Systematic Design of Modular Products at Telemechanique

Daniel E. Whitney, Liaison Scientist, Manufacturing

Summary

Telemechanique designs, builds, sells, and uses internally a wide variety of automation equipment plus the associated controls and software. This article focusses on problems and methods in the design of multi-part electromechanical items that are made in a wide variety. How does one control the design process so that an easily made product emerges? How does one assure high quality and low defects while switching effortlessly from one version to another in unpredictable batch sizes? What rules are needed to make sure that the design process is systematic, that the number of parts does not grow uncontrollably, and that the varieties available meet the needs of customers without strangling the manufacturer?

Background

Telemechanique is a large manufacturer of industrial controls and automation equipment. The company has over 15000 employees world wide and FF 10 billion of annual sales. More than half the sales and almost half the employees are located outside of France; these fractions are growing.

Its products are similar to those of Allen Bradley: programmable controllers, factory communication systems for control and data acquisition, electrical distribution and motor control, contactors, relays, manual motor starters, pneumatic controls, and so on. All of these are sold separately and are being integrated into the newer business of providing computer-integrated manufacturing systems. They are generally highly engineered and made in wide varieties. Thus they have some characteristics in common with Nippondenso's products. Design and manufacture in the face of technological change and wide product diversity is a major concern as well as the focus of my visit.

Because the products it sells are used in automation systems that make similar kinds of items, Telemechanique is often in the interesting position of being its own customer. It is able to simulate the business conditions and technical requirements of its external customers, to learn about them by looking at itself, and learn about itself by looking at them.

Research and Development Center Activities

The center's 150 employees work on a wide range of projects, with several funded by the EC and involving other companies and universities. Examples are robotics and assembly, semiconductors, power transistors, scheduling algorithms, and environmental problems. Recent projects include high speed robot control with KUKA, robot installation of windshields at Citroen, washing machine assembly in Italy, fuzzy logic methods of tuning servos, and software for analyzing plastic molding processes and sensors for monitoring them (with the K U Leuven). Telemechanique developed the sheet metal CAD software that MATRA sells.

Product Design for Variety

Mr. Morelli is a thinker who has tried to systematize Telemechanique's product design methods. He describes his methods as in the spirit of Nam Suh: study and implement the functional requirements. As an anecdotal example, he cites his group's study of contactors (relays that switch motors on and off): when looked at properly, a contactor is a subset of a reversing contactor, in both parts complement and function. Even though contactors are sold in much larger quantities than reversing contactors, the main design constraints are on the reversing contactor. So if one wants to take advantage of parts commonality, one must design the reversing contactor first or else the contactor will have to be redesigned. Telemechanique did not originally design them in that sequence.

He also has tried to get product design to begin with a business scenario for the product. This is similar in spirit to Nippondenso's idea: Toyota is their main customer and demands high variety, unpredictable order mix, and 24 hour delivery. So Nippondenso has designed its products to meet this environment. It is significant that the manufacturing technology for these products is not unusually high tech, although the logistical control undoubtedly is. Most of the innovation is in the design.

The same is happening at Telemechanique. In the case of a new line of contactors, the business scenario is to create a small sample of a model to show to customers. Based on their response, varieties can be made on short notice in larger quantities.

More generally, Morelli has developed an approach to designing high variety products. He teaches it at a local university. It encompasses several strategies:

Functional decomposition
Modularity
Definition of subassemblies
Reduction in apparent variety by part commonality
Design for automatic assembly

Functional decomposition (conversion of functional descriptions into specific lists of parts) is a familiar step that appears in most design methodologies. It requires experience so that the functions are represented by an economical number of parts. This step is complicated when the product must be made in many varieties because some functions, and thus their respective parts, may be in some varieties but not others. Whether to make these as separate parts or merge them with their neighbors is a constant challenge. A similar challenge occurs when parts must change identity, shape, or composition at various points along the spectrum of varieties. Increasing product size along the spectrum is an example reason. Can a scaled-up version of the smaller common part be used or must a new configuration be created? Where along the spectrum should the transition occur? Etc.

An example is given below that shows how fabrication, assembly, cost, and market demand all must be taken into account. No systematic design tools for such decisions exist.

Modularity involves making up a function by combining several identical or related parts. It is relevant to products with repeated internal structures that implement repeated functional requirements. (N contacts, where N can be chosen by the customer, for example.) The design choice is between assembling the repeated parts or designing special parts that contain the required number of elements. Significantly, Morelli is not uncritically in favor of modularity, but recognizes its drawbacks as well as its advantages. Modularity brings flexibility but requires more parts, more careful attention to tolerances that build up when these parts are assembled, and more effort in logistics to muster those parts needed for each order. The choice is also influenced by the cost of making molds and the influence of production volume of the different types of the product.

