INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 03 STOCKHOLM, AUGUST 19-21, 2003

CABLING DESIGN UTILIZING 3D CAD IN PRODUCT DEVELOPMENT OF AN ELECTRIC DEVICE

Niklas Lindfors, Asko Pesonen, Carolin Franck, Ville Lähteinen, Petri Kuosmanen

Abstract
In electrical devices, cables (in this paper both 'wires' and 'cables' are referred to as 'cables') form a significant subset both in terms of number of items and assembly time. In the field of electric industry, cabling design is often done at the later stages of product development process by means of a physical prototype, which makes the product development time longer. Because mechanical design is often done by a 3D system and electrical design by a 2D system, all the three fields of engineering are performed in different systems. Iterations that cross the lines between the fields become laborious, restricting iterative optimization such as design for assembly. 3D CAD softwares that have a cabling design module provide a possible solution to design cables in the same system with mechanical and also electrical design. In principle, this will make iteration loops shorter in time axis because data transfer occurs in the same system and physical prototype is no longer needed. The research objective is to compare the cabling design processes assisted by a physical prototype to the process utilizing 3D CAD; do the design iterations in cabling design become easier and on which conditions. The research is carried out by interviews and by redesigning the cables by 3D CAD to four different devices. The results show that use of a physical prototype is not necessary when cables are designed by 3D CAD. This makes it possible for cabling design to be closer to concurrent engineering and enables design iterations in order to apply design for assembly and other iterative optimization methods also to cabling design. Effective use of the 3D cabling module requires that it have been taken into account in naming the electrical components, in the modeling practice and in the model libraries of standard components.

Keywords: Concurrent engineering, computer-aided design, cable, harness, wire

1 Introduction

In electrical devices, cables (in this paper both 'wires' and 'cables' are referred to as 'cables') form a significant subset both in terms of number of items and assembly time. In the field of electric industry, cabling design is often done at the later stages of product development process by means of a physical prototype. From the point of view of design, cables combine the information from electrical and mechanical design, and this is not done until the prototype stage. According to Ng et al. cable harnesses are often addressed almost as afterthoughts at the end of the product design process [1]. In addition, because mechanical design is often done by a 3D system and electrical by a 2D system, all the three fields of engineering are performed in different systems. As a consequence iterations that cross the lines between the fields become laborious due to the work required in data transferring and information updating. Iterative optimization such as design for assembly is restricted by the design process. As stated in [2], the labor involved in electrical connections can far outweigh the labor involved in mechanical parts when products contain a significant number of electrical connections. Cable assembly can take from 30…50 %, even 75 % of the assembly time [3, 4].

3D CAD software that have a cabling design module provide a possible solution to design cables in the same system with mechanical and also electrical design. In principle, this will make iteration loops shorter in time axis because data transfer occurs in the same system and physical prototype is no longer needed. Fluent data transfer between mechanical and electrical design has been found to be one key factor in designing according to the concurrent engineering principles [5].

In this paper the information flow between electrical, mechanical, and cabling design is being studied. The objective is to compare the cabling design processes assisted by a physical prototype to the process utilizing 3D CAD; do the design iterations in cabling design become easier and under what conditions, and how will the information flow in product development change. Because of the essential role of ready-to-assemble harness subcontractors also that part of the process is included.

2 Research methods

2.1 Field of industry

The research work is performed in two companies in the field of electric industry. Company A manufactures electric devices for industrial applications. The longest dimension of the devices varies from 0,5 meters to several meters. The devices have from dozen to several hundreds wires, cables, and harnesses. The focus in company A was from midsize products to the largest products. In these products, single wires with a small cross sectional area form a majority both in number of items and in assembly time.

Company B manufactures electrical devices, the longest dimension varies from approximately 0,5 meters to 2 meters. The devices have from dozen to approximately one hundred wires, cables or harnesses. In company B’s products, harnesses form a bigger share than in company A’s products. The size of company B’s product development organization, as well as the whole unit, is a lot smaller than company A’s.

