engineering change management,
interference analysis
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DETECTION OF ENGINEERING CHANGE INTERFERENCE

The demand of the dynamic global market for higher quality and lower cost products with shorter development lead-time has forced industries to focus on various new product development strategies. The integration of different phases and fields of industrial activities emphasises the interconnection of different technical and management functions within a company by using computer systems from design through manufacture and assembly. The authors' aim was to develop a computer application, which makes possible to analyse geometric-topological interrelations, interdependencies between the components even in the case of complex assembling block (assembled product) consisting of huge amount of assembling components. The realistic "Volume Section Method" – has just been developed by the authors – utilises the global (volumetric) dimensions of the component surfaces. The VSM is capable to map the topological interference with estimating of the realistic intersections or overlaps between the boundary surfaces of the components, following to analyse complex topological interference without requiring more computing time as necessary or/and acceptable for an industry proven application.

1. INTRODUCTION

The recent concurrent engineering and change management teams in the companies are facing first the problems as follows: Globalisation; Increasing competition; Migration from vendor-oriented to customer-oriented market; Numerous product variants; Shorter product innovation cycles; Numerous product versions; Frequent and complex product modifications which have to be efficiently managed. The integration of different phases and fields of industrial activities basically lead through three characteristic strategies, as follows. Lean production strives to minimise the development and administration costs by making organisational and cultural changes with higher employee involvement and optimal exploitation of proprietary knowledge. Simultaneous (in this concept still non-concurrent) engineering focuses on integration of complementary engineering expertise, co-operation of multiple competing perspectives, communication of upstream and downstream product life-

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cycle concerns, and co-ordination of group-problem-solving activities. Other strategies such as virtual design and manufacturing are all trying to address the critical issue of product development productivity in order to the industrial competitiveness.

Although each of the above strategies has somewhat different focuses and approaches, they all share one fundamental requirement: that is the need for advanced information technologies to integrate and co-ordinate various life-cycle considerations during product development activities. A central issue among these needed information technologies is the process-oriented product modelling, which generates an information reservoir of complete product data to support various activities at different product development phases.

The challenge is to first generate process chains (product development workflows, production workflows, maintenance tasks, and administration) for specific products, and then manage the co-operation and integration between process chains (involving different departments and resources, clarifying authorities and responsibilities…) for different products in a company. Even if only one component of a product within the end-product scale has been modified, it is not allowed to neglect the effect of the specific change to the other products and to the work processes or concerning workflow. The biggest challenge for the enterprise level information management (EIM) and one of the most important points of the engineering change management (ECM) is to generate a new integrated product and process development workflow [3][5].

Generating process chains of integrated product development is the principal and most critical task of engineering change management and thus the biggest challenge of the company level workflow management.

2. INTEGRATED PRODUCT DEVELOPMENT PROCESS

The goal of Engineering Change-Workflow Management (ECWM) is developing or helping development of organisational structure and project management in a company strongly influences the information flow and how decisions are made dealing with different product development and product modelling activities. EC-Workfow is a multi-facets subject determined by many complex factors such as human, organisation, product strategy, and available information technology.

Development of an advanced Engineering Change-Workflow Management solution leads through the scopes as follows:

?? development of a fundamental approach to dynamic linking workflow design and execution to product structures to achieve product object-driven workflow management functionality for concurrent engineering

?? the application of autonomous knowledge acquisition techniques to obtain intelligent workflow management functionality for recurrent engineering tasks

?? the implementation of a product-object-driven workflow management tool in terms of bi-directional associative linking of product data and workflow management systems

Engineering Change-Workflow Management in its complete sense, therefore, consists of two interrelated aspects: product development models and workflow development models.

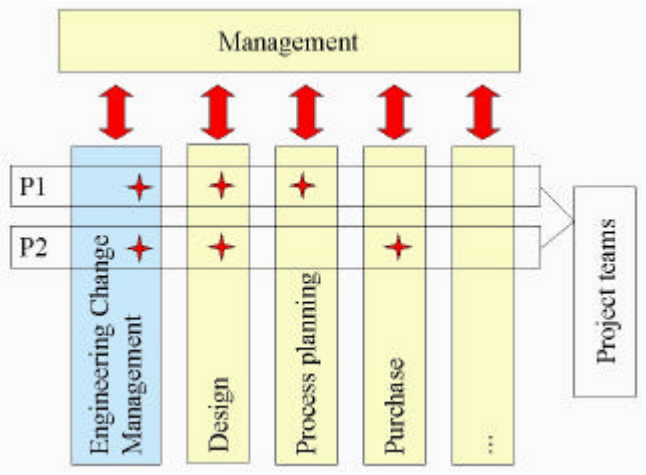

Figure 1 Advanced Engineering Change Management in the Company

Here, the product models and product development are referred to concurrent engineering activities, product modelling, product model databases and their associated management and access algorithms. Process chain and workflow development, which are also commonly referred to as product development workflows or product modelling processes, represent the product modelling processes consisting of a set of technical and management functions required to transfer initial ideas to final products.

