher who measured the dynamic displacement of the bar edge with an electrode plate to verify logical analysis of elastic propagation.

In this laboratory, a sensor was developed that uses reflection at the bar edge of an elastic wave pulse generated inside the Davies' bar by collision of an airframe and a characteristic evaluation technique of a measurement device.

[Application to Evaluation of Characteristics of Acceleration Sensors]

Acceleration sensor characteristic evaluation is

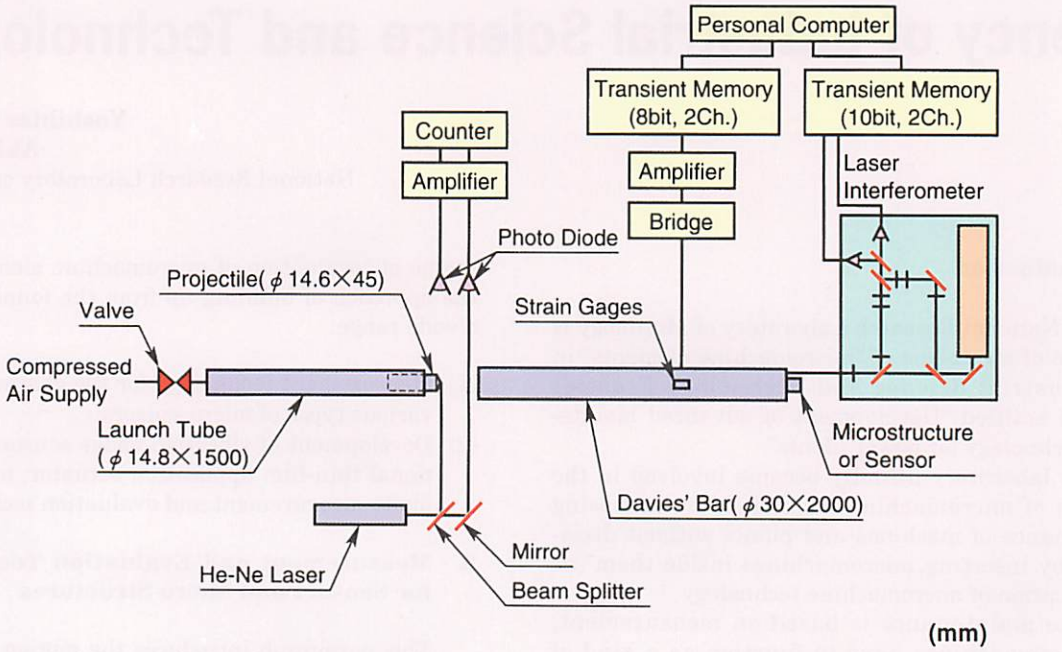


Figure 1 Dynamic response evaluation device of sensors and micro structures by shock

one of the applications available. Under the present situation, when a commercially available acceleration sensor is purchased, no clear data for frequency characteristics is included, for the following reasons:

(1) The acceleration standard that is currently approved internationally relates to vibration acceleration up to several tens of Gs; no shock acceleration standards are available.
(2) Despite the fact described above, high acceleration speeds can be measured.

With the technique that we developed, micro movements of the bar edge can be measured at high speed and precisely using a laser interferometer by setting the acceleration sensor to be evaluated firmly at the edge of the Davies' bar. The peak response of the sensor is determined by comparing the output of the acceleration sensor to the edge motion acceleration read on the interferometer, as a function of time. Frequency characteristics including phase characteristic of the sensor is determined by comparing the sensor output to interferometer readings, as a function of frequency.

The basis of the laser interferometer that is used as the basis of movement measurement is the Michelson interferometer, which detects Doppler shift. The interferometer processes all the laser interference signals of high speed microdisplacement through high speed sampling, stores them in a storage unit, and evaluates the characteristics by performing analysis after termination of the test.

The maximum value for acceleration that can be generated by this technique is 10^6 m/s^2 and the minimum value is 200 m/s^2. Figure 2 shows an example: the peak acceleration value that was given is on the order of 10^4 m/s^2. In addition, investigations of the frequency band area of commercially available reference acceleration sensors indicate that the frequency band zone area is only 5 kHz, while it was set to be 20 kHz. This measurement and evaluation technique was proposed to ISO/TC108/SC3 (Calibration methods for vibration and shock measuring pickups) and consequently, examination on standardization was begun.

[Application to Evaluation of Frequency Characteristics of Laser Vibrometers and Displacement Devices]

A second application to frequency characteristic evaluation of a laser vibrometer and a laser displacement devices can be considered.

Microstructures are often handled in micromachine technology, and as a result, the frequency generally tends to be higher than that of ordinary machines when the microstructures cause movements. Therefore, to measure movements, a laser vibrometer or a displacement devices is often used. Actually, a laser vibrometer with band width of 1.5 MHz is available on the market and is used in many

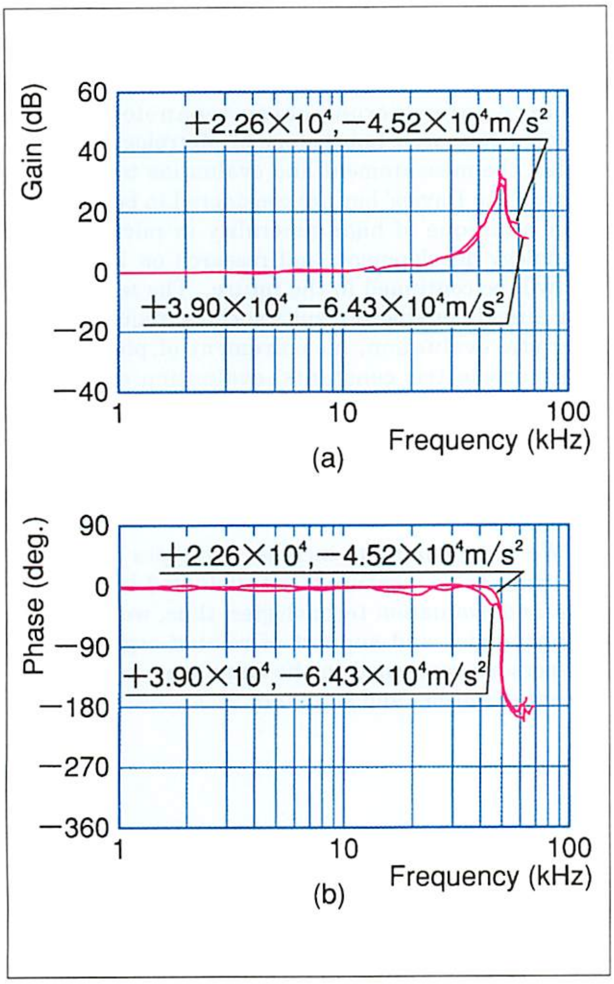


Figure 2 Typical evaluation of frequency characteristics of acceleration sensors

fields such as probe type microscopes, piezoelectric materials, and process related vibration monitoring. However, under actual use conditions, no technology is available to check and evaluate the frequency zone area characteristics of these measurement devices.

