CAD and Product Design Methodology at Hitachi

Background

I visited Hitachi Yokohama works on June 11. My host was Mr. Michio Takahashi of the Production Engineering Research Lab (PERL). The visit focussed on design of VCR mechanisms and camcorders and our hosts were designers in the Image and Media System Lab (I&MSL), which is next door to PERL.

The I&MSL is a product development lab within the Consumer Products Division. Its role is to create new technology for products as well as to design new kinds of products embodying such technology. Products are manufactured at factories (called works) and such works also have design departments. The latter make small updates to existing designs and lead in the conversion of preliminary designs into manufacturable ones. PERL is one of 9 research labs, others dealing with energy, basic research, mechanical engineering, systems development, microelectronics, design, and "advanced research."

Hitachi's organization is a hybrid of product-line orientation and function orientation. Each business group (such as Consumer Products, Industrial Products, Power Plants, etc.) reports directly to the president. But there is a separate Production Engineering Department that also reports directly. Finally, the 9 research labs also report directly. This means that the president directly can control research, marketing, and production engineering and can in principle mediate disputes among them. These are among the deepest disputes that can occur in a diverse technically sophisticated manufacturing company.

In many Japanese companies, there is an executive vice president of production engineering, attesting to the importance these companies give to manufacturing excellence. In most US companies the organization is strictly by product line, with each factory having its own manufacturing engineers. These people usually have little say in the design of the product and often merely take care of equipment that the company has purchased outside. Differences like these contribute to relative strengths and weaknesses of manufacturing companies, in my opinion.

At the I&MSL there are 350 researchers, of whom 70% have an electronics background while the rest are mechanical, physical, and chemical. Products include VCR's, camcorders, optical disk storage systems, HDTV's, digital audio tape systems, and their associated electronics. The lab has extensive LSI design and test fabrication facilities and obviously puts most of its efforts into the electronic aspects of design.

Most of the above information and what is reported below are illustrated (though sketchily) in a brochure they gave me about the I&MSL.

Focus of the Visit

The focus of this visit was Hitachi's approach to the design of complex mechanical items. Mr Takahashi chose the VCR, and it is a good choice. The tape changer-player mechanism typically has 300 metal and plastic parts, stamped or injection molded. Most parts are riveted together, although there are a few very small screws. This is a delicate, precise mechanism which must be rugged and reliable while at the same time handling delicate tape, being light weight, easy to assemble, and low cost. Similar products are made by Sony, Matsushita, and other companies.

Products with similar characteristics include compact disk players, cameras, and miniature hard disk drives for laptop computers. Such products are often called "mechatronic" to call attention to their hybrid mechanical-electrical-optical-computational character. Major issues in their design include deciding whether to embody a function optically, electronically, computationally, or mechanically. Their fabrication and assembly involve cleanliness, high tolerances, as few adjustments as possible, and extreme efforts at uniformity and quality of output. An additional complication is that all such products are extremely small and getting smaller.

My goal in visiting was to see how Hitachi meets these challenges, what computer aids if any are being used, and what future computer aids Hitachi thinks it needs. Additional goals were to see where Hitachi obtained the computer tools it has and to see whether it plans to develop its own in the future, deal with universities, or buy from commercial companies.

Summary of Discussions and Tours

I met in the morning with Dr. Yoshihiko Noro, Chief Researcher, and several of his main assistants. We discussed the product design cycle for miniature VCR's, including how long it takes, what the chief obstacles are, and who does what. I was also shown the CAD center.

After lunch, I got a brief tour of PERL's robotics lab where I saw several things I had seen in earlier stages of development on previous visits (6 in all since 1974).

Finally, there was a presentation by PERL of a recent paper on their approach to Concurrent Design (see report on visit to Prof Fujimoto) and an open discussion on this topic. We planned several additional visits, including to factories where washing machines and automotive components are made. These visits are covered in other reports.

VCR Design Cycle

The I&MSL is responsible for consumer stand-alone VCR's, VCR's inside camcorders, and professional studio VCR's. The latter are their newest product and are made at the glacial rate of 10 per month. By contrast, the others are made in the hundreds of thousands per month. Naturally, the design of something made at 10 per month is quite different from 100,000 per month, since automation of the latter is almost a necessity. Thus each part must be very simple, must be able to be picked up by a simple gripper, and installed in a simple straight-line motion.