2.2 Interviews

In the beginning, we conducted an open-ended interview at both companies. The product development personnel were interviewed in groups consisting of electrical designers and mechanical designers and a manager. Later on during the project, the same personnel were interviewed again as individuals in order to get additional information.

Five subconctractors were interviewed by using the same form with 32 open-ended questions. The questions were divided into 5 subcategories.

2.3 Experiments with 3D Cabling

Four different cases were performed to experiment the 3D cabling. Cabling of two different existing products was modeled as they were in the physical products. One cabling design case was made to a 3D model, which was assembled for this purpose from models of existing components and modules, in order to experiment with complicated large assemblies. One case was based on an ongoing product development of a new product. Two of the cases were from company A, two from company B. All the experiments were made with Pro/ENGINEERs cabling design module Pro/Cabling. The versions used were 2000i[2] and 2001.

2.4 Design Structure Matrix

Design Structure Matrices (DSM) were first introduced by Warfield in the 70's, and Steward in the 80's. It has been further developed by Massachusetts Institute of Technology's design process modeling research team [6]. In this research DSMs were used to study the combined hardware -, mechanical - and cabling design processes.

3 3D CAD Cabling module

3.1 Input information and the 3D model of a cable

Cabling design requires input information from both electrical design and mechanical design and is even itself of iterative nature between the two fields of engineering. During the iterations, the cable type can be changed and the electrical components can be moved, but to start designing cables, the electrical connection points have to be defined and for the cable type have to be given at least an initial estimate. The 3D models of the components that include the connection points have to exist in the model.

The design tool can handle a single wire, multi conductor cables and flat cables. Fibers and coaxial cables are modeled the same way as cables. Additional cabling features such as bundles, tie wraps, and markers are available. The cables look real, but they are solid pipe so that insulation and the conductive material cannot be handled separately. Software, that can also handle electrical properties such as resistance or EMC do exist [7], but using them will introduce one more design system to the process. In the field of industry in question, including the cables in the 3D models make them look like the real products, which enables the use of 3D models in e.g. assembly documentation and service manuals. The cables' mass can be calculated, but for example no electrical simulations can be performed without further modifications.

3.2 Modeling practice

Cerezuela et al. have grouped the design process of a harness into four steps [8]:

1. The cables are first routed.
2. Then, they are cut according to the bulkheads.
3. For each cable, one connector is chosen.
4. Finally, the cables are grouped into harness.

In 3D modeling, the step 3 is made first. After that the cable is routed between the connectors. Step 2, cutting, is done when the routing to the second connector is finished.

A 3D cabling model is divided to four levels: cabling assembly, harness part, cable, and location points. Single cable is a feature that is created to a harness part that can contain as many cables as necessary. Harness parts are created into cabling assemblies that are normal 3D assemblies. Harness parts differ from normal 3D models; they cannot be used without the assembly that they are created into. The hierarchy of the 3D assemblies must be chosen carefully in the beginning of the design process since changing it afterwards is laborious. The hierarchy of the model should allow easy finding of components and changing the design without restructuring the assembly. In order to make concurrent engineering possible also the ability to divide design data to many designers is important. How the hierarchy should be formed depends on the product. One possible practice is to divide harnesses into manufacturing modules as shown in figure 1. This way cabling can be designed separately to each sub module. On the top level of the assembly is the main harness assembly that includes cables that connect the whole product together. [9]