One of the most important result from process chains is the product development process and model data.

In recent concept the main phases of an object oriented or product driven Engineering Change Workflow are the followings:

?? Identification of all objects affected by the change

?? Definition of tasks and responsibilities

?? Specification of the order in which the defined tasks have to be executed

?? Control of the change progress and monitoring of the progress

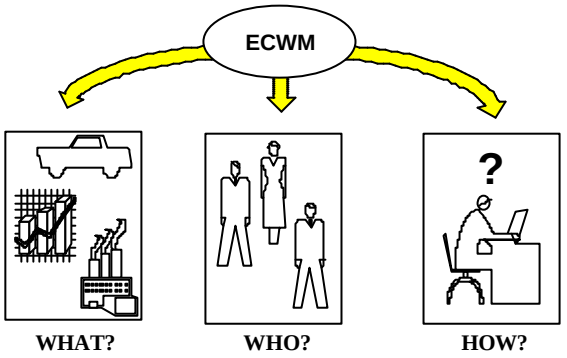

Figure 2 ECWM – Engineering Change-Workflow Management

From the above discussion, it is clear that the proper information technology for product modelling should be able to support product development process chains throughout the product life cycle and store all necessary information as product model data. To be effective and efficient in industrial practice, such a product modelling technology should fulfil the requirements.

Therefore modelling, models and databases of product component interference, analysis of interdependencies influencing the engineering change processes; specification of the type and the way of component attributes affecting each other (as the main scope of this document) can be one of the ***"key-fields"*** of successful *Engineering Change-Workflow Management*.

The initial and – in the same time – critical element of an integrated product development process is to detect the effect of an emergent engineering change request. Which components, documents, production objects or processes (divisions,

participants, …) and how they are affected indirectly by an expectable change - initiated directly by the ECM - on an object (e.g. new component design of a sub-assembling block in a marketable end-product)?

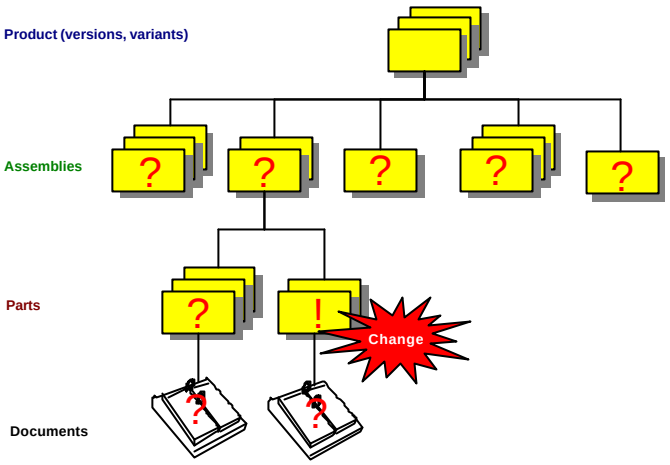

Figure 3 Emergent Object Oriented Engineering Change

Nowadays there are plenty of PDM and WFM systems on the management disposal for handling, sharing and exchanging overall product and concerning process data, but there are rather less and recently weak solutions for mapping the interference and relations between them necessary for really project oriented management [6][7]. Even the state of the art CAD/CAE/CAM systems do not meet the demands of industry and cannot provide industry proven solutions for detection of realistic component interdependencies [2][8].

3. PRODUCT MODEL INTERFERENCE

Geometry and geometric information have a special role in engineering. Indeed, technical drawings, mainly consisting of geometry, are traditionally the primary means of product documentation and communication amongst engineers. Electronic documentation and communication on the basis of geometric modelling techniques have augmented more recently technical drawings. To record the needed geometric information, the various systematic geometry presentation methods and conventions that constitute engineering drafting methods were developed. Eventually these became the *lingua franca* of engineering: Every new generation of engineers was educated to communicate design and manufacturing information in terms of engineering drawings, and these drawing conventions ensured that drawings were produced and interpreted in a uniform and consistent manner.