These VCR's are an incredible jumble of stacked, nested, and intertwined levers, rollers, springs, sliders, cams, and bars, run by a motor and several little rubber belts. Most of the parts occupy the bottom 3mm thick layer of a unit that is about 2cm thick, 10 by 14 cm. Design is therefore an exacting process requiring fitting parts into small spaces as well as determining how the moving parts will travel while carrying the tape from the cassette to the read head.

A totally new product may absorb two years of advanced development of its basic technologies before any specific product design begins. Then it takes about two more years to create a product. For a relatively mature product, one of these years will be devoted to design development at the lab while the other year will be spent converting it into a manufacturable item utilizing the works' designers. For less mature products, correspondingly more of the two year cycle is spent at the lab.

Design is accomplished using CAD (see below) but most of the early effort is put into a series of prototypes. These are uniformly named at Hitachi as follows:

First prototype - preliminary design

Second prototype -- the main focus is to achieve a design that fits the size required by the market goals; the I&MSL engineers use Hitachi's assembly evaluation method during this phase

Third prototype -responsibility of works designers - main focus is cost reduction; in this prototype, Hitachi's AEM is used in cooperation with the production technology group

Pre-mass production prototype - 30 units made on production tooling and tested for performance, then 100 more tested for quality assurance and final checkout of the tooling

I was shown several such prototypes.

Computers are used to lay out the mechanical parts, check for interference during functional motions, see if straight line assembly motions are possible, perform stress analyses, and avoid "simple" and "obvious" errors that would seriously delay the design. See below for details of computer facilities. It appears that computer models are mainly used to fix ideas that have been previously worked out in the designers' heads, on scratch paper, and physically using prototypes. How the original concepts are generated and what role if any a computer plays are not easy to determine.

In answer to my question, they said that the main design challenges are weight, cost, part count reduction, meeting the spec, reducing the cost, and getting the production tooling and factory up to speed. These are, of course, just the concerns one would expect, but the order in which they were given might be indicative of descending order of difficulty.

The early prototypes are naturally very clunky and heavy, with many hand-made parts. Function can be tested but final size and weight are difficult to discern. When the works designers begin converting the design to a manufacturable form, they apparently deal directly with the physical prototype itself rather than a computer rendition. A major tool available for this purpose is Hitachi's Producibility Evaluation Method (PEM) of which they are very proud. More on this below.

The Tokai works where these units are made is two hours away by train. This distance might be a barrier in a US company but it is nothing to them. Meetings occur every week or two, with the majority at the lab during the first year, at the works during the second. This communication is "difficult" but apparently effective. Electronic communication is used mostly for sending text. Hitachi is aware of the advantages of being able to send engineering drawings between designers by computers but right now such capability appears too costly in comparison to the benefits.

It is important to understand the scale of typical design projects when comparing use of computers and strategies for communicating between designers and works. In the car industry it is common for projects to involve 3000 or more engineers. Here we are talking about a few dedicated people working feverishly 10 to 14 hours per day, with almost no assistance from draftsmen or technicians. These people will really own this design and will know every screw and hole.

Can the design cycle be reduced substantially below its current duration? In response to this they noted that use of the computer cut a short time out but in my opinion the amount quoted is not a lot. Could it be reduced by half? Their response is that the current duration is about the minimum, but this must be evaluated in the context of the kind of computer aids they are using and their outlook on what the future holds in CAD. As discussed below, this view is somewhat narrow. The computer saves them from time-consuming mistakes such as interfering parts that must be made over. They claim that they will try to reduce the number of prototypes but they did not discuss or show me any concrete techniques for accomplishing this goal.

CAD Facilities

The mechanical design activities of I&MSL are supported by a CAD system comprising Hewlett Packard workstations running HP's ME 30 solid modeling CAD software plus Structural Dynamics Research Corporation's (SDRC) I-DEAS solid modeler. Hitachi's contributions to this setup are a data translator for exchanging ME 30 and I-DEAS files plus a finite element package called CADAS. In addition, they have a nonlinear finite element package called ADINA, purchased from a small company founded by Professor Bathe at MIT. ME 30 is used mainly for its ability to represent many separate solid models of parts and assemblies of them, whereas I-DEAS is used because its solid models can be linked to analysis software such as FEM and plastic mold filling simulations. Apparently no single design package can do all the things Hitachi wanted, a common situation.