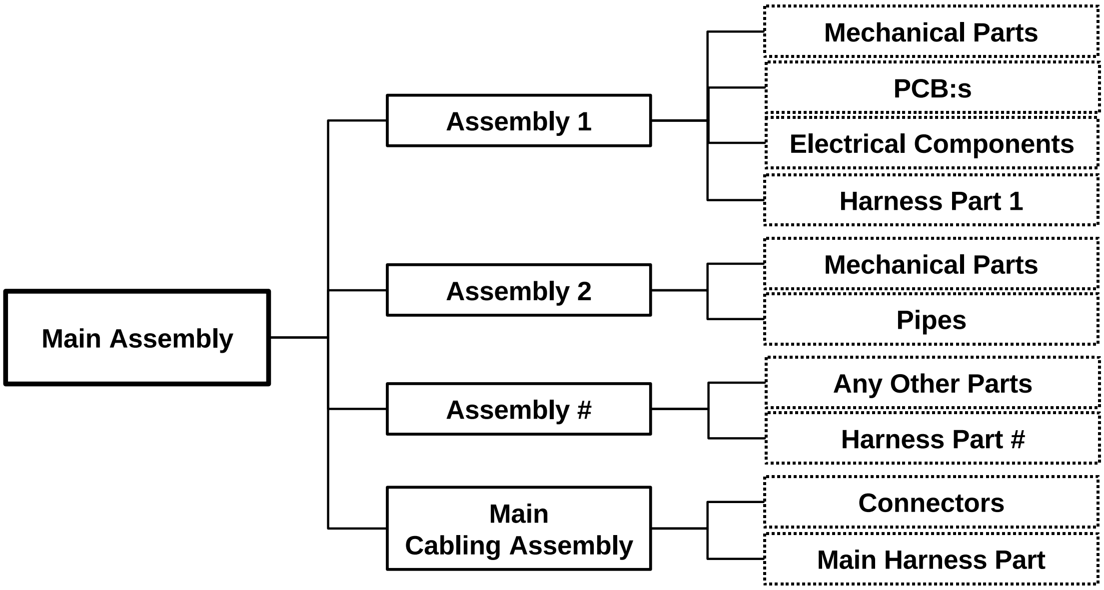

Figure 1. Cabling hierarchy divided into manufacturing modules

Cable types are defined with spools that can be stored in spool library. Cables are modeled to 3D assembly with location points, which attach them to 3D assembly. It is essential to choose appropriate features for attaching locations. Features that are not going to go through major changes and will not be deleted should be chosen as attaching points. Location points can also be redefined if attaching feature disappears. Location points can also be attached to distinct assembly parts that are assembled to 3D assembly. This way these assembly parts are easy to reassemble with normal assembly commands and the cables will follow the changes. Cable segments are created between location points. [9]

Cables are connected to electrical components. The components must contain a coordinate system in which cables are connected. Every electrical pin can be modeled with coordinate system or all component pins can be presented with one coordinate system. Two other features that can be useful in cabling are assembly coordinate system for quick component assembly and direction points for controlling how cable approaches the component. Before a 3D model can be used for cabling it must be designated as an electrical component and as the coordinate systems used as pins must be designated. Terminal components such as crimp terminals can be added to electrical components with component parameters. These parameters can be created manually or with a terminator table that is a powerful tool for automating creation of terminator parameters. With the terminator table parameters can be added to components with certain rules that can be based on e.g. cable size. [9]

4 Results

4.1 3D CAD

In 3D computer aided cabling design electrical connection information is transferred directly to assembly model. After importing connection data the cabling module of the CAD-software guides the designer on how to designate electrical components and route the cables. For example components and coordinate systems are highlighted in the locations where the cables are connected, which helps routing significantly. Computer aided cabling design makes the handling of large amount of cables easier by allowing only the right electrical connections. Evaluation of cabling design by comparing it to wiring diagram is possible with an automatically generated comparison list. In this research the electrical and mechanical (including cabling) design were made with different software. Data transfer between the two software sets some special requirements, for example the names used for components and pins must be exactly the same in mechanical and electrical design. Also same electrical components must be found in both systems. This is not self-evident. Because of their different backgrounds the mechanical and the electrical design handle the same components in a different way and the logic in naming the components is traditionally different. In the 3D model the component naming has to be unambiguous.

