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The Construction of Assembly semantic model AHGD-F Based on Functional Components and the Analysis of Polychromatic Assembly Compatibility

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Abstract:

With the rapid development of intelligent manufacturing, the data demand of assembly planning for product model tends to be diversified, standardized and accurate. Assembly model is the key to the expression of assembly semantics. The assembly hybrid G-diagram (AHGD), a model containing the semantics of assembly linkage and assembly priority relationship and capable of data transformation, is constructed based on the assembly structure of the product. From the perspective of part attributes, the functional parts are regarded as the main nodes of the assembly semantic model combined with the star topology to construct the assembly hybrid G-diagram based on functional parts (AHGD-F), which provides a visual model and data basis for subsequent intelligent planning under the premise of ensuring product functions. The assembly compatibility of AHGD-F model is analyzed by multicolor principle, so as to meet the requirements of assembly feasibility and ensure the functionality of assembly semantic model. The assembly semantic expression of AHGD-F model is verified by milling fixture, and the multi-color assembly compatibility analysis is carried out to provide effective assembly semantic verification for subsequent assembly sequences. The construction of visual assembly semantic model can clearly reflect the assembly relationship of product parts. The mapping and conversion of model and data provide reference and data information for later intelligent assembly, which can effectively reduce the error probability of assembly relationship data input.

***Keywords**: Assembly semantic model, AHGD-F, Polychromatic principle, Assembly compatibility analysis.*

I. INTRODUCTION

As a data source for complex products, 3D assembly models involve a wide range of information sources with characteristics of multiple sources, strong geometric correlation, expression uncertainty, and retrieval diversity[1]. In the background of digital design widely used, with the increasing complexity of structures, a large number of 3D assembly models rely on human integration of relevant information to

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meet the reuse of product information has appeared structural information irregularities, missing information, cumbersome updates and other problems. Therefore, the construction of digital models incorporating assembly information has become a hot spot for research.

Assembly model is the carrier to meet the needs of the product, and the realization of product function requires the collaborative completion of parts after assembly. The assembly relationship between parts reflects the flow relationship during the assembly process. Therefore, using assembly semantics which is more convenient for product design to describe the assembly relationship between components is more conducive to the interaction and simulation of virtual assembly[2].

Assembly semantics is an abstract description of the assembly relationship and assembly process information between the assembly structure of product parts, where the assembly relationship covers the assembly sequence, following rules and other characteristics. The description process of assembly semantics is object-oriented in nature, and the reuse of knowledge is achieved by integrating structural and assembly constraints in engineering.

As an effective information to describe the assembly relationship between product components, assembly semantics need to provide sufficient information sources for virtual assembly planning. Therefore, product information model based on assembly semantics should have the following conditions:

(1) Assembly semantics should cover sufficient constraint information to meet the generation of assembly sequences in virtual environment ; can accurately identify assembly interference conditions ; accurately determine the assembly relationship of assembly parts when the assembly structure is satisfied ; it can realize automatic reasoning to judge the rationality of assembly sequence and effectively avoid wrong assembly sequence.

(2) The ultimate goal is to obtain product assembly specification. Therefore, the accuracy of assembly semantics covering information must be ensured. The difference of assembly semantics and the change of assembly relationship mapping each other directly affect the subsequent assembly planning.

(3) Assembly semantics should be as concise as possible to avoid being too complex and facilitate data integration in different information environments.

It is not difficult to find that there are mainly three types of assembly models currently used : relational model[3], hierarchical model[4] and model-based definition (MBD)[5]. The relationship model takes graph theory as the framework to express the relationship between assembly parts concisely and intuitively, but the assembly system is not clear, the expression is limited to inertial thinking, and the difficulty increases sharply when there are too many parts. Most of the hierarchical models are top-down with tree structure, which meets the inertia thinking of the public. It is easier to reflect the assembly structure system, clarify the assembly tomography, and effectively decompose the assembly difficulty. Of course, relatively speaking, the assembly relationship of parts is fuzzy, the assembly constraints at the same level cannot be

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intuitively reflected, and the subassembly division criteria are not clear. The representation object based on MBD model is clear and definite, but it often belongs to special construction. The application criterion, division principle and universality are not strong, and it belongs to one object and one rule.