The interference fringe counting displacement devices that are commercially available were examined regarding the high speed microdisplacement of the Davies' bar edge using the laser interferometer which we developed. The result shows that the frequency band width which was supposed to be up to 100 kHz is actually only up to 20 kHz.

[Application to Evaluation of Frequency Response Characteristics of Strain Gauge]

As the third application, evaluation of frequency response characteristics of strain gauge can be considered.

As shown in Figure 1, a strain gauge to be evaluated is attached on the side of the bar. By measuring the high speed microdisplacement by reflection of the elastic pulse, the strain of the incoming elastic wave pulse to the edge is detected. The strain of the elastic wave pulse that passes the gauge can be determined by reverse calculation of the wave transmission. That is, since output can be detected for the input to the gauge, the frequency response of the strain gauge can be obtained. Figure 3 shows an example of measurement records. These data are the world's first example of actually obtained frequency response characteristics of a strain gauge. Strain gauges are frequently used in strain measurement over a long period of time. This is a good example of a classic problem (measurement of frequency characteristics) solved in the new frame of micromachine technology.

Taking a different view, the Davies' bar with strain gauge that was calibrated by a laser interferometer is a general movement generator for microstructures and can also be used as a secondary measurement standard device for various sensors related to displacement such as sensors for micro acceleration and ultra-sound.

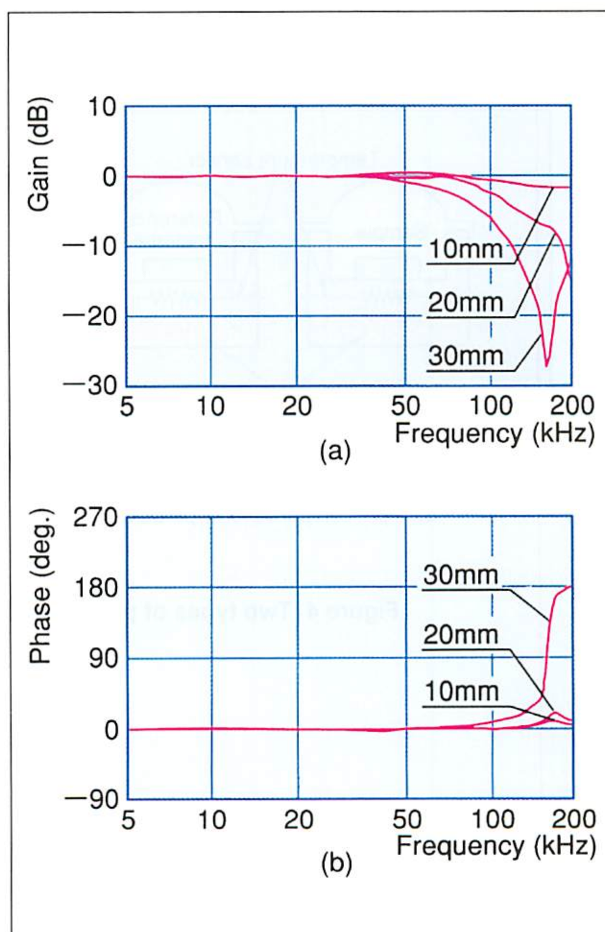


Figure 3 Frequency response of strain gauge using gauge length as the parameter

3. Development of Sensors and Actuators

In sensor development, a torsional resonator with two degrees of freedom is being developed. By applying two degrees of freedom, the distance between electrodes is reduced and, at the same time, large amplitudes can be achieved.

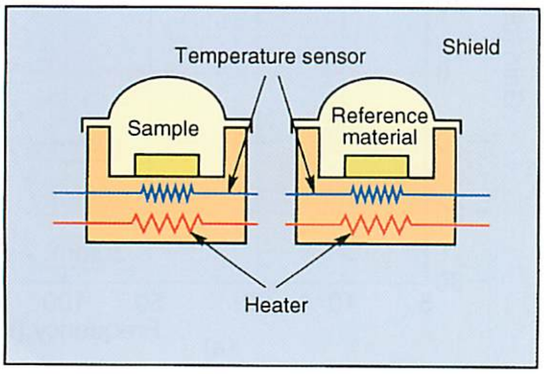
In the development of an actuator, research is being carried out starting from production of shape memory alloy thin films. Currently, the optimum production condition is retrieved within the possible range, and the parameter setting range is being selected.

As shown in (a) and (b) in Figure 4, two types of measurement principles are available for differential scanning calorimeter (DSC) used to measure phase transformation temperatures. It is becoming clear that the mass of the sample has significant influence and the measurement results are uneven if the sample is very small.

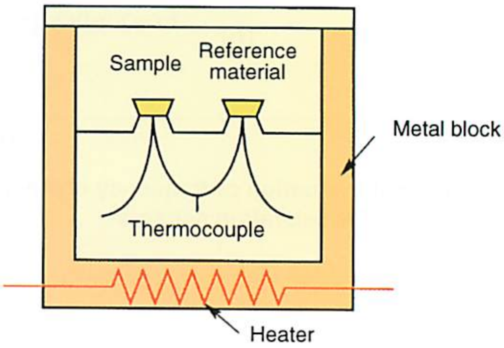
4. Conclusion

This article describes the results achieved by the research into micromachine technology in the National Research Laboratory of Metrology. In particular, the measurement and evaluation technologies that use the Davies' bar are considered to be an evaluation technique of high generality in micromachine technology development, and research on its application will be continued in the future. The technologies have already produced results such as frequency characteristic evaluation, measurement of piezoelectric film piezoelectric constants, evaluation of residual stress, and measurement of characteristic frequencies of microstructures of ultra-sound sensors, piezoelectric force sensors, and impact hammers. However, descriptions of those matters are omitted from this article.

We are planning to increase the types of physical quantities to be measured and evaluated in measurement and evaluation technologies; thus, we invite the further advice and support of related organizations and persons concerned in the same way as for development of sensors and actuators.

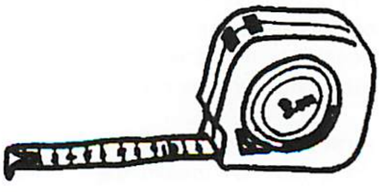


(a) Input compensation type DSC



(b) Heat flux type DSC

Figure 4 Two types of principles of differential scanning calorimeter (DSC)



Course of the Micromachine Symposia

The First International Micromachine Symposium combines the Micromachine Symposium with R&D Presentation on Micromachine Technology formerly held independently each other and aims the promotion and dissemination of micromachine technology under the theme "Foundation of Industrial Technology in the 21st Century" by asking, from the international view point, the participation to the people at home and abroad who are interested in R&D for micromachine technology.

The keynote lecture on the first day is being given by Dr. Keiko Nakamura of the Biohistory Research Hall. Ten invited lectures will follow on the subjects: "The Path to New Industries in the 21st Century," "Activities in U.S.A. and Europe" and "Presentation on Innovative R&D." Twenty-one papers are to be presented on the second day, including the 1st phase results of the ISTF Program "Micromachine Technology," a ten-year project started in 1991. The content of the symposium is expected to be substantial and informative.

