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COMPUTER INTEGRATED DEVELOPMENT OF PROCESSES AND ASSEMBLY SYSTEMS

KOMPUTEROWO ZINTEGROWANY ROZWÓJ PROCESU I SYSTEMU MONTAŻOWEGO

Abstract

The paper presents the trends in the development of methods and systems for assembly process planning on the background of Concurrent Engineering strategies. The solutions for the functional integration of design/manufacturing and production preparation are proposed. The concept and the example of integrated process and assembly system planning in PLM (Product Lifecycle Management) environment are presented.

Keywords: *Concurrent Engineering*, *process/assembly system integration*, *PLM*

Streszczenie

Artykuł przedstawia kierunki w rozwoju metod i systemów komputerowego wspomagania dla projektowania procesów montażu zgodnie ze strategią inżynierii współbieżnej. Prezentowane są rozwiązania dla funkcjonalnej integracji faz konstrukcyjnego, technologicznego i organizacyjnego przygotowania produkcji. Przedstawiono także koncepcję i przykład zintegrowanego projektowania procesu i systemu montażowego w środowisku PLM.

Słowa kluczowe: *Inżynieria współbieżna*, *proces/system montażu*, *integracja*, *PLM*

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1. Introduction

According to the new development strategies, the product development focuses on as much as possible parallel execution of all development related product life cycle phases, thus creating CE (Concurrent Engineering) approach. CE strategy assumes the development of resources and production facilities at the early product design phases to shorten the production start-up time. The key condition for the effective concurrent engineering is the computer integrated environment of design and manufacturing – the common platform for computer aided systems for the product development.

2. Integrated process and assembly systems development

Features of modern development strategies indicate the need for product development phase integration.

Integration and parallel execution of activities were received through the separation of the conceptual design stages, allowing for the creation of the variant solutions Fig. 1. Variants are then evaluated in the view of the requirements of the next development phase The selected variant fulfilling the established criteria is next further developed in the detail design stage [3].

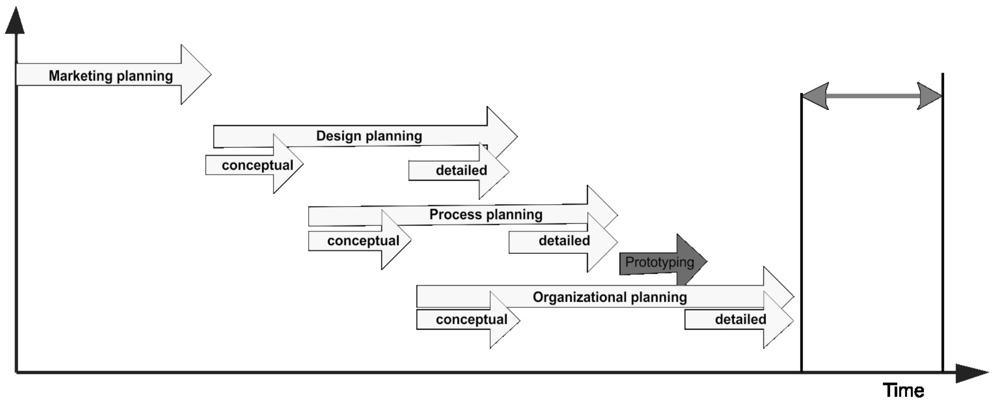

Fig. 1. Parallel execution of product development phases
Rys. 1. Równoległa realizacja faz rozwoju wyrobów

The Product is created in design planning phase. The result of the designer work is the design structure of the product.The product design represented in the digital form in CAD system is the base for making engineering calculations, dynamic, static and kinematic analysis.

The integrations of process and assembly system development suggests the separation of the following phases:
– conceptual process planning phase,
– detailed process planning phase.

The integrations of manufacturing and organization product development suggests the separation of the following phases:

– conceptual production organization planning phase,
– detailed production organization planning phase.

2.1. Conceptual process planning stage

The assembly process is created on the basis of the digital product model prepared with CAD system. The process planning activities includes:
– development of the product assembly structure – separation of the assembly units (assemblies, subassemblies and parts),
– development of the assembly process plan including the basic parts for separated assembly units, methods and hierarchical order of assembly of these units to receive the design features of the product,
– mounting of subassemblies, assembles and parts based on the developed assembly plan,
– assembleability analysis of the product and for iterative improvement of the design form in view of the assembly requirements.