As the sole means of documentation and communication, technical drawings are unsatisfactory in light of the requirements of agile production. In general, technical drawings require human interpretation, and hence are subject to errors and misinterpretations. They cannot record all aspects of a product that are needed during the various stages of its design and manufacture. The specification of a complex product is split into thousands of individual drawings, the consistency of which is difficult to maintain. The drawings cannot effectively be reused as a resource for the design and manufacture of similar new products.

However, it may not be out of place to survey shortly these – perhaps ‘obsolete’ – technical documents for learning the industry proven requirement and general roles of

handling component interference. On the other hand it should be more relevant benefits to summarise the relations between computerised and the most widespread hand-made documents and graphical illustration of the entire products at the end. Over and above the extension of computer system application in engineering the product component interdependencies in the certain industrial practice are detailed and illustrated by a dozen of traditional documents appearing and prepared on the different levels of production management. These traditional technical documents are the followings: Design structure or product family tree; Exploded assembly structure; General arrangement draw; Shop-draws; Assembly family tree ; Part lists and Bill Of Materials; Operational and handling manuals; etc.

There are several (but mostly ad. hoc.) direct or/and indirect manual detecting methods of component interference at the disposal of industrial engineers and managers. They are applied just at the moment of appearing questions within design or manufacture;

- visualisation of topology connection with making a simply survey of e.g. *exploded assembly structure* and *general arrangement draw*,
- textual directives and prescriptions e.g. either on the *operational* and *handling manuals* or on the *general arrangement* or *shop-draws*,
- standard tolerancing and identification of connecting and joining components,
- engineering process determinate surface integrity parameters (e.g. roughness, accuracy, material structure and the states of heat treatment) that compose essential connections in the engineering workflow belonging to the different components.

The ***exploded structure*** shows the building up of the final product in graphical form. It illustrates the joining units (sub-assembling blocks and components) and generally does not contain textual descriptions, drawing dimensions or any engineering standard symbols. The aim of this 'famous' document is to illustrate positions of the components and the topological structure of the product for helping interpretation of the couple of 2D drawings and textual descriptions.

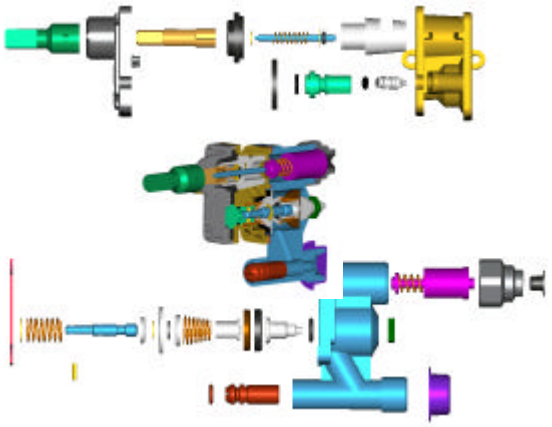

Figure 4 Exploded Assembly Structure of Gas Cock No5340

The ***general arrangement draw*** shows the building up of the final product in 2D graphical form. It illustrates the joining units (sub-assembling blocks and components). It also contains the general dimensions (size and shape), tolerances, part numbers, references and every essential textual directives for production and assembly. It applies the generally used drawing standards. It can contain any fundamental directives for engineering. The *general arrangement draw* is one of the most important and characteristic documents of engineering and production.

The ***design structure*** (*product family tree*) shows the constructional units and levels of an assembled product. The final product consist of several constructional and functional units,

which are built up from building blocks and components such as machine parts, formless and raw materials and other type supplements. A building block itself consists of sub/assembling blocks or/and other composing components providing different levels of the product building structure. The main goal of creating design structure in industrial practice is to clarify the possible product units and considerable existing parallel production processes belonging to various products rather than supplying particular information for the assembling connections.

From the viewpoint of engineering change management we can realise the following benefits with utilising instructions clarified in design structure:

- as all building blocks and components present in this structure (with considerable identification numbers) the levels, stages and number of changes can be recognised at the first glance with comparison of the actual and planned product design structures of the analysed object.
- with using suitable coding system (as it is general in industrial every-day practise) for identification all building units of the product we are able to detect directly the possible connections and similarities of the actual engineering workflow being analysed and the existing processes concerning on other product units or the previous version of the current one.

Following: the design structure provides useful but indirect (mostly virtual) information about the functional and technological connections and interdependencies.

