Recent Cooperative Research Activities of HDD and Flexible Media Transport Technologies in Japan

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Abstract:
This paper presents the recent status of industry-university cooperative research activities in Japan for mechatronics of information storage and input/output equipment. There are three research committees for promoting information exchange of technical problem and research topics on head-disk interface in hard disk drives (HDD), flexible media transport and image printing process which are supported by the JSME, Japanese Society of Tribologists and the Japanese Society of Precision Engineers. For hard disk drive technology, Storage Research Consortium is supporting more than 40 research groups in universities to perform basic research for future HDD technology. The past and present status of these activities are introduced, particularly focusing on HDD and flexible media transport mechanism.

1. INTRODUCTION

Information technology (IT) is the strongest driving force of the industrial evolution today in Japan and all over the world. The information industry consists of the production of information processing equipment and devices, utilization of computer systems for general production, and application to internet communications and consumer electronics. Today's features of information technology are personal and mobile computers, digitalized consumer electronics, and internet communications for realizing a ubiquitous society. This new stage of IT society cannot be realized without large capacity, high performance, and low-cost hard disk storage and high speed and high quality input/output devices.

Figure 1 shows typical desktop personal computer which consists of storages such as HDD, CD/DVD and input/output devices such as scanner, memory cards, USB flash memory, flexible disk, digital camera, video-camera, printer, copier, etc. Among these equipment, HDD is the most important random access mass storage for available use of information, while scanner/printer is the most important input/output equipment for the transforming the natural information into digital electric data and vice versa. Today the input/output functions have been unified into one equipment.

Figure 2 shows a schematic diagram of the data transformation between time series data for data processing and spatially allocated data on recording media in HDD/ODD and scanner/printer. The data transformation is made possible by a relative motion between reading/writing head and recording medium. For example, in case of HDD/ODD, a disk is rotating in relative to a head and the head moves in radial direction by head positioning actuator. Thus the head can write and read data in any position of the disk surface. In a printer, paper is transported in one direction, while the head moves in another direction perpendicular to the paper transport direction.

The most important performance index of storage is areal density and that of scanner/printer is dot density. The bit density can be increased by increasing the positioning accuracy between head and medium. In HDD, five tracks per micron and 30 bits per micron in the track direction have currently been achieved. In high performance printer or copier, 1200 dot/inch has been achieved. The simple structure of HDD and printer contribute to high density, high-speed and low cost write/read processes of data. Thus, mechatronics for achieving accurate rotating and linear motions of recording head and media and for reducing

Fig. 1 Component equipment of personal computer

Fig. 2 Transformation between spatially allocated data and time series data in HDD and scanner/printer
various disturbances is very important.

In Japan there are three HDD producing companies and many part companies producing heads, disks and disk spindles, bearings. Therefore, information exchange activities between university and industry have been done for a long time. Today, Storage Research Consortium is the most powerful organization to promote cooperative basic research of HDD between industry and university. In addition, we have two research committees to exchange current issues and research achievements in HDD: "Tribology in File Memory" in Japanese Society of Tribologist and "Micro/Nano-Tribology and Micro-Dynamics in Information Micro/Nano Systems" in JSME.

Regarding input/output equipment, there are many companies which are producing printers, copiers, ATM, ticket handling machines, etc. Therefore, a cooperative research committee of "Technology and Science of Flexible Media Transport" was organized in June 1998 under the industry-university cooperative research program in JSPS. From 2002, a new research committee of "Simulation for Advanced Image Printing Technology" was organized in JSME.

Below I will present these cooperative research activities between academic people and engineers in companies focusing on HDD and flexible media transport technology.

2. Cooperative Research Activities in HDD Technology

Figure 3 shows the history of the increase in areal recording density and the emergence of the new disk size of HDD. Modern HDDs have recording density of 100Gb/inch², that is 5×10⁷ times that of the original HDD, RAMAC 350. The size of the drive has been reduced by (1/24)¹⁰⁰(=7/10⁶). The recording area has decreased by (1/24)² (=1.7×10⁹). The storage capacity has increased by 400000/5 (=8×10⁹). Today's 2.5 inch one platter has a data capacity of 50Gb/platter, while 0.85 inch disk has 2GB capacity/platter.

Dated back to the developing process of HDD technology in Japan, from 1960s to 1970s, the level of HDD technology was low and had to catch up US (IBM) technology under the national project in which the largest computer user NTT supports the development by the research group in addition to the fund. In 1980s, the level of Japan HDD technology became competitive with that of US through the cooperative development between NTT laboratory and HDD companies in 1970s. From Japan fear, US strengthened the R & D power to compete with Japanese group by establishing several research centers of HDD in universities and National Storage Industry Consortium (NSIC). By contrast, at the end of 1980s, NTT laboratory closed the R & D group from the decision that Japanese companies can continue to compete with US companies without support of NTT group. However, in the process of rapid downsizing from 8 inches to 3.5 inch form factor, developed by HDD companies in USA, Japanese companies were left far behind from US group, and the worldwide share of HDD shipment decreased down to less than 5%. After dissolution of NTT group, each Japanese company lost a coordinator such as NTT laboratory to exchange up-to-date information of HDD technology, while a new technical knowledge can rapidly be transferred to other HDD companies by spinout engineers moving from one company to another in US.