Design form of the product is the base for the determination of the assembly product structure:

$$SM = \{JM_R \{JM_{R-1}\{JM_{R-2\ldots}\ JM_1\}\}\},$$

where:

R – level of product decomposition on assembly units,
JM – assembly unit.

In the set of assembly units on M level, the following elements can be separated:
– assembly aggregates which can be further decomposed into the lower aggregates,
– elementary part which can't be further decomposed.

So the product in the term of its assembly can be described as:

$$WRM = \langle SM, WM, \beta \rangle,$$

where:

SM – assembly product structure,
WM – set of assembly constraints,
β – mapping on the set of assembly units.

$$\beta: JM \times JM \rightarrow WM$$

In the set of assembly units on R level, the following elements can be separated:
– assembly aggregates which can be further decomposed into the lower aggregates,
– elementary part which can not be further decomposed.

The assembly form of the product represented in digital form in CAD system is the base for making assembly simulation of the product.

The product assembly structures is the base for the determination of the assembly sequences. The determined sequence of connection of assembly units, presented as a graphical assembly plan is the base for the definition of the assembly tasks and their characteristics. On the set of assembly tasks, the graph GOK can be describing:

$$GOK = \langle ZM, RK, \mu \rangle,$$

where:

ZM – set of assembly tasks – ZM = {ZM_i}, $i = 1, \ldots, n$,

RK – set of precedence relations,

μ – mapping on the set of assembly tasks.

$$\mu : ZM \times ZM \rightarrow \boldsymbol{RK}$$

Precedence relation can be described by the matrix $\boldsymbol{RK}\,[rk_{i,j}]_{n\times n}$ $i, j = 1, \ldots, n$

$$rk = \begin{cases} 1 - \text{when task i precedes task } j \\ 0 - \text{in the other case} \end{cases}$$

The multivariant nature of the assembly processes is due to the possibility to use several assembly sequences with the application of methods and manufacturing means and different automation levels. On the base of the defined variants of manufacturing/ assembly processes, the manufacturability analysis DFM and assembleability analysis DFA are carried out [4]. The results of the subsequent iterations are used to simplify the product design (by minimization of the number of parts and the integration of parts), thus decreasing the time and costs of the assembly and to estimate the times and costs for different manufacturing methods of constituent product elements.

DFA classify the degree of difficulty of assembly actions and uses it for the determination of the assembly time of all assembly task T_i. The time determined by DFA methodology results from the classification of design features influencing the execution of assembly actions. On this planning stage, it is possible to evaluate the total product assembly time T_a.

The product design resulting form the subsequent iterations and its assembly plan form the base for defining the graph of the assembly activities, representing the admissible variants of the execution of product assembly.

2.2. Conceptual production organization planning stage

The conceptual organization stage is used to select the appropriate form of the production organization, production pace, and for the initial calculation of the number and type of functional subsystems. On this stage, also the type and organizational form of assembly system are selected.

The determined number and type of functional subsystems are the base for the initial organization calculations. For calculate cycle time T_s are required production volume P and the allowable production time T_p.

$$T_s = \frac{T_p}{P}$$

The conceptual process planning outcomes:

- information about all tasks which need to be done within process ZM,
- duration of their execution T_i and precedence relations RK,
- total duration time for all tasks.

Based on these data, the theoretical, minimal number of stands can be calculated using the equations:

$$LS_{\min} = \frac{\sum_{n=1}^{n} T_i}{T_s}$$

where:

T_i – time needed to complete i[th] task,

n – number of assembly tasks.

Taking into account the precedence relation RK on the set of assembly tasks, the tasks can be preliminary assigned to work stands. It should be noted, that no assembly task can belong to two separate sets, because the same assembly task can't be executed on two assembly stands, i.e.:

$$ZM_{\mu} \neq ZM_m$$

Completeness of assembly is described by condition:

$$\bigcup_{m=1}^{m=M} ZM_m = ZM$$

To obtain this, all operations shall be grouped into M sets creating the assembly stands in manufacturing line. If the duration of the executed planning tasks is greater from the production pace, parallel stands need to be placed to synchronize the flow. The number of stands is calculated by dividing the duration of the operations be the mean production pace and rounding to the whole units.

$$L_s = \frac{T_i}{T_s}$$

The outcome of these actions is the conceptual assembly system forming the base for the subsequent detailed process planning.

