Title	Aiming to create innovative machine tools with abilities comparable to humans : Production engineering as the fruition of research into interdisciplinary fusion
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The Research

Associate Professor Yasuhiro Kakinuma is featured in this issue, whose field of research focuses on innovative manufacturing based on intelligent technology of a field of precision engineering.

Aiming to create innovative machine tools with abilities comparable to humans

Production engineering as the fruition of research into interdisciplinary fusion

Associate Professor Yasuhiro Kakinuma specializes in precision engineering and the scope of his research is truly diverse and extensive. Using an interdisciplinary approach – sometimes taking advantage of knowledge from materials engineering and control engineering and from nanophotonics at other times – he has created a variety of innovative manufacturing technologies, which puts him in the spotlight. We asked him about his energetic research activities and achievements.

Expectations are high for application of functional gel with surface adhesion that change in response to an electric field

Dr. Kakinuma specializes in production engineering, centering on micro/nano-machining technology and development of machine elements. He currently tackles three pillars of research: ① development of machine elements based on electro-adhesive gels; ② development of intelligent machine tools that can "feel the applied force"; and ③ ultra-precision machining of hard-and-brittle materials and elastic polymers.

What characterizes his research activity is that in any project he challenges the development of unprecedented production engineering while introducing elements of other disciplines.

Take electro-adhesive gels, for example. These gels are based on "Electro-Rheological (ER) fluids", the viscosity of which changes by applying a voltage. A kind of functional fluid, ER fluids were discovered in the 1940s and their application development was energetically promoted in the 1990s mainly in the automotive industry.

"ER fluids are a functional fluid that changes viscosity when electricity is applied – like milk transforming into Bavarian cream and into cheese. In other words, it hardens by applying a voltage. As such, expectations are high for application of ER fluids in various industrial fields. But this fluid was not without problems: its effects decline as its particles precipitate and condense with a lapse of time; and as a fluid, it is hard to handle. In the early stage of my research, I aimed to develop an ER fluid-applied device. So I took one step further into the field of materials development, which was not my line though, in an attempt to make the ER fluid into a gel that is easier to handle. This attempt brought an unexpected result," Dr. Kakinuma remarks.

One day, he mistakenly injected more than double the amount of a gelation material, which happened to produce an almost rubbery gel. He investigated the properties of this material and found to his surprise that its surface could take on adhesion when electricity was applied.

"Its image was like Scotch tape, the front surface of which has transformed into the reverse side due to electricity, so to speak. In this phenomenon, the adhesion was generated because micro particles, which had been dispersed in the silicone gel, condensed due to application of electricity. This in turn squeezed the gel inside out to the surface. Since this field was out of my line, I was conducting research with the cooperation of a chemical maker. As a non-specialist, I was not enmeshed by ready-made ideas, which eventually proved to be lucky for me," he continues.

Taking advantage of electro-adhesive gels' characteristic feature – the ability to fix things with adhesion simply by applying electricity – Dr. Kakinuma is now intent to develop its application: to the fixing of semiconductor silicon wafers during processing and transfer; to dampers for suppressing vibration; and to clutches and brakes of precision machinery.

He says, "I'm moving forward with application development of electro-adhesive gels, making the most of my

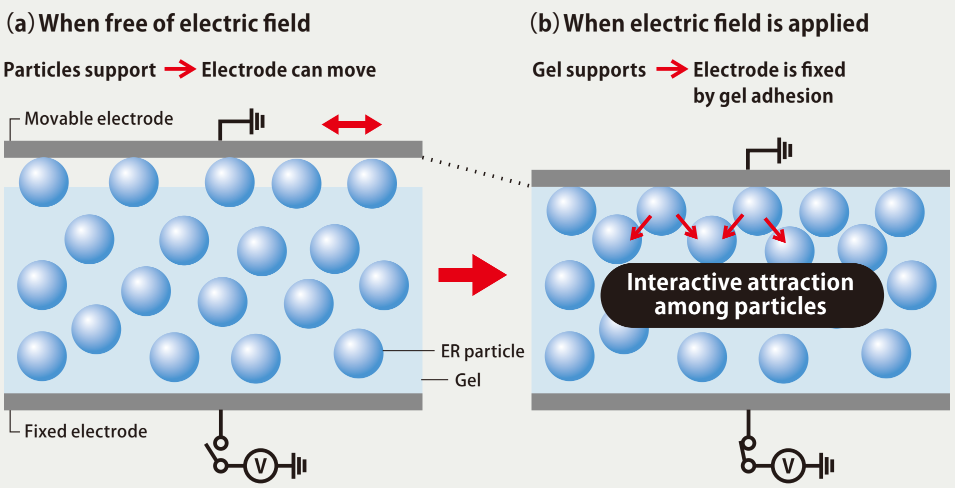

Fig. 1 Mechanism for generation of electro-adhesive effects

(a) When free of an electric field, ER particles, which have protruded from the gel surface, support the movable electrode. The mobile electrode can move freely because ER particles have excellent slip characteristics.
(b) When an electric field is applied, dielectrically polarized ER particles attract each other. This causes the particles, which have protruded from the gel surface, to move into the inside of the gel. Meanwhile, the gel rises and adheres to the mobile electrode.

specialty, production engineering, by enhancing their adhesion by laminating and downsizing."