Consider the case where motor control protectors with three or four poles (contacts) must be made. The following table shows four different ways they might be designed. The assumption is that the cost, complexity, and design/build time for a mold for making the parts will increase with the number of cavities in the part for holding poles. Each different design alternative is intended to generate both varieties of the product:

Design Alternative Number of Poles	Design 1	Design 2	Design 3	Design 4
3 Poles	a special 3-cavity piece	3 single-cavity modules fastened together	a special 3-cavity piece	3 single-cavity modules
4 Poles	a special 4-cavity piece	4 of the same single-cavity pieces as above	the above 3-cavity piece plus one of the single-cavity pieces	a special 4-cavity piece

Designs 1 and 4 are not likely to be economically viable alternatives if 4-pole units are low volume sellers while 3-pole units are high volume sellers. Designs 2 and 3 are more feasible in this case but it is not immediately obvious which is the best.

The net effect of this example is that to design the product properly requires a good model of the market, plus the ability to predict the cost of the associated molds and the tolerance buildups in the alternative assembled units, and the ability to model the cost structure of the product as a whole: how costs are distributed over materials, logistics, fabrication, inspection, assembly, and test. Since there is some probability that the market might change, increasing the demand for 4-pole units, a statistical decision theory approach might be taken. Researchers have studied this method but Morelli did not mention Telemechanique doing this.

More generally, one must be careful not to offer so many modules that the customer becomes confused. One way of selling offers the customers the chance to "design their own" by choosing from a catalog of the modules. Part of marketing such a product is the ability to direct the customer right to the variant he needs. So one must understand the spectrum of needs and then construct the modules so that it is easy for the customer to see what modules to combine.

One must be careful not to confuse the designers either. When a large number of varieties must be encompassed and some common parts are involved in each variety, a design change in one part can cascade changes throughout the design in unpredictable ways. A strong database is needed to keep track of such interrelationships. I doubt that one exists because it would need to know about related part features on different parts at a geometric level as well as about sets and relations between part families at the module level. This lends additional richness to the idea of a "product data model:" another example of a model that contains data to support the design process, not merely to describe the product.

"Subassemblies" could be different from "modules." This is a new distinction for me, since I have used the two terms interchangeably in the past. Modules, as stated above, may be related to the customer's or salesman's needs. Subassemblies are directed only to the manufacturer's needs. These include integration of made and bought parts or the maintenance of mechanical stability and control during assembly. For example, it may be useful to fabricate two parts near each other and assemble them immediately. This will establish their relative position tolerances while they are under complete control and keep them from being damaged or jostled out of their desired orientations during transport to another assembly point. Many other criteria for defining subassemblies exist but were not discussed at this meeting.

The next consideration is seeking commonality. Morelli drew a table that placed many product varieties in columns next to each other. The rows represent the various functions. Each entry in the table represents a way of realizing a function in a model version. If the same realization is used in all versions, the row reads the same all the way across. Deviations from this desirable pattern can be seen right away. Then one seeks the reasons for the deviations: lack of design oversight, carelessness, change in conditions in the product requiring a different realization, historical evolution, and so on.

Another basic step is design for automatic assembly. Here, again, the impetus and approach are similar to those seen in other companies, but a lot of care has gone into certain key concepts that deserve mention. The main one is the concept of the reference surface. Every item handled by automation must be gripped at a reference surface; such a surface is then toleranced to all the other internal features that must be dealt with by the automation. These are places where other parts are attached or manufacturing operations are performed. This is not a new idea but it takes on added significance when a variety of parts might be handled by the same automation.

An example is electric contacts. These come in four generic shapes, each suited to a desired amount of current and thus a required amount of contact force. In order to pack the contacts into a small space, designers have created different spring shapes to store the energy that creates the contact force. There are no design rules for choosing the correct shape in each instance, and no standardized way to define the required reference surfaces. He is in the process of defining this problem and getting the rules out of expert designers. These rules will ultimately be linked to parameterized geometric models. "When we have all of this in place, then we will have CAD," he says.

Once the main functions have been realized in terms of common and different part sets at a conceptual level, detail design begins in consultation with tooling designers. Manufacturing process design also begins, in consultation with assembly system designers. Cost analyses are done and redesign needs are discovered. When the parts are satisfactory, then shop floor equipment is designed.