In a retrospective of data given in previous symposia, the 1st MEMS workshop, "Small Machines, Large Opportunities," drew attention to small actuators being developed in Japan, principally by the silicon process, and raised tantalizing prospects for their potential roles in new mechanical systems in the future. It was against this backdrop that the Micromachine Society was established in 1988 by a group of researchers from interdisciplinary areas seeking new applications of micromachines.

The First Micromachine Symposium, sponsored by the Micromachine Society, was held on December 17, 1988 at the JA Hall of Otemachi, Tokyo, with the following lectures and subsequent panel discussions:

- "What Changes can be Brought by Micromachines to Medical Science?," by Iwao Fujimasa, Research Center for Advanced Science and Technology, The University of Tokyo
- "The Current Status of Research of Micro Electronics," by Hiroyuki Fujita, Institute of Industrial Science, The University of Tokyo
- "Micro Sensors and Micro Actuators," by Yukuo Karube, Research Center for Advanced Science and Technology, The University of Tokyo
- "Micro Engines and their Surroundings," by Naomasa Nakajima, Faculty of Engineering, The University of Tokyo

The 2nd Micromachine Symposium, also sponsored by the Micromachine Society, was held on March 14, 1990 at the Kikai-Shinko Building in conjunction with the 1st Micro System Technologies Japan.

The 3rd Symposium was held on March 20, 1991 at the Kikai-Shinko Building. Since the 2nd Micro System Technologies Japan had been held in January in Nara together with the MEMS '91, this year's symposium was held independently. This was the first time that applications for paper presentations were invited from the public.

The 4th Symposium was held for the two days of March 11 and 12, 1992 at the TEPIA Hall in Kita Aoyama, Tokyo, together with the Micromachine Exhibition. This was the first symposium held after the ISTF Program "Micromachine Technology" began in 1991, and marked the first time the Micromachine Center had been one of the sponsors.

The 5th Symposium was held for the two days of April 20 and 21, 1993 at the Science Museum in Kitanomaru Park, Tokyo. Twenty papers were presented on the latest research at home and abroad on micro technology in medical treatment, photoforming process, and micro parts and actuators; three invited lectures and two reports on international conferences rounded out the program. MITI began its support at this time as did many academic societies and other organizations including the Japan Society of Mechanical Engineers.

The 6th Symposium was held for the two days of May 11 and 12, 1994 in the same location in Kitanomaru Park, Tokyo, with four special and invited lectures and 19 research reports given on manipulation, cell machines and micromachines, medical treatment applications, new actuators and information communication.

Micromachine Exhibitions

Micromachine exhibitions have always been planned to advance micromachines as a leading-edge technology and to disseminate them in a broad range of economically-oriented fields. This year's exhibition will be the 6th.

The first was held in 1990 when this Center had not yet been established, and was under the sponsorship of the Micro-robot Development and Investigation Sub-committee of the Japan Industrial Robot Association and the Micromachine Society. It was held for only one day.

The second one was jointly sponsored by the Japan Industrial Robot Association and other organizations and held along with the Workshop on Micro Electro Mechanical Systems, MEMS '91.

It was the third exhibition in 1992 that Micromachine Center became one of the sponsors. At this exhibition the direction of R&D and research results of the first year of the National Project "Micromachine Technology" was released. Because in 1991 Agency of Industrial Science and Technology (AIST), MITI started the National Project "Micromachine Technology" in order to establish the basic technology for micromachines under the Industrial Science and Technology Frontier (ISTF) Program that one of the purpose is to support fundamental and creative R&D contributing to economic and social development through new technological systems or breakthroughs. Thirty-one exhibitors participated in this exhibition and about 1700 people visited.

MITI has always been a supporter since the fourth exhibition, when 63 exhibitors participated and there were about 3,500 visitors.

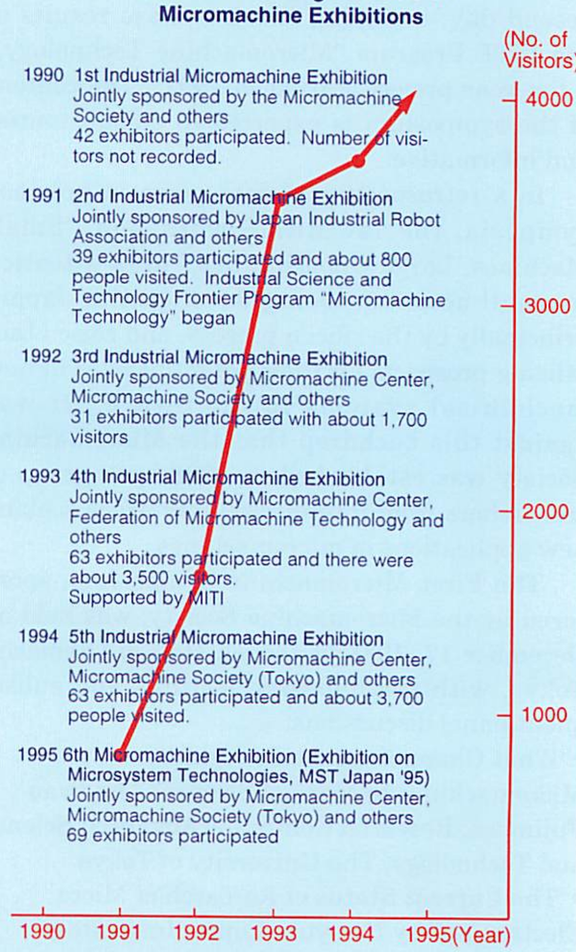
The fifth exhibition saw 63 exhibitors participating and about 3,700 people attended.

The sixth exhibition was sponsored jointly by the Micromachine Society (Tokyo) and our Center, with "Micromachine, a Dream Fostering Technology" as its theme. This is the final year of the first phase of the "Micromachine Technology" project and the research results for the past five years were reviewed; further advancements are planned. Promotion of a better understanding of the current status of R&D and the future potential of micromachine technology is also planned; there are great expectations for industrial and medical applications. This exhibition will be the largest to date, with even the area of the site about fifty percent larger than last year's. Sixty-nine organizations both domestic and foreign participated, not all of them from micromachine-related businesses; they were principally supporting members of the Center and some national laboratories and universities.

The name of the five earlier exhibitions included the word "Industrial," but this time, aiming at broader application, "Exhibition on Microsystem Technologies" was used.

Date: Oct. 31 (Tue.) through Nov. 2 (Thu.), 1995
Venue: Science Museum, Tokyo
Tel.: 03-3212-8485

A Brief Chronological Table of Micromachine Exhibitions



Progress of the Visitors

Evening Seminars in Fiscal 1995

Evening seminars have been held regularly every third Wednesday of every month, and the one held in September was the 20th in the series. They are held to promote mutual understanding of micromachine technology and friendship among individuals in government, industry and universities. Lectures are given principally by the heads of sub-committees responsible for "basic research on micromachine technology" which is conducted by the Center. Since the first seminar in September of 1993 topics have covered a broad range of subjects: micro science and engineering, medical applications, design methods, control methods, small functional element technology, and instrumentation evaluation technology. There is active exchange of firsthand information on micromachines among participants and lecturers at these sessions and the following social gatherings.