The typical data flow of a design begins with a simple two dimensional layout in Hitachi software called GMM which is sent via local area network to the HP machine for conversion to a rough solid model in ME 30. Some animation of the motions is done by using a separate computer to generate intermediate position data for moving parts and loading the data into ME 30 to create a series of views. No kinematic analysis software is used, although such has been available for almost 20 years. Hitachi will soon buy a package for this called ADAMS, which has recently been interfaced to I-DEAS.

After simulation, the rough solid model is refined into a complete model. Since there are 300 parts, this step can take a month or two. The model is broken into separate parts, on some of which FEM or mold fill analyses are done. A line drawing in 3D is then done and sent by LAN to another computer which makes conventional-looking drawings for the machine shop to use.

The above description is not intended to imply that 2D and 3D work are done sequentially; much work is done in parallel, with 2D being used for simple almost plane parts and 3D for complex parts or those with many surfaces.

In their opinion they could not design these VCR's without the 3D modeling. However, they admit that such tools permit only functional modeling and basic part fit studies. They cannot do tolerancing, kinematics, cost analyses, or their AEM. Reluctantly they admitted that they want to integrate AEM into

CAD but they acknowledged in later discussions that they really do not have a technical approach for doing this.

Hitachi's View of the Product Development Process

My hosts from PERL made a presentation of the contents of a paper describing their approach to product development [Miyakawa]. No one from the I&MSL was present at this time so I do not know the extent of their agreement with its contents or whether they follow this process. It is likely that the paper represents an idealization of a procedure that has emerged over a long period of time.

Simultaneous Cooperative Development

The process has both an organizational component and a technological one. The organizational component is called SCD (Simultaneous Cooperative Development) and is similar in spirit and methodology to Concurrent Design (CD), Simultaneous Engineering, and so on. However, SCD has developed "cumulatively," whereas they see CD as a US innovation implying a drastic new development that puts SCD on computers and makes heavy use of computer technology, design aids, and communications. Hitachi is presently surveying CD methods and research world-wide, especially in the US. "Everyone in Japan sees the need to do SCD better and faster and it seems that the US has more researchers working on this. Only a few Japanese companies see how to do it."

Hitachi admits that the idea of SCD is easier to define than to implement. It requires cooperation between marketing, design, and manufacturing to create a design that balances the goals of each group: utility, assurance of performance, and producibility. "Conflict breaks out as soon as the project starts." The spirit of cooperation is instilled by defining the ultimate user of the product as the one they are all working for. This is a good slogan but there is nothing to back it up in their methodology except to hold lots of meetings. The only clear guideline is that the project leader is someone assigned by the factory that will make the product, and this person, similar to the heavyweight defined by Clark and Fujimoto, draws on the skills of several labs and works to form his team.

Producibility Evaluation Method

The Producibility Evaluation Method (PEM) is an outgrowth of the Assembleability Evaluation Method (AEM) dating from 1976 combined with the Machining Productivity Evaluation Method (MEM) developed in 1985. Since AEM and MEM can have conflicting recommendations about the design of parts, the goal of PEM is to blend the two and give a composite evaluation.

These evaluations are done on a part-by-part basis and are intended to give a designer a way to evaluate his own design. The method is designed to be simple and easy to use with minimal training. Thus it demands very little of the engineer. The evaluation proceeds by means of a checklist in which the designer deducts points from each part's score based on various undesirable features. For example, one might deduct 5 points if the part must be twisted while being inserted; another 10 points might be deducted if there is almost no space for fingers or a tool around the part during insertion. A perfect part gets 100 points, and a part with a score of less than about 70 is a definite candidate for improvement.

The procedure for a group of parts in an assembly is to attack the lowest scoring parts first, then the higher ones, until no further improvement can be made or the average reaches about 80.

Hitachi's main claim for the AEM and MEM is that they have validated some cost reduction ratio predictions that accompany the checklists. These predictions are said to be valid within +/- 15% on individual part assembly cost reduction and +/- 10% on product assembly cost reduction. Details of the method are hard to come by because Hitachi sells it and reveals little to those who do not buy.

Hitachi is quick to claim that this method is superior to the Boothroyd & Dewhurst method for Design for Assembly that is widely used in the US. The difference seems to be that Hitachi's cost reduction predictions have been validated in an industrial setting whereas Boothroyd and Dewhurst's (according to Hitachi) have not. Otherwise the methods are quite similar.

How Will Hitachi Drastically Improve Its Product Design Cycle?