Desiring recovery of Japanese HDD technology, HDD industry established Storage Research Consortium (SRC) in 1995. Twenty companies and more than 50 professors participated in SRC through 6 (later 7) technical divisions. In terms of mechanical problems, Head-to-Disk Interface (HDI) division and Mechanics and Servo (MS) Division were organized from the beginning. Seven to eight researchers have been joining HDI division, while three to six professors have been joining MS division. Every year research project starts in June. An interim report meeting together with whole and division overview reports of current HDD technology is held in late November or beginning of December. The final report meeting with reviews of the market and technology trends of HDD is held in May. In addition, during these two big meetings for all divisions, each technical division holds its own meeting once. At this division meeting, the current technical issues are presented by the participating companies, so that academic researchers can know the current technical issues from companies through the division meeting.

The target of the first stage was 200Gb/in² at the end of 2001 fiscal year. However, it was achieved by 2000, one year earlier than the schedule as seen in Fig. 3. Thus the second stage started from 2001 for the new target of 200Gb/in² to be achieved by the end of 2002. The third stage of the project started from 2003 to achieve 600Gb/in² by the end of 2005. However, as seen in Fig. 3, the increasing rate of areal density was slow down due to various difficulties in recording media, head and HDI.

Figure 4(a) shows the three key mechanism in HDD: flying head mechanism, disk spindle mechanism, and head positioning mechanism. At present, the size of bit cell is 30nm in length and 200nm in width. The spacing between head and disk is about 10nm and the tracking accuracy of head is less than ±20nm. In order to increase recording density we should decrease the spacing and track width by half. However, HDI group are confronted with a crucial
problem such that a head slider cannot stably fly over a disk surface with several nanometer spacing due to unstable bouncing vibration.

In HDI division, research subjects of academic researchers are as follows:

1. R &D of ultra-thin protective layers for read/write head and recording media by K. Watanabe in Aoyama Gakuin University
2. Development of extremely thin protective film and quantification of slightly contact damage for magnetic head-disk interface by S. Miyake in Nippon Institute of Technology.
3. Development of new structure at head-disk interface by tribocorrosion approach by S. Mori in Iwate University.
4. Measurements and modeling of dynamics of head-disk interface by Y. Mitsuya in Nagoya University.
5. Near contact head dynamics considering gas-liquid interactions by S. Fukui in Tottori University.
7. Experimental study on slider/lubricant interface development by N. Tagawa in Kansai University.
8. Development of simulator for investigation of slider dynamic contact by K. Ono in Tokyo Institute of Technology.

In MS division the research subjects are as follows:

1. Dynamic absorber suspension for windage reduction by K. Ono in Tokyo Institute of Technology.
2. Measurement of exciting force and modeling of head positioning mechanism for contact recording by H. Yamaura in Tokyo Institute of Technology.
3. Reduction of flow induced vibrations by fluid structure interaction analysis by S. Kaneko in University of Tokyo.
4. Flow instability and vibration of shrouded corotating disks by S. Masuda in Keio University.
5. Sampled-data TDOF control for track seeking considering residual stiffness of neglected vibration modes by M. Hirata in Utsunomiya University.
6. Concept of MEMS based mechanical and servo system for a 2Tb/inch² device by H. Fujita in University of Tokyo.

Some typical results of these studies will be presented in the IIP annual conference.

Through SRC, academic researchers can know the current technical problems and research status of the participants. Because the research fund in the next fiscal year is dependent on the research results in former year, research activities of participants are competitive and the research level will be very high. Many technical papers presented in the related international conference, for example in ASME/STLE Tribology conference, will result from the competitive research activities in SRC.

Information exchange and technical discussion on current topics have also been done in the research committees of “Tribology in File Memory” in Japanese Society of Tribologist and “Micro/Nano-Tribology and Micro-Mechanics of Information Micro/Nano Systems” in JSME. The research committee of “Tribology in File Memory” was founded by Prof. Kaneko in JST in 1983 and chaired by him until 1990. The chairman was changed to Prof. Miyake in Nippon Institute of Technology and then, in 1998, changed to Prof. Kawakubo in Shinshu university. From 2004, Prof. Tagawa in Kansai University is chairing this meeting.

In JSME, I founded a research committee of “Mechatronics of Information Equipment” in 1990s and had chaired this committee until 1992 and then organized a new research committee of “Micromechatronics of Information Equipment” in 1996 and had chaired it until 1998. Based on this cooperative research activities in these committees and IIP division of JSME, the first International Conference of Micromechatronics for Information and Precision Equipment (MIPE)” was held in 1997 in conjunction with the Centennial Anniversaries events of JSME.