Therefore, taking the product 3D assembly geometry model as the research object, the visual information model which can fuse assembly semantics is explored. With assembly semantics and graph theory as the framework, the requirements of assembly structure semantics and set constraints are met, and the assembly relationship between parts is effectively expressed. Combined with the mathematical matrix transformation characteristics of the graph, the assembly semantic information model--assembly hybrid G-diagram (AHGD) is constructed with star topology structure. Further refinement of part attribute definition function parts as the main node to ensure product functionality, multi-color principle analysis of assembly compatibility to meet subsequent assembly requirements.

II. MATERIALS AND METHODS

2.1 Mapping of Assembly Semantics and Graph Theory Model

As the description subject of structure relation in assembly model, assembly semantics mostly appear in words[6]. The most intuitive visualization of assembly relationship is the assembly topology model. Assembling topological structure is to embody the connection relationship of parts by topological graph model. At the same time, the conversion of topology and matrix can synchronously meet the needs of later data.

When constructing the topological structure of assembly with graph theory model[7], it is often necessary to meet the mapping definition from assembly semantics to model. Common mapping relationships are described below.

When the assembly structure is combined with the graph theory model, nodes usually represent parts. The nodes are connected by an undirected edge, and the undirected edge represents the assembly relationship between components, and the assembly undirected topology diagram can be obtained. The nodes are connected by directed edges, and the directed edges represent the assembly priority constraint, so the directed topological structure of assembly can be obtained.

In the assembly topology diagram, the degree of undirected edges of nodes is the number of other components connected by components. The path generated by nodes and edges alternately represents the assembly relationship between different parts by undirected edge connection, and the assembly priority constraint of different parts is expressed by directed edge connection. The path satisfying the assembly priority constraint relationship is a assembly sequence of corresponding parts.

In the assembly topology diagram, due to the alternate connection between nodes and edges, the starting point and end point of the path are different, and the nodes are not repeated to meet the assembly

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sequencing requirements of parts. The topological structure graph containing assembly semantics constructed by undirected edges should be a connected graph, in which the end part with degree 1 is included, but there should be no node part with degree 0.

2.2 Assembly Hybrid G-Diagram (AHGD)

2.2.1 Basic elements for building models

Assembly information model is a mathematical model that integrates assembly information and provides information basis for subsequent work. The assembly model based on graph theory needs to reflect the assembly relationship and constraint relationship of parts in the form of graph. At the same time, the assembly model based on graph theory enables the assembly information to be understood intuitively and also ensures the effective intelligent recognition data of computer. Modeling based on graph theory is mainly directed graph and undirected graph.

The undirected graph constructs a binary group $\langle V,E \rangle$ by node set ***V*** and edge set ***E***, $V=(v_1,v_2,\cdots,v_n)$ represents the assembly part set, ***n*** is the number of parts ; $E=(e_1,e_2,\cdots,e_m)$ represents the set of constraint relations between parts nodes, but there is no specific direction, and ***m*** is the number of edges.

The directed graph is constructed by node set ***V*** and edge set ***DE*** as binary group $\langle V,DE \rangle$, $V=(v_1,v_2,\cdots,v_n)$ represents assembly parts set, ***n*** is the number of parts ; $DE=(d_1,d_2,\cdots,d_k)$ representing the direction constraint relationship between parts nodes, ***k*** is the number of edges.

Three basic definitions of elements involved in building a graph model are as follows:

(1) Node: Each node represents a component in the assembly structure.

(2) Undirected edge: the undirected edge connecting the two nodes represents the assembly connection relationship between the corresponding two parts. No matter thread connection, bolt connection or welding, assembly semantics can be simplified as undirected edges.