An outline of the evening seminars held this fiscal year is as follows:

April (16th)

Lecturer: Nobuyuki Moronuki, Associate Professor, Faculty of Engineering, Tokyo Metropolitan University

Subject: Dynamic instrumentation methods of micro mechanisms

Outline: To measure the force acting on an object of instrumentation, a force-measuring instrument must be inserted into the dynamic chain of the object. Care should be taken in the insertion to minimize impact on the object. Further, for dynamic instrumentation, increase in characteristic frequency is demanded and the requirements for the instrument are quite severe. The instruments meeting these requirements are very few.

May (17th)

Lecturer: Masayoshi Esashi, Professor, Faculty of Engineering, Tohoku University

Subject: Construction methods of integrated function devices

Outline: A micro system in which the dissimilar elements such as sensors, circuits and actuators are integrated can be realized by combining the micro-processing technology of integrated circuits and laser-applied three-dimensional micro-processing technology. This makes it possible to produce a "machine which runs flexibly and gently," for example, something rarely possible with existing technologies. High expectations are held for these devices as tools for use in narrow spaces, which will be essential for the maintenance of increasingly complicated and advanced systems in the future. Research in this area demands ingenuity in that it requires access to a broad range of knowledge, the development of equipment allowing greater degrees of freedom, the smallest possible size product easily maintained, and the ability by the researcher to take risks.

June (18th)

Lecturer: Shigefumi Nishio, Professor, Institute of Industrial Science, The University of Tokyo

Subject: Micro heat transfer and flowing characteristics

Outline: Defining the heat flow field whose space scale is below the order of millimeters as is the micro scale field, rough analysis was made of the characteristics of the latter derived from information on an ordinary scale field by extrapolation, constraint by this field on the heat flow in the micro scale field, and micro heat equipment. Information on the micro heat transfer and flowing characteristics is expected to be effectively employed to advance micromachine technology.

July (19th)

Lecturer: Naoya Ikawa, Professor, Faculty of Engineering, Osaka University

Subject: Dimension instrumentation methods for micro parts

Outline: Geometric accuracy of parts is important in the functioning of a mechanical structure in which they are used. Examples are the roundness, straightness, tooth profile accuracy and thread profile accuracy of each part of a gear and threads, on which the transmission accuracy of movement depends. This is also true for micromachines. From the speaker's analysis of the requirements of dimensional and geometric instrumentations, he proposed the urgent development of a measuring instrument with a range from several millimeters to several micrometers and accuracy from one thousandth to one ten thousandth of the measured dimensions; the instrument should also be able to measure a three-dimensional form by a non-contact means. Using examples, he indicated the resolving power and application limits and offered problems characteristic of usual optical methods.

September (20th)

Lecturer: Tsuneo Chinzei, Research Associate in the Faculty of Medicine, The University of Tokyo

Subject: Micro instrumentation methods in medical treatment

Outline: The speaker proposed a theory which would enable lengthy microscopic observation of the circulation of the living body in an awakened condition. He has designed and manufactured a prototype probe and conducted a performance test which showed that the method operates just like the theory. Its merits are as follows:

1. The unit is very simple and can be made compact.
2. It can be implanted in the body by a low-invasive surgical operation.
3. Micro circulation can be continuously observed without restraining the activity of the patient.
4. Only a weak light source is necessary.
5. It can be used for large animals.

Yet unresolved problems are:

1. Electric insulation must be strengthened.
2. Further miniaturization is desirable.
3. Resolution should be improved.

Efforts are being made to resolve these problems.

October (21st)

Lecturer: Naoki Negishi, Associate Professor, Department of Plastic and Reconstructive Surgery, Tokyo Women's Medical College

Subject: Functional materials for medical-use micromachine

The following seminars are scheduled through December:

November (22nd)

Lecturer: Masanori Okuyama, Professor, Faculty of Engineering Science, Osaka University

Subject: Characteristics of sensor materials

December (23rd)

Lecturer: Makoto Kaneko, Professor, Faculty of Engineering, Hiroshima University

Subject: Control methods of micro movement mechanisms

First Research Grant Results Presented

The research grant system began in 1993 as an independent activity of the Micromachine Center to advance micromachine technology and promote intercourse between industrial and academic societies by supporting university scientists engaged in basic research related to micromachines.

Of those granted aid the first term (fiscal 1993), five research projects have been completed and reports on them prepared.

Presentation of R&D results supported by the first micromachine technology research grant took place on Friday, September 22 in the meeting room of the Center. After greetings by Takayuki Hirano, Executive Director of MMC, the results were presented using an OHP (overhead projector) and video. Video particularly helped to realistically reproduce the actual operation of micromachines in an easy-to-understand manner. The presentation covered a broad area which included geometrical measurement, materials for medical applications, handling and actuators and sensors and was followed by active discussion.

An outline of these five research projects was given in "MICROMACHINE No. 12" and further information is expected at the second meeting of next year.

Subject	Speaker	Position
A Study on Engineering Evaluation of Geometric Accuracy of Micro Parts	Kimiyuki Mitsui	Professor Faculty of Science and Technology, Keio University
Basic Studies on Blood Compatible and Biodegradable Polymers as Materials for Medical Micromachines	Nobuhiko Yui	Associate Professor School of Materials Science, Japan Advanced Institute of Science and Technology
Development of Ultra-Precision Handling Technique Using a Laser Manipulation Method	Hiroaki Misawa	Associate Professor Faculty of Engineering, The University of Tokushima
Development of Micro Control Valve Using Functional Fluid	Kazuhiro Yoshida	Research Associate Precision and Intelligence Laboratory, Tokyo Institute of
Development of a Dynamic Tactile Sensor with 3-Axis Force and Slip Vibration Sensing Functions Using PVDF Film	Yoji Yamada	Associate Professor Department of Control and Information Engineering, Toyota Technological Institute

MITSUBISHI ELECTRIC CORPORATION

Advanced Technology R & D Center

1. Introduction

We recently visited MITSUBISHI ELECTRIC CORPORATION, a large electric and electronics manufacturer, which since its establishment in 1921 has produced a broad range of products related to space, computers, communications, semiconductors, imaging, home electronics, energy, industrial applications, public works, buildings and traffic.

The company proposes "Socio-tech (Technology for Society)" to seek ideal relationships between society and humans and between humans and the globe in these various areas. This is technology and creativity to harmonize society as a whole and individual human life.

Mitsubishi Electric also announced its so-called "Vision 21" project as a scenario for changes for advancement and a challenge to change, and intends to become a "trans-national company" which conducts its business globally viewing the world as a single market.

2. Details of Technological Development

Corporate Research & Development, which is responsible for the development of new products and technologies, has four research laboratories in Japan: Advanced Technology R & D Center, Information Technology R & D Center, Industrial Design Center and Industrial Electronics & Systems Laboratory.

