AN INTEGRATED DESIGN SYSTEM FOR MOLDED INTERCONNECT DEVICES (3D-MID)

Yong Zhuo, Christian Alvarez and Klaus Feldmann
University Erlangen-Nuremberg, Germany
{zhuo, alvarez, feldmann}@faps.uni-erlangen.de

In this paper, MIDCAD, an integrated design system for Molded Interconnect Devices, is presented and some important techniques for the development of this design system are discussed. A series of MID-related special functions and an integrated MID product model, which are not supported by conventional MCAD und ECAD systems, were developed in MIDCAD. Based on the product model, the simulation of the injection molding process is successfully integrated into MIDCAD. A module supporting the connection of MID-specific automatic placement equipment is also being developed in MIDCAD in order to be able to accomplish a manufacturing-oriented optimization and to guarantee the manufacturability of MID products.

1. INTRODUCTION

One of the fundamental and trend-setting innovations in the field of mechatronics is the direct integration of mechanical and electronic functions using Molded Interconnect Devices (3D-MID technology).

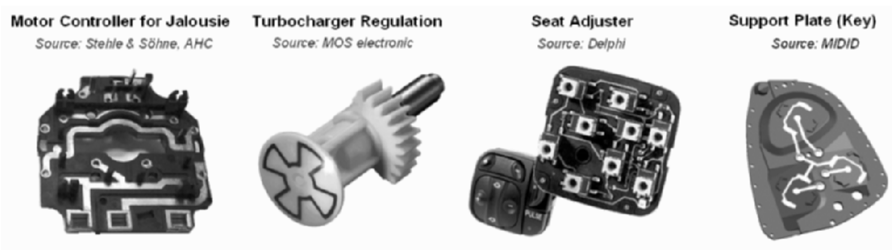

Figure 1 – Current applications of the MID technology.

Some current products using MID technology are shown in Figure 1. One can easily see that these products do not contain conventional 2D circuit board but circuits running directly on the surfaces of the 3D circuit carrier. The enhanced design freedom and the integration of electronic as well as mechanical functions in a single injection-molded part allow a substantial miniaturization. They provide enormous technical and economic potential and offer a remarkably improved ecological behavior compared to conventional circuit boards (Feldmann, 1998).

Currently, the common MID-design process uses the coupling of 2D electronic CAD (ECAD) and 3D mechanical CAD (MCAD). The MCAD system does e.g. not know what electrical connectivity is, and on the other way an ECAD system ignores any requirements of 3D circuit carriers because of its two-dimensional nature. Such a design process slows down the application of MID technology to a considerable degree.

The difference between MIDs and conventional mechatronic products is the mutual dependency between the geometry and the electronics. That makes it impossible to independently design one aspect without considering the other one in the system integration design stage (VDI 2206, 2004). Consequently, the efficient design of complex MID-products requires a special design tool which should consider the mechanical structure and electronic function of MIDs in a 3D environment at the same time. It has to provide design functions especially fitted to the needs of MIDs by combining functions of ECAD and MCAD systems. Existing tools like EM-Designer (Zuken, 2006) and NEXTRA (Mecadtron, 2006) only provide a rather limited support for an efficient design of complex MID-products (Zhuo, 2005).

2. FRAMEWORK OF THE INTEGRATED MIDCAD SYSTEM

A prototype-like MIDCAD system has been developed to provide designers with an integrated environment for design and analysis of MID products. An overview of the system architecture is shown in Figure 2.

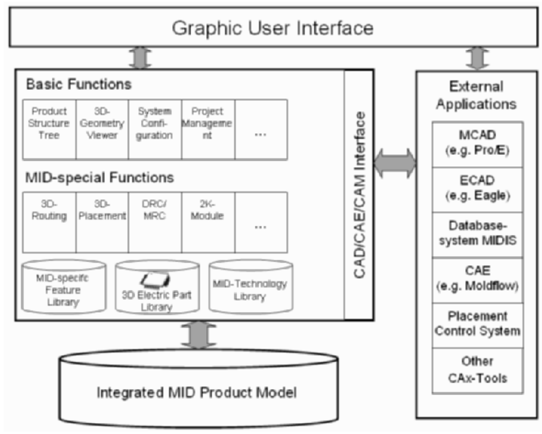

Figure 2 – Architecture of the integrated MIDCAD system.