Cabling modules of the CAD-software can do some of the routing work automatically after the necessary contact points and the routing possibilities are defined. Autorouting is based on network paths that can be designed to the assembly model. The software will route the cable from the contact point to the closest networkpoint. The cable will then follow the shortest possible route via the network to the second contact point. Network paths are created with similar tools as the cable routes. There might be some obvious paths for the network like cable channels. If there are no clear paths, enough space should be left around a network because usually it is unclear how many cables are going to be routed to it. If autorouting can be used, it is very fast to route cables compared to manual routing. Example of a routed harness is presented in figure 2.

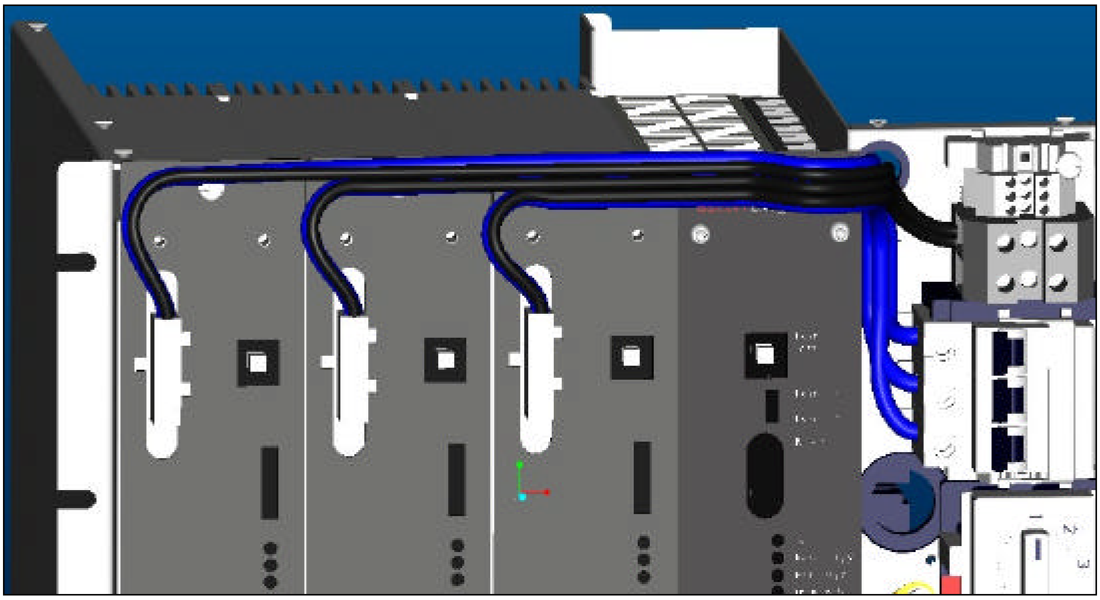

Figure 2. Example of routed harness [9]

One of the most important ways to use a 3D cabling model is to create manufacturing documents for harnesses. The three-dimensional harnesses must be laid out to two-dimensional manufacturing drawings. This is done with a separate harness-flattening tool. Manufacturing drawings are made with standard drawing module of the CAD software. Drawing formats should be designed carefully so that they include all the needed tables and the information that is needed for manufacturing harnesses. The cabling models can also be utilized for assembly and service instructions.

4.2 Design processes

The cabling design processes are presented in the Design Structure Matrices (figures 3 and 4). The DSMs are built based on the general processes in two very different organizations, which naturally makes the process look very compact compared to a detailed product development process of a specific product. Also due to the general nature of the presented processes, the applied optimization algorithms did not produce useful results. The situation could change in case of a specific product with subsystems designed in parallel.