2.3. Detailed process planning stage

The selected type, organizational form of the assembly and the graphical product assembly plan are the basis for the detailed assembly process planning. The design actions on the detailed process planning phase cover the series of activities leading to the development of assembly operations. The result of these actions is the set of actions executed in the system and the assembly process plan structure including assembly, transport and control operations.

The determined assembly process plan is the base for the selection of the organization variant of the manufacturing stands and for the detailed organization planning including the creation of the digital model of assembly system and the time normalization of assembly operation.

2.4. Detailed production organization planning stage

The selected structure of the assembly process and the determined duration times of assembly activities covered by the operations are the base for the synchronization within the isolated assembly subsystem. For analyzed production organization forms, for example production lines, these steps include the recalculation of the number of stands and line balancing.

Line balancing problem [13]can be formulated as:

There is the set of assembly tasks initially assigned to the assembly stands

$$\bigcup_{m=1}^{m=M} ZM_m = ZM$$

with the given times of execution assembly task on m = 1,…, M stands given by vector:

$$T = [T_i],\ I = 1, 2, \ldots, n$$

Line balancing problem shall consider the precedence and location constraints. Precedence constraints for the operations are described by matrix *RK*:

If the production pace fulfills the condition:

$$\max_{1 \le i \le n} T_i \le T_c \le \sum_{i=1}^{n} T_i$$

and time restriction:

$$\forall_{1 \le m \le M} \sum_{ZM_i \in ZM} T_i \le T_c$$

it is possible to determine the shortest and the longest time between the start of the given operation and the end of the other. Line balancing problem can be brought down to the problem of the determination of the working stand for the given subset of operations so, to fulfill the criteria of the minimization of the idle time of the assembly line:

$$Q = \sum_{m=1}^{M} \left(c - \sum_{ZM_i \in ZM} T_i \right) \to \min$$

where:

M – set of assembly stands,

ZM_m – subset of assembly tasks assigned to the assembly stand.

It can be noted, the minimization of the idle time means the minimization of the number of stands on the assembly line. So formulated problem shows that the line balancing is the multi-stage decision process. It is also the process dynamically changing with the time. The number of allowable subsets of operations crated on given decision stage fulfilling the precedence criteria depends on the operation duration time T_i and the length of production pace T_c.

The change in the assignment of tasks to the assembly stands necessitates the re-design of assembly stands and the re-calculation of the assembly times. The subsequent iterations improve the assembly system.

The outcome of the detailed production organization stage is the digital model of the manufacturing system linking all the components of the assembly system with assembly process plan stored in library and process schedule. The further test on simulation model are used to analyze and improve the system being developed.

3. Verification

The verification was done with PLM solutions offered by Dassault Systemes. These solutions include the following systems:
1. CAD/CAM CATIA for product, manufacturing process and resource design
2. MPM DELMIA for process and manufacturing system design [10].

Especially important was the use of Process Engineer, part of MPM DELMIA solution. It is a database application, grouping all production preparation process elements, including the products, manufacturing processes and the manufacturing resources. Results execution of design activity in Process Engineer presents [3].

4. Conclusions

The proposed methodology of concurrent development of products, processes and manufacturing systems using such PLM tools like CATIA and DELMIA increases the integration of the technical production preparation phases and covers various planning actions, including the ones executed with the computer systems like Design For Manufacturing (DFM) analysis, Design for Assembly (DFA) analysis, Computer Aided Assembly Process Planning (CAAP), MTM time analysis, ergonomic analysis and line balancing.

Nevertheless it should be noted the PLM solutions are only the tools speeding up the organizational and process planning stages of production preparation. The key condition to receive the good results are high qualifications of designer, process planners and manufacturing organization engineers developing the system components.

Additional research works are required especially for the conceptual and detailed production organization planning phases. Suggestions for the order of design actions depending on the characteristics of the process and manufacturing system shall be elaborated. Especially promising is the use of the Artificial Engineering (AI) techniques for the initial estimation of the manufacturing concepts. Nevertheless, despite the huge number of advanced computer systems for various production preparation phases, the most important decisions are still taken by experts.

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