MIDCAD was developed under the condition to ensure a large freedom of geometrical modelling while at the same time providing an integration of electronic and mechanic functions in one system. The system is based on the commercial 3D-MCAD system Pro/ENGINEER and was developed using Pro/TOOLKIT, which is a full C++ application program interface (API) that allows MIDCAD to communicate directly with Pro/E at the code level. The choice of a 3D-MCAD system as foundation has the advantage that the system can directly use the basic modelling functions and geometrical processing algorithms to build up an integrated design environment for MID products.

The basic functions provide the user with an overview of the product structure in order to facilitate the development of a complex product. By integrating MID-specific functions, the MID design is supported more effectively in MIDCAD than in other CAD systems. Among these special functions, 3D-placement and 3D-routing are essential for MID design. There are different libraries, for example a 3D electronic part library, an MID-specific feature library, an MID technology library and an MID material library available in the system. External applications refer to independent CAx-tools, which are used during the MID design process. These CAx-tools are usually mono-disciplinary and lack the ability to communicate with each other directly. In order to realize an integrated design environment, two conditions have to be fulfilled: integrated modelling for MID products and integration of independent CAx-tools. In MIDCAD, a CAD/CAE/CAM interface to realize the data exchange between MIDCAD and these CAx-tools is developed. MIDCAD also contains an integrated product model in which design- and analysis-related data are stored.

3. THE INTEGRATED MID PRODUCT MODEL

3.1 Conception of an integrated MID product model

Designing products based on MID technology is a complex process and involves interactions between different engineering domains. In this case, the product model has to contain information from the electronics domain such as the data of the circuit diagram as well as information from the mechanics domain, e.g. the geometry model of the circuit carrier. Within the individual domains specialized CAx-systems are often used. In this case, apart from the horizontal integration of the information from different domains (here: MCAD and ECAD), the product model must also vertically integrate the information from the different product development phases (here: CAD and CAE). The concept of the integrated MID product model is shown in Figure 3.

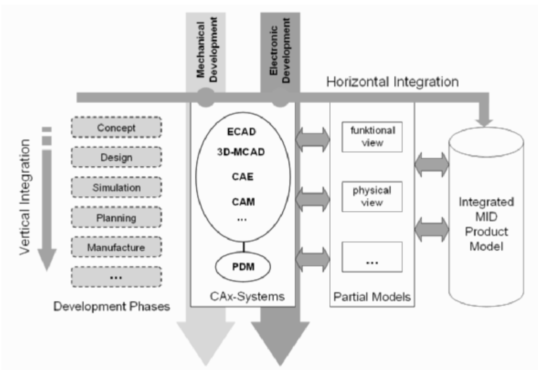

Figure 3 – Concept of an integrated MID product model.

3.2 Horizontal integration of electronic and mechanical information

In order to realize the horizontal integration of electronic and mechanical data, the product model must be composed of two partial models: one for describing the electric circuit and another one for the 3D geometry of the circuit carrier.

For the description of the ECAD and MCAD partial models, the multi-view technology is used to define a physical and a functional view. In the functional model, the data regarding electric circuits, e.g. part list, net list and electronic-referred aspects can be described abstractly. Every physical model can be connected to one functional model; the physical model describes the geometric structure information. This schema and methodology, which is similar to STEP-AP210 (Electronic Assembly, Interconnect and Packaging Design, ISO, 2001), is applied to horizontal integration and forms the basis of the whole integrated product model. In MIDCAD, the application objects of AP210 are used to describe horizontal integration and to create an electromechanical data model.

3.3 Vertical integration of CAD/CAE information

In order to realize the vertical integration of data from different product development phases, the feature technology is applied in MIDCAD. That way, analysis-related data, e.g. material data or boundary condition etc., can be assigned to the corresponding features, and later be used to create a simulation model for the injection molding process.

Definition and type of features for MID products
As the majority of MID products are thin-walled thermoplastic parts, the general feature types can be hierarchically defined (AI-Ashaab, 2003; Deng, 2002), such as wall, hole, boss, rib, round, etc. Wall features form the basis of a plastic part. Hole, rib and boss features belong to the development features, which are developed from wall features. The treatment features include chamfers, rounds and fillets which are used for the treatment of other features.

Furthermore, MID-specific features have been defined to represent some special construction elements that have additional electronic functions coming from the direct electromechanical integration. These specific features behave like electronic components, but they are only geometric structures belonging to the circuit carrier. Therefore, these special features such as vias, connectors, battery holders etc. belong to the component features. Some types of specific features are shown in Figure 4. The specific feature type “via” e.g. consists of a hole through which the electric current can run from one surface to another.