(3) Directed edge: to add arrows on the basis of undirected edge and increase directional constraint. The directed edges between two nodes represent the assembly precedence constraints between the corresponding two components. The assembly priority constraint relationship can also be divided into contact and non-contact. Non-contact assembly priority constraint refers to the existence of one part which makes another part unable to install, but there is no assembly connection between them.

The schematic diagram of the above three elements is shown in 0. The number of components is marked in the circle representing the components node in 0.

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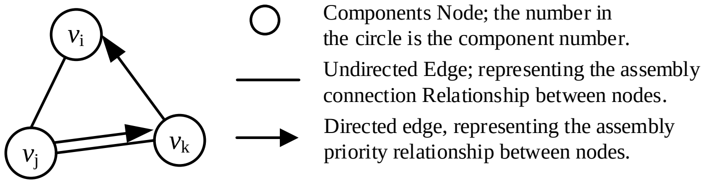

Fig 1: Basic elements for building models

2.2.2 Assembly Hybrid G-diagram (AHGD)

Combining directed graph and undirected graph in graph theory, the assembly model--assembly hybrid G-diagram is constructed by star topology structure[8]. The assembly hybrid G-diagram model can simultaneously reflect different logical relationships, and can intuitively reflect the assembly connection relationship and assembly priority relationship of components. Directed graph cannot be closed loop because of assembly priority constraint semantics, while undirected graph adopts star topology to facilitate identification of terminal parts and avoid invalid assembly sequence.

The construction of assembly hybrid G-diagram model can meet the needs of clearly expressing assembly structure, assembly connection relationship and assembly priority relationship semantics. The nodes in the assembly hybrid G-diagram represent the components, and the directed edges and undirected edges represent the assembly connection relationship and assembly priority relationship semantics between components, respectively. Nodes only represent the ontology of components, and their size, shape, material and other related information are not reflected in the model.

Assembly Hybrid G-diagram (AHGD) is defined as the graph theory model of the mixed connection nodes of directed and undirected edges which represent assembly semantics. The mathematical model is expressed as: $G=(V,E,DE)$. ***G*** represents assembly mix graph. ***V*** is the set of nodes, representing the components of the assembly model. ***E*** is an undirected edge, representing an assembly connection between the two parts. ***DE*** is a directed edge, which represents the assembly priority relationship between the two parts. Build a simple AHGD model schematic as shown in 0, where the parts are identified by number $V_i\,(i=1,2,3,4,5,6,7)$. In the figure, nodes $\mathbf{V_3}$ to $\mathbf{V_4}$ are undirected edges, indicating that there is an assembly connection between parts $\mathbf{V_3}$ and $\mathbf{V_4}$. Node $\mathbf{V_1}$ to $\mathbf{V_3}$ are directed edges, indicating that component $\mathbf{V_1}$ must be assembled before $\mathbf{V_3}$. There may be assembly connection and assembly priority between parts, such as component $\mathbf{V_5}$ and $\mathbf{V_6}$, $\mathbf{V_6}$ and $\mathbf{V_7}$; there may be only a single assembly connection relationship or assembly priority relationship, such as component $\mathbf{V_1}$ and $\mathbf{V_4}$, $\mathbf{V_2}$ and $\mathbf{V_3}$; there may also be assembly priority relations between parts without connection.

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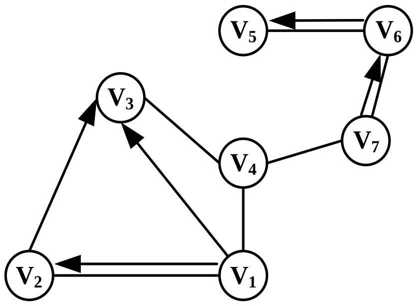

Fig 2: Schematic diagram of AHGD model

The assembly with relatively simple structure can intuitively obtain the assembly connection semantics and the corresponding assembly sequence according to the AHGD model. Once the number of parts is too large, the structure is complex, and the mapping and extraction of assembly semantics between parts are easy to make mistakes with only graphics. Therefore, using matrix to describe AHGD can realize the mathematical conversion between product parts, which is convenient for later calculation and automatic extraction.