An assembly process can be modelled or described on the bases of the different assembling operations such as handling (storage, positioning, insertion, transporting), composing, checking and special processing. This can be achieved with the aid of block diagrams, symbols and sketches. The ***assembly structure*** (assembling family tree) shows the assembling units and phases of an emergent assembled product.

The main goal of preparing assembling structure in industrial practice is to clarify the possible product phases and process-flow of assembling project. Following; from the assembly structure we can learn the number of the components, some constrains of the topological structure of the total product or partial building blocks (the placement of the components), the scheduling time and sequence of assembling actions and partially the relations between the components.

However, the entire topological or geometric interdependencies cannot be clarified by using the assembly tree structure alone.

4. THE VOLUME SECTION METHOD (VSM)

The authors' aim was to develop a computer application, which makes possible to analyse geometric-topological interrelations, interdependencies between the components even in the case of complex assembling block (assembled product) consisting of huge amount of assembling components. The method - the realistic "Volume Section Method" – had just been developed by the authors utilises the global (volumetric) dimensions of the component surfaces. These oriented (convex and concave) cubic "volume sections" as the base data of

computing are used to map the topological interference with estimating of the realistic intersections or overlaps between the boundary surfaces of the components. The method is capable to examine complex topological interference without requiring more computing time as necessary or/and acceptable by an industry proven application [9].

4.1. CONCEPT (OF COMPONENT INTERFERENCE BY VSM)

As a special implementation of the prototype algorithm the computer program is based on a specific (but most usual) interface of the Pro/Engineer© system, which is the NEUTRAL interface format. This interface format contains directly the maximal dimensions and positions of the components in the assembling object model. As the figure shows the framing dimensions determine the oriented volume sections which compose simplified but computable models of the parts, sub-assembling blocks and the assembled product itself.

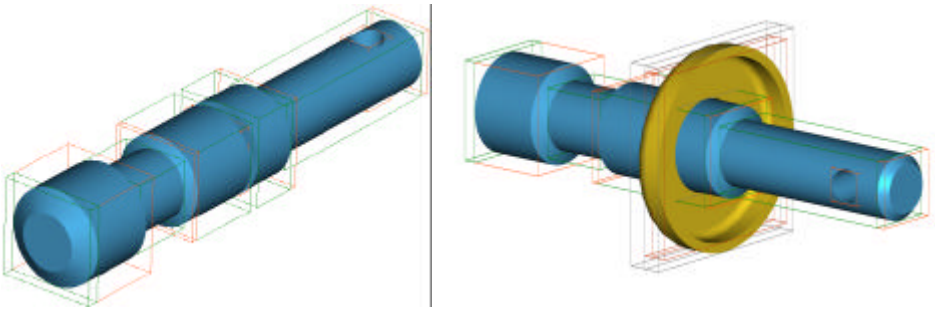

Figure 5 Characteristic volume (sections)

The emergent overlaps, intersection or/and distances between the volume sections approximating the model elements describe the geometric and topological connections of the assembling components. More differentiated but even still applicable model can be defined by distinguishing of concave and convex volume sections in the original model. In fact it increases the usability and advantage of NEUTRAL interface that contains a specific flag signing the orientation of the framing volumes (being convex or concave). Therefore a concave cylindrical surface having got negative orientation flag in the NEUTRAL file can be handled as a hole in the analysis. The “volume section method” provides the overlap dimensions (if it has) or distance (if there is not overlap) and so connection between the two elements, thus between two assembling components containing the surfaces.

4.2. ANALYSIS (OF COMPONENT INTERFERENCE BY VSM)

Different types of analysis can help the detection of topological connections in an object model depending on the aim and tools of detection. The most important and frequent events of topological detection are as follows:

?? **Intersection analysis**: Mapping of virtual or real component intersections is the main goal of topological/geometrical analysis. Although the analysis of component

intersection by VSM - with using cubic (rectangular) boxes - is based on similar simplification of complex component geometry like in the recent accessible software tools on the commercial market, it provides more detailed and realistic results for topological component interdependencies. The main advantage of VSM is that it utilises local surface level segmentation instead of using global component level approximating boxes for each models of the entire assembly.