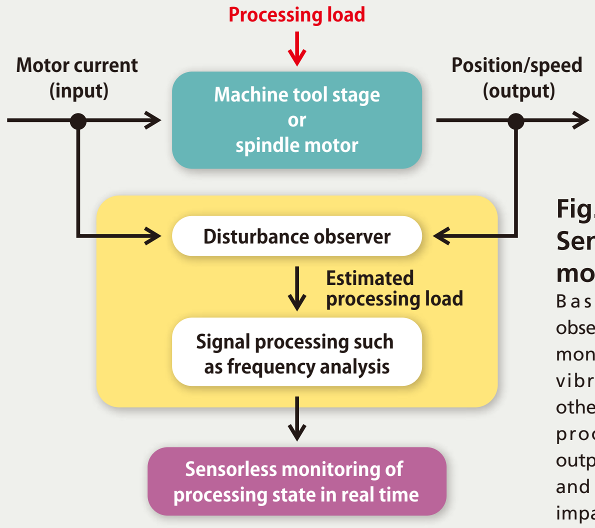

Fig. 2
Sensorless process monitoring
Based on the disturbance observer theory, sensorless process monitoring diagnoses chattering vibration, tool breakage and other abnormalities by estimating processing loads from input/output information on the spindle and machine tool stage, and by imparting signal processing such as frequency analysis to such information.

Development of an innovative machine tool with sensor-less process monitoring function

With respect to the second pillar of research – development of intelligent machine tool that can "feel the applied force with no additional sensors" Dr. Kakinuma introduced knowledge from control engineering.

"This kind of machine is a system capable of observing servo information and controlling the machining force and torque freely without using sensors. The key to this system is the application of a "disturbance observer" (tasked with monitoring external loads) to the drive control system of a linear-motor-driven table. When there is a gap between the actual output and the theoretically available output for a given input, this technology allows us to estimate what external impact has been exerted."

Intrinsically, a force sensor is required to directly measure an external force exerted on a machine. However, the disturbance observer can estimate the force applied. This is done based on an equation of motion and by using a positioning system incorporated in the machine tool, which reads the electric current flowing in the motor (input information) and output of motor speed or response position (output information). The disturbance observer thus allows dynamic processing loads to be estimated in real time – its main feature.

"As a general trend today, we see almost all machines and systems are equipped with sensors. However, sensors themselves are costly and maintenance costs inevitably increase due to shortened maintenance periods, which is another cost-raising factor. Therefore, "a sensorless mechanism" is a coveted requirement when it comes to machine tools and the like that are usually used for at least ten to twenty years. As such, sensorless process monitoring technologies are coming into focus of attention of the industry, which I'm striving to put into practical use within a few years."

Based on the results of process monitoring, Dr. Kakinuma is also tackling the development of a technology that can control the processing force. He expects that the success of this development will make it possible to avoid "chatter vibration" – the so-called "hard-to-attain longtime challenge" in machining.

"Vibrations lead to defective products and machine malfunctions. Particularly problematic is self-excited vibration (a type of in-system vibration) that unexpectedly takes place when certain conditions are satisfied as a result of a machine tool's dynamic characteristics and causes relating to its machining process. Occurrence of self-excited vibration is extremely difficult to predict; as of today, there is no effective way to prevent it. So I'm addressing this problem by using a disturbance observer to determine characteristics of such vibration in real time, the data from which I hope will provide the basis for a solution – control of a force. Some day in the future, I wish to create a machine that has human-like abilities in a true sense."

Research going as far as nanomachining of optical devices

Furthermore, in the field of ultra-precision machining of hard-and-brittle materials and elastic polymers, Dr. Kakinuma extended his scope of research to include analysis of phenomena peculiar to nanomachining. Based on this analysis, he is currently developing processing machines vitally needed in ultra-precision machining.

"When it comes to machining glass like a lens, it can break if you cut into the material in an ordinary way. However, a flawless, transparent lens can be produced if you use ultrasonic vibration or process it in the nano-range. I'm now in the process of analyzing this phenomenon. In this connection, I'm also working with young professor from the Department of Electronics and Electrical Engineering to develop an optical microresonator. The optical microresonator is designed to confine light, which travels at the light speed, in a certain place for a certain period of time. As such, it can become a device that will enable light-based signal processing" he points out.

With the current method of signal processing by means of electricity, energy loss due to Joule heat is unavoidable. Instead, if light-based signal processing becomes a reality, it will dramatically reduce such energy loss, leading to significant improvement of battery durability – our long-time headache. As you can see, Dr. Kakinuma's research activity extends as far as nanophotonics, the frontier field of light control.

"I admit that interdisciplinary fusion involves hard challenges of learning unknown fields. On the other hand, by becoming versed in both machine and control technologies, it's becoming possible to obtain heretofore unavailable research results. I'd like to continue to pursue innovative research that will benefit society," he concludes enthusiastically.

(Reporter & text writer : Madoka Tainaka)

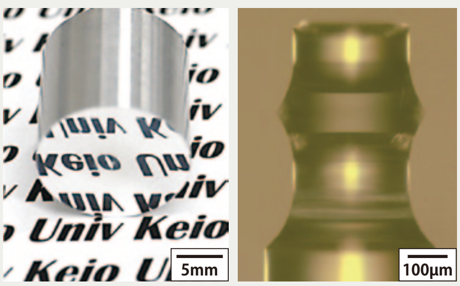

Fig. 3
Nanoprecision (ultra-high precision) **machining technology**
Left photo: This is a ultra-high precision processing machine trial-manufactured by our students. As shown here, it has a mirror-finished surface by means of a diamond tool.
Right photo: This is an optical microresonator (a container to confine light) made of fluorite (CaF_2). It was made using a ultra-high precision processing machine, taking crystal anisotropy into account.