In figure 3, the feedback from cabling prototype building to mechanical design fills the upper triangular of the DSM of the traditional design process. This makes the iteration block large, and in practice iterative optimization becomes slow and laborious. Many of the iterations cross the borders of design systems. This causes data transferring into another system, which often means non-automatic work that is not only irrelevant to the customers of the product being developed, but also introduces possibilities of errors.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
E Functional Design	1	1																							
E Define function of PCBs	2	1	2																						
E Choose components	3	1	1	3																					
E Make diagramms	4	1		1	4	1																			
E Choose cable type	5				1	5																			
E Make wirelist	6				1	1	6																		
M (3D) Frame/Cover Design	7			1			1	7	1	1	1	1									1			1	
M (3D) Place components	8			1			1	1	8	1	1	1												1	
M (3D) PCB shape and dimension	9		1					1	1	9	1	1												1	
M (3D) Reserve cable routing space	10						1	1	1	1	10	1				1		1						1	
PCB Component placement	11				1					1		11													
M Make assembly documentation	12						1	1	1	1		1	12												
Prototype (without cabling)	13												1	13											
C Designate HW components to prototype	14						1						1	1	14										
C Assemble/Route cables to prototype	15						1						1	1	1	15		1	1		1			1	
C Measure lenghts of cables	16						1									1	16	1		1	1				
C Define connectors to cables	17						1							1	1	1		17					1		
C Design harness - combine prototype cal	18													1		1		1	18	1					
C Add tie-wraps, markers and shields	19						1							1		1		1	1	19	1		1		
C Design fixing to prototype	20													1		1		1	1	1	20				
C Make harness documentation	21						1									1	1	1	1	1	1	21	1		
S Manufacture harness	22																					1	22		
Prototype with cabling	23						1							1		1					1		1	23	
Finalize prototype	24																							1	24

Figure 3. Design Structure Matrix of a traditional prototype-based cabling design process. E = electrical design, M = mechanical design, C = cabling design, S = subcontractor of harnesses

Design and documentation of harnesses is also done by a different system in this process. In interviews with the subcontractors it was found, that different companies had very different methods for documenting harnesses. Very often the subcontractors made the documents once again from the start to fulfill the needs of their own production.

If a design change occurs, also the harness design has to be updated separately. Depending on the complexity of the harness, this can be very laborious. Also the design of a harness cannot begin before the prototype is almost finished and the schedule pressure is possibly hard. We believe that because of these reasons the use of ready-to-assemble harnesses is below the optimal level in the field of electrical industry.

The advantage of the 3D-cabling design becomes evident by comparing the DSM of the 3D-CAD based cabling design process (see figure 4) to the DSM of the traditional design process. The process where the cabling design is based on a computer model instead of physical prototype is more a series of easily controlled iteration blocks, where most of the iterations occur inside the same design system.

The resources used in 3D modeling of the cables is from about 25…100 % of that of designing the cables with the prototype. In producing assembly and harness manufacturing documentation the 3D model based process is one order of magnitude faster and especially the updates after iterations are easier. In this process it is also possible to transfer the harness documentation work to the subcontractor that manufactures the actual harness. This leaves the subcontractor more possibilities to do cost optimization, and is actually close to giving a "black box" design task.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
E Functional Design	1	1																					
E Define function of PCBs	2	1	2																				
E Choose components	3	1	1	3																			
E Make diagrams	4	1		1	4	1																	
E Choose cable type	5				1	5																	
E Make wirelist	6				1	1	6																
M (3D) Frame/Cover Design	7			1			1	7	1	1	1	1											
M (3D) Place components	8			1			1	1	8	1	1	1											
M (3D) PCB shape and dimension	9		1					1	1	9	1	1											
M (3D) Reserve cable routing space	10						1	1	1	1	10	1											
PCB Component placement	11				1					1		11											
C Import diagram	12						1						12										
C (3D) Designate HW components	13								1			1	1	13									
C (3D) Add connectors	14								1			1		1	14	1							
C (3D) Assemble/Route cables	15										1			1	1	15	1		1				
C (3D) Design harness - combine cables	16														1	1	16	1					
C (3D) Add tie-wraps and shields	17														1	1	1	17	1				
C (3D) Design fixing	18														1	1	1	1	18				
M Make assembly documentation	19							1				1		1	1	1	1	1	1	19			
S Make harness documentation	20													1	1	1	1	1	1		20		
S Manufacture harness	21																				1	21	
Prototype	22																			1	1	1	22

Figure 4. Design Structure Matrix of a modern 3D-CAD based cabling design process.