Advanced Technology R & D Center conducts R&D on basic technologies and unique researches to create new businesses, key technologies specifically applicable in the anticipated multimedia society; key technologies related to electromagnetism, machinery and insulation, advanced device technology from aerospace to image information; energy technology with emphasis on environmental problems; next generation TFT liquid crystal technology; neuro-technology and solar cell technology.

The Information Technology R & D Center focuses principally on information, communications and imaging technologies, specifically information processing which can be used in human life, communications technology for use in the age of high-speed, large-volume network and digital media, interface technology which further opens the relationship between humans and machines, advanced optical and radio wave technologies, cryptographic technology for use in constructing information security systems, and technologies to commercialize bilateral image and portable information systems.

Micromachine R&D is one of the basic research projects at Advanced Technology R & D Center.

3. Tackling Micromachine Technology

Thanks to recent advances in micro-processing know-how prompted by semiconductor manufacturing and molecule- and atom-handling technologies, micromachines are being constructed by mechanical engineering done on the order of micrometers. This innovative area of micromachine technology is being pursued by Mitsubishi Electric for use in the coming 21st century.

Commissioned by the Micromachine Center, the company is now undertaking R&D on a micro-generator. This machine is envisioned as being mounted on a micro capsule and able to detect cracks while traveling in the water stream inside a power station pipe, for example; it is intended to convert hydraulic and other environmental energy into electricity to provide a supply of self-sustaining electrical power necessary for the capsule.

When its dimensions are reduced, the output of the generator will decrease in proportion to the cubed value of the generator's size. To secure the power required for the capsule thus necessitates, that optimal generation be achieved from its small size; the technology applied is therefore critical. The company is involved in research and development for manufacturing a film of a thin but very strong and permanent magnet, producing a three-dimensional device containing densely and tightly winding copper wire in a very limited space, and suspending the shaft steadily which turns rapidly.

In addition to this micro-generator, the company is also conducting unique research on various micro sensors and devices, and is devoted to the advancement of micro science and engineering, new 3-D micro-processing technology and simultaneously in furthering systematization technology of assembling, communications and control.

Seeing the passion with which researchers "attack" their work both day and night, the writer felt that micromachines would surely be realized in the near future.

Murata Manufacturing Co., Ltd.

Yokohama R&D Center

1. Introduction

This time we visited the Yokohama R&D Center of Murata Manufacturing Co., Ltd. located in the Hakusan High-tech Park of Midori-ku, Yokohama. Hakusan High-tech Park was developed by the Yokohama Municipal Government and is composed of high-tech-oriented companies which the government invited to locate there. In 1988 this R&D Center was the first to accept the invitation and to enter the park.

With the Tsurumi river flowing close by, the Center stands in a quiet place surrounded by greenery.

Murata Mfg. is a comprehensive electronic components manufacturer making excellent capacitors, filters, sensors and functional modules, using ceramic electronic functional materials. Its R&D setup comprises a Head Office Development Group, Yasu Plant Development Group, Yokohama R&D Center and the R&D department of each division. While the Head Office Development Group conducts basic research on materials and electronic components, and the Yasu Plant Development Group serves as the production engineering center for company operations at home and abroad, the Yokohama R&D Center is in charge of the development of downstream type applications close to the product needs of customers. Here, communications and sensor modules are developed to cope with advanced information communications of the next generation, such as satellite broadcasting, HA (home automation), OA (office automation) and mobile communications.

2. Characteristics of R&D

Under the concept "New products come from new components, and new components come from new materials," the company is involved in all aspects of research from materials to the finished products, and has achieved notable results.

Its research is based on "vertical integration." Electronic equipment is increasingly advanced and has multiple functions; higher frequency, lower losses and downsizing are demanded for the electronic components used in them. To meet these requirements, the company is developing unique products using new concepts by evoking synergy through the integration of many existing element technologies depending on the development theme. Activities include the "Strategic Technology Program (STEP)," which crosses boundaries of organizations, and the "Strategic Management Phase Diagram (SMPD)," in which related departments offer input simultaneously and in parallel.

In responding to a customer's wishes for a certain product, Murata's sales and technical forces are involved from the inception stage, and propose the electronic components and modules necessary to achieve the desired end product. This is called ESI (early stage involvement), another special activity of the company.

3. Tackling Micromachines

Among the new products attracting recent attention is an oscillatory type gyroscope to which piezoelectric ceramic is applied. With the adoption of a characteristic triangular oscillator and a unique circuit, a compact and inexpensive gyroscope has been realized and is now in extensive use in car navigation systems, robots and video cameras. In the future, a gyroscope will have to be micronized for attitude control and for positioning of a micro robot, as well as for vibration detection in electronic equipment. In the Micromachine Technology project commissioned by NEDO, the company is tackling the development of a micro gyroscope to which Si micromachining would be applied. A prototype of the world's smallest micro gyroscope with oscillator dimensions of $0.4 \times 0.8 \times 0.005$ mm is currently being developed. Using micromachining and signal processing technologies, sensors are expected to be increasingly reduced in size, advanced in functions and made intelligent.

The company is a pioneer in the introduction of a discretionary labor system which produces an optimal environment for employees to fully display their capabilities. The writer was able to see part of this corporate culture in which creativity is so easily realized.

Transducers' (International Conference on Solid-State Sensors and Actuators)

Masayoshi Esashi
Faculty of Engineering, Tohoku University

The 8th International Conference on Solid-State Sensor and Actuator (Transducers '95) was held jointly with Eurosensors IX at Stockholm, Sweden, from June 25 to 29 in 1995. This conference, held every other year by turns in North America, Asia, and Europe, is the world's largest conference in the field of solid-state sensors and micromachining. The history and operation of the conference are explained below.

The 1st International Conference on Solid State Transducers was held in November 1981 in Boston, USA, as a symposium on solid state transducers in the yearly convention of the Materials Research Society. About 150 participants attended.

The 2nd International Conference on Solid-State Sensors and Actuators (Solid-State Transducers '83) was held from the end of May to early July in 1983 at Delft, the Netherlands. About 350 participants attended. Since then the meeting has been called by its present name. Until then, the word transducers usually meant input units. Professor S. Middelhoek, then an executive committee chairman, used the term transducer to denote both converters in the input unit (sensor) and the output unit (actuator) in his book "Silicon Sensors." Presented papers in the 8th conference were collected and printed into two volumes, one containing 1030 pages and the other 934 pages, in contrast with the abstract collection of the 2nd conference, which contained only 181 pages. Figure 1 shows the cover of that brochure. This diagram of definition of a sensor was made into the convention flag, and is displayed in the main hall during conference. After each conference, the flag was passed to the chairman of the next executive committee, in the same way the Olympic flag is handed on.