These general and specific features are created and organized using an additional feature tree. The geometry of the features can easily be modified afterwards due to the use of a parametric modelling method.

Application of features for the integration of CAD-CAE data
The features not only contain geometric but also non-geometric information which are called feature attributes. The non-geometric information can be electronic-related data as well as analysis- and manufacturing-related data (Figure 4).

In order to support the simulation of the injection molding process, the feature attribute must contain information needed for later analysis. The part feature contains the analysis-related attributes such as material, constraints, analysis type and the relevant boundary condition and processing condition data.

Once the geometry of the carrier has been created, the general features can be defined by assigning the desired geometry to them, and the geometry of the special features can be automatically created and defined by using the developed feature functions. After the geometry has been defined, non-geometric information relating to these features can also be specified by using the provided user interface. With all the features created or defined and their relevant information specified, the features will be automatically merged into the integrated product model.

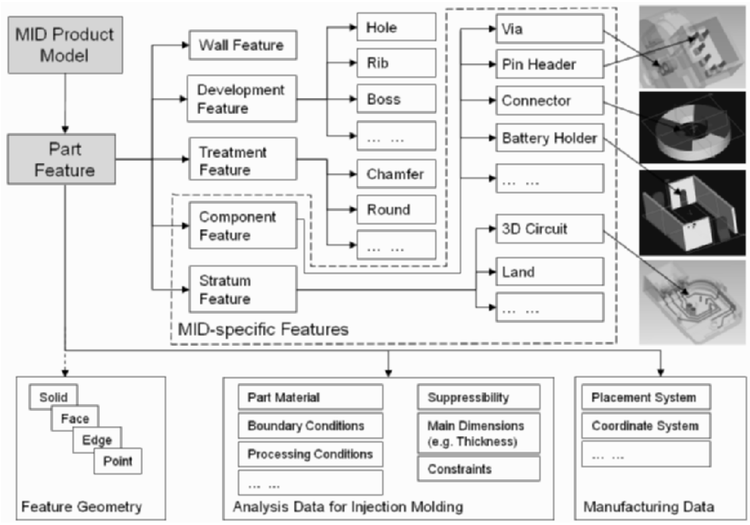

Figure 4 – Types of MID features and integration of CAD-CAE data.

4. MID-RELATED SPECIAL FUNCTIONS

The development and realization of special functions in MIDCAD can greatly facilitate the design process of MID products (Figure 5).

The most important MID design task lies in the placement of the electronic components and the routing of circuits on and/or within the circuit carrier. Therefore, the core functions 3D-routing and 3D-placement in MIDCAD are developed as a substitute for 2D-layout functions in traditional 2D-ECAD systems.

The 3D-placement function has been developed based on the Pro/E-assembly functions and had to be enhanced for the application to MIDs by performing design- and manufacturing rule checks (DRC/MRC) during placement.

Autorouting on traditional 2D multilayer Printed Circuit Boards (PCB) has been well developed since the 70s, but there are still few solutions for 3D automatic routing. Compared to traditional routing, MID-routing has to deal with a more complex geometry. For MIDCAD, new 3D autorouting algorithms (Feldmann, 2003, 2005) were developed and integrated, so that the routing on the surfaces of the circuit carrier will be completed automatically while at the same time the design rules regarding conductor and insulator width are satisfied. Due to the complexity of the 3D MID-design, manual routing, ripup and re-route functions can be used afterwards in order to improve the result.

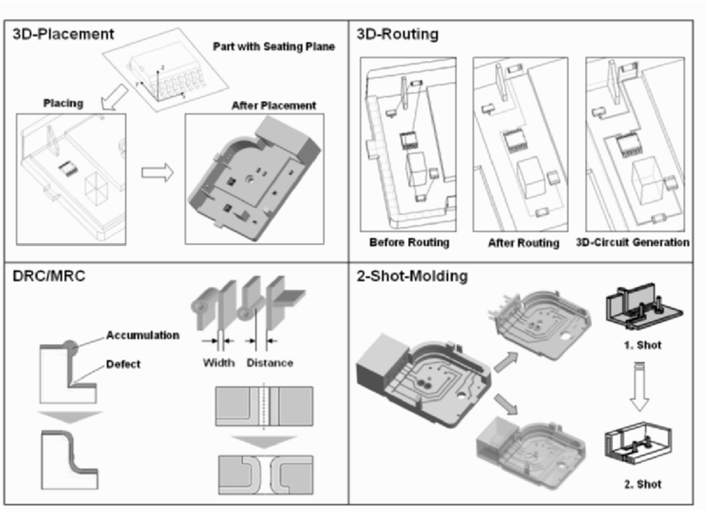

Figure 5 – Specific functions in MIDCAD.