From 1995 to 1997, Prof. Mitsuya in Nagoya university organized a research committee of “Micro/Nano-Technology in Information Equipment”, and then, he reorganized a new research committee of Micro/Nano-Tribology and Dynamics in HDI from 1998 to 2000. Based on this meeting and sponsored by IIP division of JSME, IIP/ISPS International Conference of MIPE was held in 2003. From 2004, a new technical committee of “Micro/Nano Dynamics of Information Storage” started by chairman of Prof. Fukui in Tottori University. The meetings of these technical committees are held three to four times a year.

In Fukui’s meeting held in the last September, the accuracy of flying height of slider calculated from Molecular Gas-Film Lubrication Theory (Fukui-Kaneko modified Reynolds equation) was discussed. From data presented by HDD companies and head company, the discrepancy between experimental and calculated flying height by about 2nm in sub-nanometer range was revealed. Therefore effort of developing an improved Reynolds equation that can more accurately estimate the flying characteristics of a slider in a near contact regime was strongly desired.
In the last December, the joint meeting of Tagawa's Tribology committee in JST and Fukui's Micro/Nano-Tribology and Mechanics committee in JSME was held for detailed discussion of degradation mechanism of lubricant. The Tribo-plasma phenomena was reported by Dr. Nakayama in AIST and degradation process of lubricant due to flash temperature and catalysis mechanism of Al₂O₃TiC material was reported by Dr. Kasai, former IBM researcher.

3. Cooperative Research Committee of “Technology and Science of Flexible Media Transport”

Flexible media transport technology is widely used for printers, copiers, ATM, letter sorting machine, automatic ticket gate, etc. Precise and fast transport of paper by friction drive is key technology for color printing, because of the necessity of dot density of 600 to 1200 dpi. In order to achieve reliable sheet handling of various kinds of bills without jam, it was needed to simulate paper motion in pickup process and curved feeding channel. In selection and distribution machine of mailing materials, motion of mailing materials transported by belt is not clear. In order to promote academic researchers to be interested in these problems, I was asked to organize industry-university cooperative research group in the field of flexible media handling technology. I named the cooperative research committee “Technology and Science of Flexible Media Transport”. At the beginning of the cooperative research activity, 12 university professors and 38 companies joined this cooperative research organization. In the first year, we organized four technical working groups (TWGs) in terms of technical fields; Printer/copiers, ATM, Web handling (paper sheet production, high-speed printing machines), and parts and elements including paper production, and discussed the most important and common technical issues that each company want to make clear.

Figure 4 shows a typical paper transporting mechanism for printing process. Pickup process of one sheet from stacked sheets by means of a friction drive roller and retard roller, and friction drive of sheet by means of rubber and steel rollers are two important analytical models to be treated. At the end of the first year, we arranged various problems into four research subjects; (1) Characterization of mechanical property of papers, (2) Micro-slip analysis of paper driven by rubber-steel rollers, (3) Web/paper behavior due to fluid dynamics interaction, (4) Development of simulator of paper transport. For each subject we determined one or two physical models to be solved analytically.

Then, we organized four research working groups (RWGs) to perform cooperative research on these subjects for the next three years. In RWG3, two subjects on web/paper behaviors due to fluid dynamics are studied by two groups: air bearing characteristics of paper with porosity by hydrodynamic and squeeze air film lubrication, and flutter of a paper. In RWG4, simulation methods of paper pickup process mentioned above and slipping characteristics of flexible materials pinched by rubber belt were studied.

In every meeting held four times a year, we had four RWG meetings in parallel at first and, then, whole meeting for all participants. More than one hundred people attended in almost every meeting. In particular, at the end of fiscal year, we had a final report meeting during a whole day, where all academic researchers presented the results of one year study. Typical achievement will be introduced in the symposium. At the end of 2001, 41 companies and 15 academic researchers were joining this committee.

After four year cooperative research, in 2002 we made two bound volumes. Volume one describes all discussions in four RWGs and whole meeting, whereas volume two contains the scientific research results of flexible medium transport mechanism that were done by 15 academic researchers during four years. The first phase of the cooperative research activity supervised by me ended in 2002. The second phase of the continuing research restarted in 2004 chaired by Prof. Hashimoto in Tokai University.

4. Conclusion

I overviewed the past and present of cooperative research activities between industry and university in the field of mechatronics in information equipment in Japan, particularly focusing on HDD and flexible media transport. Effort to promote academic-industry cooperative research activities in Engineering Societies and Consortium is very important to maintain a leading position in global competition of information technology. Although not mentioned in detail, another research committee of “Simulation for Advanced Image Printing Technology” organized by Prof. H. Kawamoto in Waseda University in October 2002 has been held four times a year with lively discussions, gathering more than 50 participants.