Presently, Hitachi's I&MSL depends on commercial CAD and PERL's PEM for its main design aids, plus a lot of very hard work by skilled designers. From these two groups I did not get a feeling that long term design tool development is under way. They are quite concerned that just buying CAD software and hardware from outside will not give them a competitive advantage.

The one step they are planning to take, or hope to take, is to combine CAD and the PEM, but as stated above they do not have a clear methodology for doing this. Furthermore, they do not see Japanese research institutions as having anything to contribute to such problems. For security reasons, they were reluctant to discuss their progress in this area.

It was interesting to compare this attitude to that of a researcher familiar with Hitachi's VLSI computer support. This software does what most such systems do, namely supports all aspects of VLSI design from circuit simulation to manufacturing. Naturally, I asked what competitive advantage it gives Hitachi and the answer was "Hitachi's extensive database." Such data include materials behavior, design rules for line width, methods for calculating capacitance, and so on. Thus a lot of engineering expertise and company experience and standards have been captured and is available to other designers. While no definitive competitive comparisons can be made, it is clear that Hitachi has been able to put a great deal of its own work into this system, differentiating it from anything commercially available.

What is the analog of such a system in design of mechatronic items? Apparently Hitachi has no vision of such a system. However, several research groups in the US, Europe, and Japan are investigating such problems under the covering name of integrated product models. A common theme is "Feature-based Design." This approach seeks to extend the idea of using a computer to capture the shape of parts so that non-shape information is captured and stored along with the shape. Such information includes materials properties, tolerances, assembly approach directions, manufacturing process plans, process costs, and so on. Typical features might be threaded holes, slots, ribs, round passageways, and so on. Since many of these have obvious functional attributes as well as manufacturing and assembly aspects, one can imagine building up enough information to support a physical simulation of the design.

At this time, there is no agreed-upon approach to constructing such design systems. A number of barriers exist. One is a lack of understanding about how designers like to work and express their ideas. Another is a lack of mathematical models of physical behavior of sufficient accuracy to capture the behavior of a whole product. A third is how to achieve unity in a model of a part or product by building up from many individual features. It is not clear how a concept of the whole item can be achieved based on many little pieces or if this is necessary in every case.

Other important engineering and computational barriers exist. Foremost among these is the need to represent the stochastic nature of manufactured items. While the design describes the perfect item, each real part differs in many ways from the ideal. This fact is impossible to overcome. Instead it is acknowledged that reality can be approached more nearly with increasing cost, and that a point is reached where cost overwhelms the effort or adequate performance can be had without additional improvement.

Knowing where this point is constitutes a major challenge in every design activity, and virtually no computer support exists for it. It is called the tolerancing problem and is "solved" in every company by using experience, company guidelines, and prototypes. In many cases, tolerances are set based on the best the factory can be expected to do.

The only systematic approach to this problem that I know of is called the Taguchi method in the US, or statistical quality control and statistical process control in Japan. Usually this involves making a series of controlled experiments to determine the most important variables, typically utilizing ANOVA, and then focussing design efforts on these variables. The approach is to choose values for the most sensitive parameters in order to minimize the effect that these variables will have on performance. The Taguchi method is most easily applied to tuning a manufacturing process, since the experimental series can be accomplished by varying process parameters. To apply it to design requires making many prototypes or manipulating a mathematical model of the design. Both are difficult to do: prototypes are expensive and take a long time to create; accurate comprehensive math models usually do not exist.

Among the people I talked to at Hitachi I could find no one who had formulated these long term problems in terms similar to those used above. I did not even hear such blockages listed and identified as ones whose solution was fundamental to drastically improving the product design cycle. Finally, I did not hear an alternative description of the problem or an alternative list of target subproblems. Or, if they recognize the problems, they have not identified sources of solutions inside or outside the company. Yet the people I talked to have definitely taken on the task of improving design methods. I will try to find out if others at Hitachi have similar goals as well as what their approaches and progress are.

It is important to note (see report on visit to Prof Kimura at Todai) that in spite of any shortcomings in either Hitachi's CAD or view of future design tools, they are able to design remarkable products just the same. Would "better" design tools make them supermen or just get in their way?

Also, Hitachi is not alone in having goals but few methods for achieving them. Many other companies seem to be in the same fix. Only a few have detailed plans and a clear statement of the blockages.

Reference

[Miyakawa] Miyakawa, S., "Simultaneous Engineering and the Producibility Evaluation Method," presented at the International Conference on the Application of Manufacturing Technologies, Detroit, April 1991.