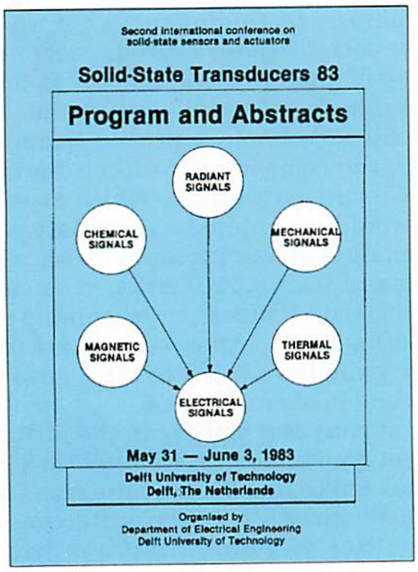


Fig. 1 Abstracts of the 2nd Conference

The 3rd International Conference on Solid-State Sensors and Actuators (Transducers '85) was held in Philadelphia, USA. "Transducers," the subtitle of the meeting, was first added at this time.

The fourth conference was held in Tokyo, Japan, the fifth in Montreux, Switzerland, the sixth in San Francisco, USA, and the seventh in Yokohama, Japan.

This eighth conference, the latest, was held under the organizing committee chaired by Professor I. Lundström of Linköping University, Sweden, and 555 presentations (comprising 19 presentations by invited speakers, 240 oral presentations, and 296 poster sessions including 40 late news) were made, and 1200 people attended from 46 countries. The number of papers submitted was 1251, significantly exceeding the 460 papers of the preceding conference, proving that the importance of sensors and actuators is well understood and that the field is rapidly growing. The impression was that papers from Europe and Korea increased, while the US researchers made reports on quality studies. On the evening of the 27th, a general session entitled "Industrialization of Sensors" was held, where five panelists (including Dr. I. Igarashi of Toyota Physical and Chemical Research Institute as the Asian representative) spoke on how to succeed in the sensor business, winning enthusiastic applause from the audience. There are enjoyable occasions for opinion exchanges such as banquet at the Bertha Museum and reception at the City Hall, the place where the Nobel Prize Awards Banquet is held.

The conference is steered by the international committee. Committee members from Japan are Professor K. Takahashi of the Nishi-Tokyo University, Professor A. Sasaki of Kyoto University, Mr. K. Nitta from Matsushita Electric Industrial Co., Ltd., Professor H. Fujita and Associate Professor S. Ando of The University of Tokyo, Professor M. Esashi of Tohoku University. Retiring from the committee after many years of devotion were Dr. I. Igarashi of Toyota Physical and Chemical Research Institute, Dr. S. Kataoka of Sharp Corporation, and Dr. H. Yamazaki of Yokokawa Research Institute Corporation.

The next (9th) conference will be held from June 16 to 19, 1997 in Chicago, USA, under the executive committee chaired by Professor K. D. Wise of the University of Michigan.

The next after that (10th conference) will be held from June 6 to 10, 1999 in Sendai, Japan, hosted by the Institute of Electrical Engineers of Japan. We will appreciate your cooperation.

Report from Australia

Photo 2 Executive Director T. Hirano making speech

As part of a survey of trends on micromachine technology, Executive Director Takayuki Hirano and Research Department Manager Munehisa Takeda from the Micromachine Center (MMC) and Manager Takeshi Yoshioka from Mitsubishi Heavy Industries, Ltd. attended MICRO '95, a microelectronics-related conference, in late July. The three also visited microelectronics research organizations such as University of South Australia, Adelaide University, Australian National University, Griffith University, Royal Melbourne Institute of Technology, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Monash University, and New South Wales University, to survey the current situation of micromachine-related studies in Australia. Some of the survey results are reported below.

1. MICRO '95 (Adelaide, July 17 to 19)

MICRO '95 is the thirteenth in a series of conferences on Australian microelectronics. There were 7 speeches by invited guests, 40 oral presentations, and 10 poster sessions. In technical lectures divided into two sessions on technology and architecture, reports centered mainly on process and structure of sensors and other microelectronics devices. A small exhibition by national and private Australian research organizations (10 in total) was also held (Photo 1). About 80 participants attended. Executive Director T. Hirano from MMC made the keynote speech, and explained the researches of micromachine project in the Industrial Science and Technology Frontier Program and other projects of MMC (Photo 2). The Advertiser, the local paper, carried the summary of this speech on July 19. Professor M.R. Haskard from University of South Australia proposed the development of a micro engineering (British and Australian term for micromachine technology) network in Australia. This proposal was fundamentally acknowledged. Australian micromachine studies are promising to accelerate.

Photo 1 CSIRO booth in exhibition

2. CSIRO (Melbourne)

Commonwealth Scientific and Industrial Research Organisation (CSIRO) is a national research organization founded in 1926. It holds over 7,000 staff including about 3,000 scientists. The organization has 32 divisions, offices and laboratories across Australia. The reporter team visited an electron beam lithography laboratory in the Division of Materials Science and Technology. The laboratory has developed a unique technology called EXELGRAM. With this technology, optically variable images like holograms are created by electron beam lithograph machines in a class 16 clean booth within a class 100 clean room where an auxiliary power supply is available to assure that operation will continue regardless of power failures. Such images can be transferred from a glass substrate to seals, and the people at the laboratory are trying to apply this technology to anti-counterfeiting of bank notes, cheques, and postage stamps. The cost is less than one cent per seal, they said.

3. University of South Australia (Adelaide)

University of South Australia founded its Microelectronics Centre two years ago. The center, directed by Professor M. R. Haskard, is engaged in basic researches on micro accelerometers, micro pumps with a silicon diaphragm, micro chips covered with metal for cold cathode, and so on. Construction of a new clean room had commenced on July 12.

Micromachine Technology (VII)

Micro Science and Engineering

1. What is Micro Science and Engineering?

As this series reading has explained, research and development of various technologies for processing and assembling micromachine parts and mechanisms has reached the stage of practical application. Using these processing and assembling technologies, however, if we were to fabricate a machine of familiar structure, but on a much smaller scale, we could hardly expect it to function normally. This is because the operating conditions and environment of a micromachine are nothing like those of a conventional scale machine. For example, volume forces such as gravity and inertia that work on a machine vary in direct proportion to the $(\text{Length})^3$, while surface forces such as viscous force and attraction force vary in direct proportion to the $(\text{Length})^2$. As a result, the effect of surface forces on a micromachine are relatively greater than the effect of volume forces. Therefore, the effect of surface forces that can be ignored with conventional size machines cannot be neglected with micromachines. This principle can be easily understood by imagining a wet paper scrap sticking to your finger or to tweezers; you must shake it hard to make it let go. Similar phenomena occur in the operating environment of micromachines. Micro science and engineering is the basic and theoretical study of such particular physical phenomena that are not significant on conventional scale mechanisms but are conspicuous in the microscopic world.

Micro science and engineering are not very familiar subjects yet. Still, they exhibit extreme importance in three reasons:

1) Because micromachines operate in special "micro" environments differing from conventional machine operating environments, it is essential to study the basics and theories of physical phenomena in these special environments and to develop various technologies to adapt implementations to the environments, in order to make micromachines that function reliably in the micro world. In other words, micro science and engineering present an academic foundation for optimum design and manufacturing of micromachines.

2) Another probability of micro science and engineering is to clarify and actively utilize particularities of the micro environment, the opposite standpoint from adaptation of mechanisms to the micro environment mentioned in 1), to develop new structures and mechanisms based on new principles. This means opening up a new horizon beyond conventional machine technology, which is very attractive to machine technology researchers.