When constructing the AHGD model according to the assembly, there are mixed connection nodes of directed and undirected edges. In order to clarify the semantic expression of assembly relationship, AHGD model $G=(V,E,DE)$ can be divided into undirected graph $G1=(V,E)$ representing assembly connection relationship of parts and directed graph $G2=(V,DE)$ representing assembly priority relationship of parts. Assume that the assembly model contains ***n*** parts, AHGD model contains ***n*** nodes. The split ***G1*** and ***G2*** also contain ***n*** nodes. ***G1*** and ***G2*** can be defined by two ***n***-dimensional matrices, respectively.

Defining matrix:

$$\boldsymbol{G1}=\left[\mathrm{e}_{ij}\right]=\begin{bmatrix} e_{11} & & \cdots & & e_{1n} \\ & \ddots & & & \\ \vdots & & e_{ij} & & \vdots \\ & & & \ddots & \\ e_{n1} & & \cdots & & e_{nn} \end{bmatrix} \tag{1}$$

Represents the assembly connection between component ***i*** and component ***j***, where ***n*** is the total number of components. $e_{ij}=0$ indicates that component ***i*** have no assembly connection with component ***j***; $e_{ij}=1$ indicates that component ***i*** has assembly connection with component ***j***; when $i=j$, $e_{ij}=0$. Component ***i*** and component ***j*** are assembly connections, so ***G1*** is a symmetric matrix of order ***n***.

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Defining matrix:

$$\boldsymbol{G2}=\left[\mathrm{d}_{ij}\right]=\begin{bmatrix} d_{11} & \cdots & d_{1n} \\ & \ddots & \\ \vdots & d_{ij} & \vdots \\ & \ddots & \\ d_{n1} & \cdots & d_{nn} \end{bmatrix} \tag{2}$$

Represents the assembly priority relationship between component ***i*** and component ***j***. ***n*** is the total number of parts. d_{ij}=0 indicates that there is no assembly priority constraint relationship between component ***i*** and component ***j***; d_{ij}=1 indicates that component ***j*** must be assembled before component ***i***; when $i=j$, $d_{ij}=0$. Part ***i*** has precedence relation with part ***j*** assembly, so ***G2*** is an asymmetric matrix of order ***n***.

Taking the model constructed in 0 as an example, the assembly connection matrix ***G1*** and assembly priority matrix ***G2*** are:

$$\boldsymbol{G1}=\left[e_{ij}\right]=\begin{bmatrix} 0 & 1 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 1 & 0 \end{bmatrix} \qquad \boldsymbol{G2}=\left[d_{ij}\right]=\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

2.3 Assembly Hybrid G-Diagram Based on Functional Components (AHGD-F)

2.3.1 Component attribute classification and definition

In product-oriented assembly planning, priority should be given to ensure product functionality and practicality. Therefore, the product parts in the planning will also consider its functional properties of the corresponding process planning and arrangement[9]. As the information model of products, AHGD model not only needs the support of bearing function but also meets the needs of assembly relationship. From the perspective of parts, the establishment of information model and the expression of assembly relationship are closely related to parts. Therefore, in order to ensure the function and assembly constraint relationship of product assembly model, it can be divided into two types according to the functional attributes of parts: functional parts and connectors.

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The Assembly Hybrid G-diagram Based on Functional Components (AHGD-F) is connected with each other by functional parts as the central node. Each central node radiates outward to connect with the connector by star topology structure. The overall model is based on functional parts. The assembly semantics of functional parts are given priority to, and the product efficiency is effectively guaranteed. The connector is considered as an auxiliary structure. Functional parts and connectors are complementary to each other in the assembly structure. Functional information and assembly relations are involved in product-oriented information modeling. The corresponding definitions are described below.

(1) Functional components

Parts with functional characteristics in product structure can achieve certain functions.