5 Discussion

The traditional design process needs a physical prototype. Before the cabling design can start, the components have to be designed, documented, manufactured, ordered, etc. If this process is shortened in time axis, there will be a point where the speed of manufacturing and its support functions set a minimum. Iterations requiring new design and manufacturing of components will repeat the process.

The traditional process has had a traditional distribution of work, which has to be reconsidered if 3D cabling design is used. It is not self-evident who has the best conditions to do the cable modeling. The modeling can be done by mechanical designers, but they need the input information from electric designers, and possibly don't have the abilities to fully utilize the iterations. For example identifying possible heat or EMC problems when routing cables. On the other hand, 3D modeling softwares have so far been mainly used by mechanical designers, so that electrical designers possibly don't want to do the work or they might need more training. A third solution is to have separate personnel to do cabling modeling.

3D modeling of cables will make the 3D model of an electric device closer to a virtual prototype. The use of a virtual prototype instead of a physical for designing and verifying issues like assemblability is effective from the point of view of design iterations. On the other hand using a 3D assembly model this way requires resources on design: a strategic decision to do long term work to reach this aim is necessary.

6 Conclusion

Successful and resource-effective use of the 3D cabling design module requires that: 1) The naming of the electrical components and their 3D models is carried out with the same logic throughout the organization. 2) Information transfer from electrical design to the 3D design software is effective and reliable 3) The modeling practice (for example hierarchy of the assembly model) takes cabling into account 4) A maintained library for the 3D models of the electrical components and cables is available.

The results show that the use of a physical prototype is not necessary when cables are designed by 3D CAD. The iteration loops become shorter and they will remain inside one system. This makes it possible for cabling design to be closer to concurrent engineering and makes the design iterations effective enough in order to apply design for assembly and other iterative optimization methods also to cables. Additionally 3D cabling can also help in standardizing the cables and electrical components used.

References

[1] Ng, F.M., Ritchie, J.M., Simmons, J.E.L., Dewar, R.G. Designing Cable Harness Assemblies in Virtual Environments. Journal of Materials Processing Technology, 2000. Volume 107, pp. 37-43. ISSN 0924-0136.

[2] Boothroyd, G., Dewhurst, P., Knight, W. Product Design for Manufacture and Assembly. New York: Marcel Dekker, 2002. 668 p. ISBN 0-8247-0584-X

[3] Lindfors, N., Lähteinen, V. & Ekman, K. Applying DFA Guidelines in Practice, Proceedings of Nord Design 2000, Lyngby, Copenhagen, Denmark, August 24-25, 2000, 10 p.

[4] Lindfors, N., Lähteinen, V. & Ekman, K. DFA in Cabling Design of an Electric Device, Proceedings of Nord Design 2002, Trondheim, Norway, August 14-16, 2002, 8 p.

[5] Ruotsalainen, P., Kuosmanen, P. Concurrent Engineering in Design of Electronic Product. Proceedings of Nord Design 2000, Lyngby, Copenhagen, Denmark, August 24-25, 2000, 7 p.

[6] http://web.mit.edu/dsm/Tutorial/tutorial_intro.htm

[7] Gyorki, J.R. Smart Software builds a better harness. Machine Design, 1998, No7, pp. 89-92.

[8] Cerezuela, C., Cauvin, A., Boucher, X., Kieffer, J-P. A decision support system for a concurrent design of cable harnesses: conceptual approach and implementation. Concurrent Engineering: Research & Applications, 1998. Volume 6, Nro 1, pp 43-52. ISSN 1063-293X.

[9] Pesonen, A. Developing Cabling Design in the Electric Industry. Master’s thesis, Espoo 2002, 96 p. Helsinki University of Technology, Machine Design

For more information please contact:

Niklas Lindfors
Helsinki University of Technology, Machine design.
P.O.Box 4100, 02015 HUT Finland
Email: niklas.lindfors@hut.fi