3) Conventional mechanical engineering primarily deals with macro phenomena. Mechanical engineering will be more inclusive and precise as a system with rich content as the results of advances of micro science and engineering are added.

2. Contents of Micro Science and Engineering

Micro science and engineering deals with every physical phenomenon that appears prominent on a micro scale. Typical themes are listed below with their conventional science and engineering field.

1) Micro mechanical dynamics

Even a micromachine is placed under the control of the conventional Newtonian equation of motion as far as it operates on the earth. A remarkable difference from conventional size machines is that inertia is negligible and is surpassed by friction and viscous force. Another point is the extremely high ratio of manufacturing error and surface roughness to design dimensions, which will possibly exert adverse effects on the motion property of a micromachine. Micro mechanical engineering studies such particularities of micromachine dynamics.

Other fields are briefly explained below.

2) Tribology

Study on tribological phenomena (friction and wear) on a micro contact surface under micro load of the micro mechanisms where the effects of surface forces are more significant than those of gravity.

3) Micro material mechanics

Study on mechanical characteristics of minute materials constituting the components of a micromachine, such as thin sheets and thin films. Material mechanics in the region where it is difficult to treat a material as a conventional continuum.

4) Micro fluid dynamics
Study on fluid behavior in micro passages (such as tubes and clearance). Fluid dynamics in the region where surface effects of the passage and molecular motions of the fluid are dominant and it is difficult to treat the fluid as a conventional continuum.

5) Micro heat transfer engineering
Study on heat transfer of micro structures and heat radiation in a micro clearance.

There may be other fields that should also be mentioned, but in micro science and engineering, individual approaches to independent phenomena would be insufficient. The analysis of interconnecting field is very important.

Micromachine tribology, the significance of which is keenly noted and in which progress are expected, is described in detail below.

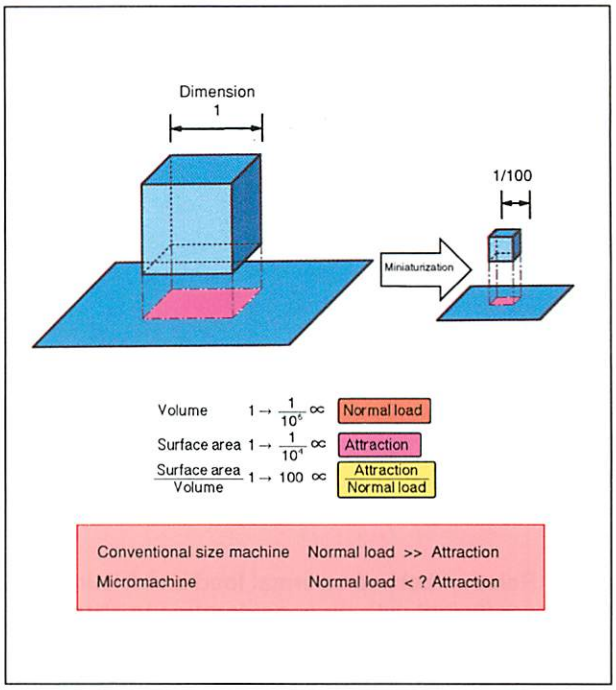


Fig. 1 Comparison of attraction and normal load between surfaces

3. Micromachine Tribology

3.1 Forces Acting between Micromachine Surfaces

When the reader was a high school student or even younger, perhaps there was a heavy road leveler in your school yard. When starting this device, much power is required to move the leveler. Once it starts moving, however, it requires less power. This is the effect of inertia. A micromachine is extremely light and has so little inertia that no special force is required to start it moving. Instead, it is much more affected by attraction between surfaces.

Typical attraction forces are electrostatic force, surface tension of liquid condensed upon the surface, Van der Waals force, and bonding force between atoms. These forces are negligible for machine parts measuring millimeters or greater. On the scale of a micromachine, however, these forces have far greater effects than the weight of the parts (Fig. 1).

Among these forces, the bonding force between atoms occurring from donation and acceptance of electrons only has an effect under special conditions such as between fresh surfaces in an ultra-high vacuum. Electrostatic force, though having extremely long range of reach and strength among other surface-to-surface attracting forces, occurs only under limited conditions, and can be removed relatively easily.

The most problematic attractions for a micromachine are surface tension of liquids (usually water in the atmosphere) condensed on a surface, and Van der Waals force.

3.2 Attraction and Friction

According to the Coulomb's law of friction, a friction force proportionate to normal load, and the factor of the proportionality (coefficient of friction) is a constant which is independent from the normal load. However, for a micromachine whose dead weight and externally applied normal load are extremely light, attraction forces between surfaces become dominant and the Coulomb's law of friction apparently does not hold.

Fig. 2 shows the relation of the normal load and friction coefficient when there is attraction between surfaces probably originating from water surface tension and Van der Waals force. As can be seen from the figure, the friction coefficient increases as the load decreases. The friction coefficient shown in the figure was obtained simply by dividing the friction force by the externally applied normal load.

Attraction between the contacting surfaces

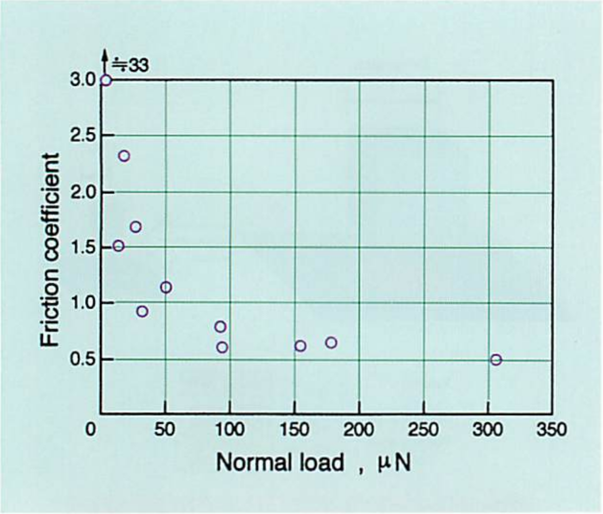


Fig. 2 Relation between normal load and friction coefficient with no consideration to attraction between surfaces

can be calculated by measuring the force required to separate the surfaces. Assume that the measured attraction (pull-off force) has an effect similar to that of the normal load upon the friction force. Add the pull-off force to the normal load, and divide the friction force by the sum. The friction coefficient obtained this way (Fig. 3) is almost constant across the whole range of the load, in contrast to the friction coefficient, which is calculated with no consideration to the pull-off force. Clearly a friction force that works on a friction face of a micromachine is significantly high relative to the size of the machine.

To reduce the friction force on a micromachine, the attraction between the surfaces can be reduced. One method for this is to reduce the contact area. This is in contrast to conventional size mechanical parts where contact area is extended for fluid lubrication. Another possible method is to apply a coating to reduce surface energy.