(2) Connectors

The parts used to limit the position and freedom of the auxiliary function parts in the product structure are limited to the role of auxiliary connection and spatial positioning, and are not directly related to the product function. There are not only standard connectors, but also special connectors that are not directly related to the product function structure.

(3) Basic components

It is the functional part with the most complex assembly relationship as the assembly core in the product. It occupies an important position in the assembly space and can affect the assembly of most parts in the product.

Mechanical products as a whole need to have a basic assembly. General basic components have a variety of assembly connections and assembly priorities, which have important engineering significance in the assembly stage. Therefore, the base parts need to be installed as the first place in the assembly process, and have multiple assembly connections. In AHGD, the base element is represented as the node with the most undirected edges. That is, traverse all parts and take the parts with the largest number of undirected join edges as the base parts.

2.3.2 Assembly Hybrid G-diagram based on Functional Components (AHGD-F)

The current models describing assembly relations mainly focus on the correlation information between assembly structures. The association information expresses the cluster relationship and institutional relationship of parts from different perspectives, but the attribute information of parts is less concerned. Most assembly do not discuss the assembly relationship and properties of the connector.

In order to improve the reasonable planning of all parts in the assembly process, the assembly relationship model is reconstructed according to the different attributes of the parts based on the AHGD

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model. According to part properties, all parts involved in assembly can be divided into functional parts and connectors, and the base part is one of the functional parts.

The schematic diagram of the structural properties of the Assembly Hybrid G-diagram Based on Functional Components (AHGD-F) is shown in 0.

0 shows the importance of AHGD-F model in terms of base parts, functional parts, and connectors in different sizes of nodes and colors from deep to shallow. The base node is the deepest red ring and the largest area; the function part is orange circle area; connector for the lightest blue ring body area minimum.

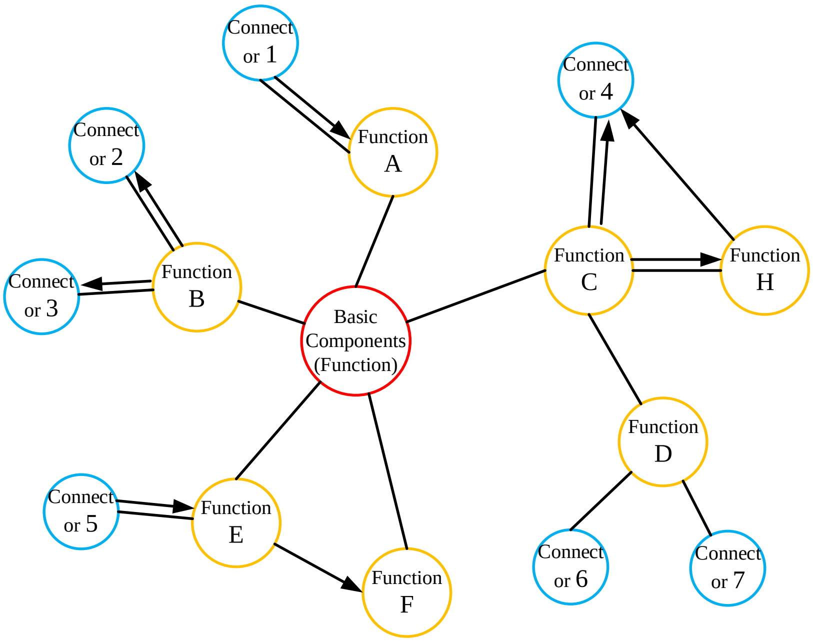

Fig 3: Schematic diagram of AHGD-F structural properties

According to the assembly logic, the base parts as the assembly center often need to be installed as the first place. In theory, the base parts should have a directed constraint prior to all parts. Therefore, the first installation of the base parts can be defined directly when the assembly relation model is constructed, and the pointing constraints of the base parts are omitted in the structural diagram, which are prior to all the parts of the base parts, effectively reducing the rendering complexity of the model, and the effective constraints are more concise and easy to understand. In Fig 3, the AHGD-F model has optimized the pointing constraint that the base parts give priority to all parts.