- **Empty space analysis**: Special analysis for detection of suitable gaps or empty spaces for additional planned component being assembled into the product model in the future. In the VSM method that means the pivot (questioned) component is virtual, represented by a simple cubic volume defined by diagonal corner point co-ordinates. The future development of the method is to extend input variables with non-positioned virtual components, for that the analysis can provide all possible gaps and place (so position) in a complex assembly.
- **Finite space analysis**: This kind analysis is pointing out a prismatic element of the global prism/box of the total assembly model instead of questioning any "real" model component. The result of detection is the identification of connected components with the questioned/pointed finite space element. The main advantage of this – quasi-finite element - analysis is the opportunity to increase optionally the accuracy of detection with increasing number of elements.
- **Searching of the nearest neighbour(s)**: The goal of detection is to clarify the neighbours of the actual component in a prescribed distance field around the specified component. The VSM provides the nearest neighbours within given interpretation or tolerance field for the specific component

4.3. DETECTION ALGORITHMS BY VSM

Considering the content of input and output data of Volume Section Method – detailed in [9] – we have got at least four application ways;

- Part level i/o object (e.g.: part, purchased block, sub-assembling block)
- Feature level i/o object (e.g.: feature, macro-component, connected surface group)
- Geometric component level i/o object (e.g.: surfaces, curves, edges, points)
- Parameter level i/o object (e.g.: geometric dimension, dimensional-chain element)

The interference analysis starts with loading and interpretation of the whole assembling model with all components. It defines and allocates first the simplified model building up from elemental and oriented volume sections. Afterward, depending on the aim of analysis, the connections between a specific and all other components are mapped with taking account a tolerance factor as well. This tolerance factor can be null (zero increase) modelling the real connections (contacts) between the components. The positive tolerance supposes additional material around the frames or positive change of dimensions in case of convex surfaces and opposite in the case of concave ones. In such way the negative tolerance supposes removed material around the frames or negative change of dimensions in case of convex surfaces and

opposite in the case of concave. The algorithm provi des the list of components having overlaps with or being closer than the predefined tolerance to the specific (questioned) components. This way it is possible to estimate the effect of an emergent engineering change request pointing on a component with the “Volume Section Method” providing the affected components within a predefined tolerance field.

5. ENGINEERING CHANGE-WORKFLOW MANAGEMENT

An efficient (i.e. advanced) Engineering Change-Workflow Management Process can only be achieved and managed with the help of a well-structured database.

Depending on the content and characteristics (i.e. different filling up process leads to different data context in the database) of the database there are at least two different ECW determination process (Figure 6) realisation possibilities; ad.hoc. analysis based on “in-process” or quasi knowledge based “stand-alone” ECWM.:

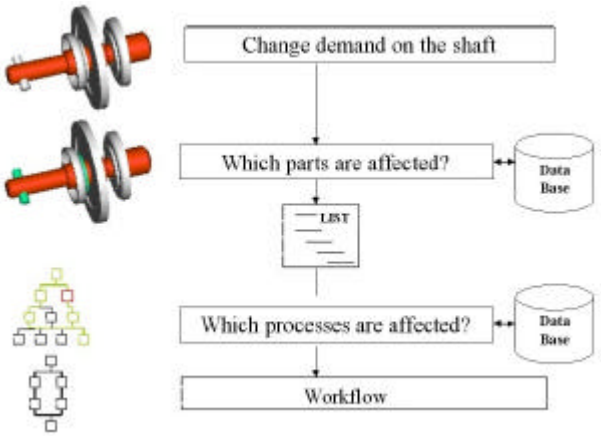

Figure 6 Engineering Change Workflow determination process based on component interference

?? in first case; the interference analysis must be made when determining the list of affected parts. Certainly, the results of the actual analysis can be stored in an entire database for near applications. In this case the database can be interpreted as quasi handling or utilising process independent knowledge base helping any kind ECWM process in the future (“stand-alone”).

?? in second case; the affected components can be determined directly from the database without applying interference analysis, except for the events if the concerning fields of the database are empty or not complete, or in order to achieve process dependent result instead of the general one. In this case the database can be interpreted as simple - process independent - database helping“ in-process” the current ECWM process.

6. CONCLUSION

The companies - producing complex marketable products consisting of huge amount of components and various end-product structures - are not allowed to avoid of advanced engineering change workflow management (ECWM). Time-compressive enhancement of the

engineering changes is essential factor of the company effectiveness. However, automation of ECWM still leads through some difficulties and troubles in industry.

In this paper the authors tried to summarise the causes, sources and initial points of integrated product development and engineering change and workflow management. The paper emphasises that the starting point of a computer system based ECWM should be the exact and efficient detection of the product component interference. The volume section method – has just been developed by the authors – as a mere mean of analysis can give a chance for detection of the interrelations and interdependencies between the CAD model components, and still in the design phase of the engineering change management.

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