Such attempts have been made recently (Fig. 4). Another problem in the practical use of micromachines is wear. The functionality of a micromachine can be fatally damaged by a subtle wear of its micro components. Elaborate studies on atomic to nanometric wear are being made using the atomic force microscope (AFM). How a single atom is removed by friction is an important subject of micro science and engineering. As practical use of micromachines is revealing, micromachine tribology research is increasingly important.

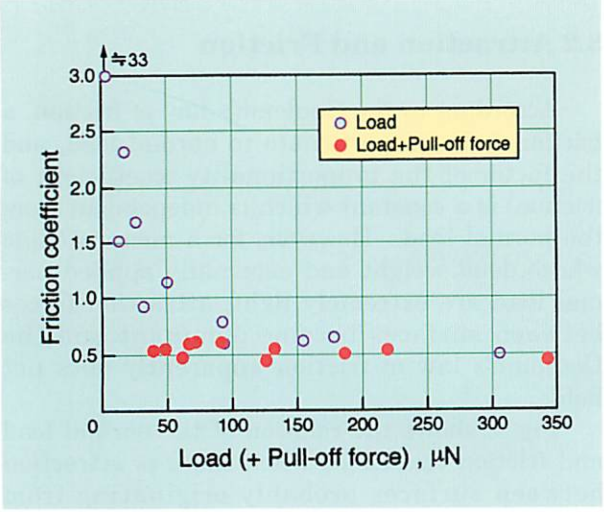


Fig. 3 Relation between normal load and friction coefficient with consideration to attraction between surfaces

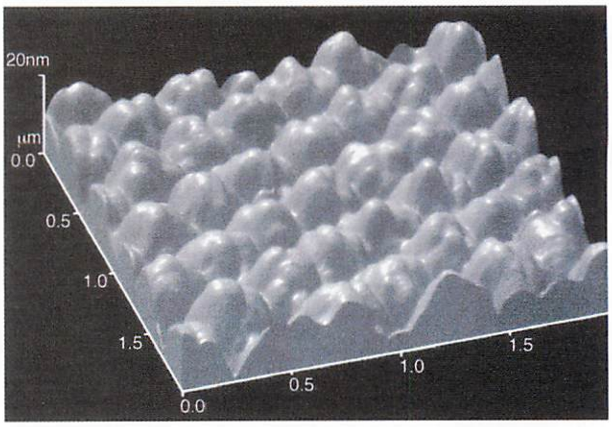


Fig. 4 Silicon surface knurled by focused ion beam (FIB) so as to reduce attraction between surfaces

Yamagata Micromachine Seminar

Evening seminars are held at MMC once a month for those interested in R&D of micromachine technology, and authorities studying basic technologies are invited to speak.

Participants have been primarily from the Tokyo area, so it was decided that beginning this fiscal year two or three of these seminars would be held in other locations to further disseminate information on micromachines.

Each seminar has four parts:

(1) Lecture on national technical development policy
(2) Lecture on activities of the Center
(3) Technological lectures
(4) Presentation of the results of the "Micromachine Technology" project of the Industrial Science and Technology Frontier Program

The first seminar of this series was held on September 12 at the multi-purpose hall of the Yamagata Prefecture Advanced Technological R&D Center, with support given by Yamagata Prefecture andthe Yamagata Prefecture Life Support Technology R&D Organization.

The first three segments were presented by Toshimi Negishi, Agency of Industrial Science and Technology, MITI; Takayuki Hirano, Executive Director of MMC, and Tokio Kitahara, Mechanical Engineering Laboratory, respectively.

The fourth segment was covered by three presentations given by research supporting members of MMC:

(a) "Ultra precision micro processing" by Kiyoshi Sawada, Basic Research Laboratory of FANUC LTD
(b) "Micro gyro" by Katsuhiko Tanaka, Yokohama Development Center of MURATA MFG. CO., LTD.
(c) "CCD micro camera" by Kazushige Ooi, Multimedia Engineering Laboratories of TOSHIBA CORPORATION

About 80 people were present. Participants were principally those engaged in R&D and production engineering of local businesses in Yamagata Prefecture who were interested in micromachine technology and individuals from universities.

Invitation to Join the General Supporting Membership

The Micromachine Center (MMC) was established on January 24, 1992, with the approval of the Minister of International Trade and Industry. Its objective is to promote the dissemination of micromachine technology in Japan, and contribute to the development of Japan's industry, economy, and the advancement of international communities.

MMC would like to invite your interest and support for its projects and activities—and call for your direct support through membership in MMC itself.

Membership privileges include:

1. Participation in surveys and research undertaken by MMC, and use of the results.
2. Use of delegated survey, research and development results not classified as secret.
3. Participation in study groups and other activities of the center.
4. Use of MMC's data bank.
5. Receipt of publications.

Membership requires an initial payment of ¥ 4 million and annual dues of ¥ 2 million.

For further information, please contact the General Affairs Department of the Micromachine Center.

Fukuoka Micromachine Seminar

Seminars for those interested in R&D of micromachine technology are also held at locations other than Tokyo. The first took place last September in Yamagata, and the next is scheduled for Fukuoka, Kyushu:

1) Date: Thursday, January 11, 1996
2) Place: Kita-Kyushu Technology Center
3) Co-sponsored by Fukuoka Industrial Technology Center
4) Seminar program:

Classification	Time	Subject	Lecturer
Lecture I (MITI)	13:00-13:30	National Policies on Industrial Science and Technology	Masayuki Kondo, Director for Machining and Aerospace R&D, AIST
Lecture II (MMC)	13:30-14:00	Activities of MMC and Technological Promotion by MMC	Takayuki Hirano, Executive Director, MMC
Lecture III (National Laboratories)	14:00-14:30	Technological Lecture	Yuichi Ishikawa, Mechanical Engineering Laboratory, AIST
(Coffee break)			
Lecture IV	15:45-16:15	Presentation of ISTF Program Research Results (1): "Micro Photovoltaic Devices"	Hiroaki Izu, Chief Researcher, New Material Laboratory, SANYO Electric Co., Ltd.
Lecture V	16:15-16:45	Presentation of ISTF Program Research Results (2): "Micro Generators"	Hiromu Narumiya, Group Manager, Advanced Technology R&D Center, MITSUBISHI ELECTRIC CORPORATION
Lecture VI	16:45-17:15	Presentation of ISTF Program Research Results (3): "Tube Type Manipulators"	Kazuhisa Yanagisawa, Assistant Manager, Research Department, OLYMPUS OPTICAL CO., LTD.
Lecture VII	17:15-17:45	Presentation of ISTF Program Research Results (4): "Micro Inspection Machines"	Koji Idogaki, Project Manager, Research Laboratories, NIPPONDENSO CO., LTD.

High-tech Symposium Yamaguchi '95

This seminar will be held as part of the program of High-tech Symposium Yamaguchi '95 sponsored by the Faculty of Engineering, Yamaguchi University and supported by MMC.

1) Date: Friday, January 12, 1996; 13:10-17:00
2) Place: Tokiwa Kosui Hall, 254, Oki-ube, Ube, Yamaguchi Tel.: 0836-51-7057
3) Program:Same as the Fukuoka Seminar

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