Among the various MID manufacturing processes, 2-shot-molding offers the greatest geometric freedom of design. The term 2-shot-molding refers to the molding of two plastic materials on top of each other (3-D MID, 2004). The 2K-Module is a special function to support the MID-design using 2-shot-molding. Different types of 2-shot-molding can be selected and the cross section of circuits can be defined. Based on the geometry model of the carrier and the routing result of the 3D circuit, the geometry model of the first and the second shot for the mold design are created automatically.

The basic function of the DRC/MRC module is to check the minimum 3D-distance between the electronic components and special features such as tracks, pads, vias etc. According to the selected design or manufacturing rules, DRC/MRCs run automatically by extracting the corresponding data and relationships from the product model.

5. INTEGRATION OF THE SIMULATION OF THE INJECTION MOLDING PROCESS

As most circuit carriers of MID products are thermoplastic, either one- or two-shot-molding is used for manufacturing. By simulating the molding process, moldability and measures of quality can be assured in an early development phase.

To perform the simulation, a special analysis model has to be built from the integrated product model. After the analysis-related information is defined and vertically integrated into the product model, the simulation model can be abstracted.

This involves the derivation of a simplified geometric model and the abstraction of non-geometric analysis-related information, such as gate location etc. Simplifying the geometric model is realized by suppressing non-significant features.

In order to provide an integrated environment for MID product design, the CAE-system "Moldflow Plastics Insight (MPI)" is to be directly connected to MIDCAD. Even though Pro/E already has an integrated module called "Pro/PlasticAdvisor" to simulate the molding process, designers still need to manually generate an analysis model and to specify the analysis-related information. Both systems are in fact connected on a relatively low level. The application programming interface (API) of MPI makes MPI functionality available to external applications like MIDCAD. A special interface is developed based on the API of MPI so that MIDCAD can automatically activate the analysis routines in MPI to run an injection molding simulation. The simulation model with the geometric and non-geometric information can be used directly without extra data or file exchange.

6. CONNECTION TO MID PLACEMENT EQUIPMENT

The development of suitable placement equipment and assembly systems for MID products is mainly affected by the complex geometry of the circuit carrier and the positions of electronic parts. Two alternative specific placement equipments were developed and realized at the author's institute (Krimi, 2001).

The number of electronic components to be placed on the circuit carrier is usually so large that a manual input of the assembly-relevant data would be far too time consuming and too expensive. An automatic generation of manufacturing data and connection to the placement equipment are therefore very important to improve design efficiency and product quality.

Hence, in the 3D part library of MIDCAD the location of the sucking point and a corresponding coordinate system must be defined for every part. Apart from the coordinate system, the seating plane and geometric information of the individual part are also necessary. Based on the 3D-placement the part placement position with respect to the coordinate system of the circuit carrier and placement machine is to be calculated. Then the static collision checking must be carried out to identify potential problems during placement.

After the first static collision check in MIDCAD, the collision-free instruction list from the design view can be provided with the help of the interface between MIDCAD and the control system of the placement machine. Afterwards, the control system processes the part-relevant data together with other machine-relevant data, e.g. mapping file, feeder position etc. Before creating the final collision-free instruction list, a kinematics simulation for dynamic collision checking during assembly can be applied.

7. CONCLUSION

Designing products based on MID technology is a complex process and involves interactions between many engineering domains: electronic circuit, mechanic geometry etc. The design automation and optimization level for MID-products is much less advanced than for many other high-tech products. In order to improve MID design, MIDCAD, an integrated design system for Molded Interconnect Devices is presented and some important techniques for the development of this design system are discussed. MIDCAD contains a series of MID-related special functions, which are not supported by MCAD and ECAD systems now. Apart from these special functions, the development of an integrated product model in MIDCAD is a key task. The integrated product model has been developed based on multiple views, feature modeling and STEP techniques to support not only mechanical and electronic integrated design but also other product development phases. For the design of MID-products, the simulation of the injection molding process is a vital prerequisite to ensure moldability and measures of quality. Based on the product model and developed interface the simulation of the injection molding process could be integrated successfully into MIDCAD to support the concept of design for moldability. A module supporting the connection of MID-specific automatic placement equipment is also developed in MIDCAD in order to be able to accomplish a manufacturing-oriented optimization and to guarantee the manufacturability of MID-products according to the concept of design for manufacturing.

8. REFERENCES

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