Example Product Designed by These Methods

Morelli described a product that had been designed this way and is now assembled in a computer-controlled factory at Dijon. It is a miniature motor circuit breaker with an innovative arc-breaking mechanism. At least 72 varieties are made. Each unit has 76 parts, of which 28 are common to all varieties. It was designed and put into production over a period of 4 years ending in 1988, partly with French government funds. The objectives were similar to those of Nippondenso, Allen Bradley, General Electric, and several others who have sought to use design to make high variety manufacturing easier: flexible production, easy changeover from one version to another, 100% test and zero defects, optimized production costs, and realtime computer management and control. An integrated product-process design team approach was taken, set up in a "skunk works" with top management support and special shielding from top management interference.

The assembly equipment consists of standard modules made by Telemechanique. Some provide transport while others are the foundations for either manual or automatic assembly workstations. The modules plug together so that mechanical, electrical, electronic, and pneumatic connections are made automatically. All interfaces to higher level communication networks are also made automatically. Several wide and local area networks are available as standard Telemechanique capabilities.

Parts are delivered with automated guided vehicles (AGVs). In his opinion this was a mistake. The main reason is that the vehicles cost so much and carry a few low cost parts. The tracks also take up a lot of floor space. They do not save much money because a person still has to unload the parts onto the workstation.

Design Data Management Software

Dr David Pherson, former student of Prof Boothroyd at the University of Massachusetts, described software he is developing to help manage design data. In this, his effort has much in common with that of Dr Schacht at Siemens. That is, a lot of designs exist and no one knows how to organize and sort the data about them. Even the MRP data for different varieties in the same family cannot be compared or checked because each is represented by a 6" thick printout.

He is trying to use the MRP bill of materials (BOM) for something that perhaps it is not suited for. At any rate, he can show it graphically as a tree structure. At the leaves are the parts and their manufacturing processes. He can invert the tree and branch it out from common processes, to see what production capacity in each process he needs. He can also combine the BOM with the assembly sequence and figure out how much assembly plant capacity he needs, or how many instances of a kind of equipment are needed. In this way the production impacts of design decisions in high variety design can be determined readily.

Conclusions

M. Morelli is an interesting designer, researcher, and teacher who should be visited periodically. His methods present an interesting counterpoint to those of Nippondenso, another company whose systematic design methods I try to follow.

Topics for future research that emerge from this visit are:

1. Organization of design of products with many varieties. A great many products fit this description, perhaps the majority. However, only some have regular internal structures like relays have. Thus such products might present a useful subset on which to focus research. Later, products with less internal structure might be tackled. In either case, some of the issues involved are

- how to map the required functions across the spectrum of varieties so that a top-down design approach to the entire set can be undertaken (M. Morelli's table of varieties vs functions is an example of such a "map")
- how to design something for "upward compatibility," that is, with the knowledge that the above map will be incomplete and that additional versions will be needed later; will they fit in smoothly

2. Composition of the product data model. As mentioned above, designing products with many varieties means designing a set of products at once rather than designing each member of the set individually. What inter-variety data are required in the PDM? In the report an example was made of capturing the functional and physical relationships between parts so that design changes can be propagated. Here, again, the content of the PDM reflects the needs of the design process and does not merely describe the product in a functional/physical way. Another PDM question concerns what kind of cost and process data are needed so that the module/part/subassembly tradeoffs can be made.

3. Communication between designers. In theory, if one person designs the entire set, he will be able to keep track of all the varieties and their implications. The "map" mentioned above would help. Keeping track may be more difficult when several designers are working, especially if a hierarchical approach is taken, that is, successive subdivisions of functions into subfunctions, etc. As the hierarchy gains levels, each lower level will have more elements in it, requiring more designers. These designers can stumble over each other unless some cumulative method for monitoring their work is put in place, especially if each level has more than one designer.

Points of Contact

Principal:

M. Albert Morelli
Director, Automation and Productivity
Telemechanique R&D Laboratory
33 bis, avenue du Marechal Joffre
92002 Nanterre Cedex, France
tel 33 1 47 25 96 08
fax 47 29 08 67

others:

M. Jean-Louis Andreu
Vice Chairman and President
43-45 boulevard Franklin Roosevelt, BP 236
92500 Rueil-Malmaison, France
tel 33 1 47 32 92 12
fax 47 08 01 59

M. Denis Sornicle
Corporate Director, R&D
same address and phone as Morelli