2.4 Assembly Compatibility Analysis Based on Polychromatic principle

2.4.1 Polychromatic principle

Polychromatic principle is a systematic theory that can be used for information processing based on the

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traditional set theory combined with matrix, mathematical logic and fuzzy mathematics[10]. The mathematical model of polychromatic principle can abstractly and dataize the structural composition and coherence of the target, and transform it into the relationship between elements, overall properties and element properties in polychromatic sets. The essence of polychromatic set modeling is to simulate different target objects through a unified mathematical model[11]. Object can be a process or a product, a hierarchy, or attribute information, such as node and edge attributes. Multicolor collections give different colors to the collection as a whole and its contained elements. 'Color ' represents the collection as a whole and its properties that contain elements, or relationships between elements, etc.

The traditional graph theory model is mainly used to describe the combination of nodes and edges, which cannot directly describe the properties of nodes and edges. If the nodes and edges of a color mapping are selected, the graph theory model presents a single color, which is called a monochromatic graph. Compared with the traditional graph theory model, monochromatic graph has the simulation function, but the simulation function of only giving a single color to the graph is limited. If a graph can render nodes and edges in multiple colors at the same time, it can express multiple properties and attributes at the same time, and the graph is a multicolored graph. Polychromatic graphs can simultaneously simulate parameters, attributes, indicators and features, and the functionality is stronger than that of monochromatic graphs[12].

Polychromatic graph is the embodiment of the graph form of polychromatic sets, which is mainly composed of three parts. The expression is:

$$PG=\left(F(G),PS_A,PS_C\right) \tag{3}$$

Where $F(G)=\left(Fg_1,Fg_2,\cdots,Fg_n\right)$ represents the overall uniform coloring of the polychromatic graph; $PS_A=(A,F(a),F(A),[A\times F(a)],[A\times F(A)],[A\times A(F)])$ represents the set of nodes in a polychromatic graph, $F(A)$ is the coloring of nodes, and the Boolean matrix of $\left[A\times F\left(A\right)\right]$ is used to determine the coloring of nodes. Features and properties of nodes are expressed abstractly in different colors. Boolean matrix is denoted as:

$$\left\|c_{i(j)}\right\|_{A,F(A)}=[A\times F(A)]=\begin{array}{c} \begin{array}{ccccc} F_1 & \cdots & F_j & \cdots & F_m \end{array} \\ \left[\begin{array}{ccccc} c_{1(1)} & \cdots & c_{1(j)} & \cdots & c_{1(m)} \\ \vdots & & \vdots & & \vdots \\ c_{i(1)} & \cdots & c_{i(j)} & \cdots & c_{i(m)} \\ \vdots & & \vdots & & \vdots \\ c_{n(1)} & \cdots & c_{n(j)} & \cdots & c_{n(m)} \end{array}\right] \end{array} \begin{array}{c} a_1 \\ \vdots \\ a_i \\ \vdots \\ a_n \end{array} \tag{4}$$

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Where F_j is a component of $F(a_i)$ that constitutes element a_i, then $c_{i(j)}=1$.

The process in which the characteristics and properties of edges are expressed abstractly in different colors is denoted by Boolean matrix as:

$$\left\|b_{i(j)}\right\|_{C,F(C)}=[C\times F(C)]=\begin{array}{cc} \begin{array}{ccccc} F_1 & \cdots & F_j & \cdots & F_m \end{array} & \\ \begin{bmatrix} b_{1(1)} & \cdots & b_{1(j)} & \cdots & b_{1(m)} \\ \vdots & & \vdots & & \vdots \\ b_{i(1)} & \cdots & b_{i(j)} & \cdots & b_{i(m)} \\ \vdots & & \vdots & & \vdots \\ b_{l(1)} & \cdots & b_{l(j)} & \cdots & b_{l(m)} \end{bmatrix} & \begin{array}{c} c_1 \\ \vdots \\ c_i \\ \vdots \\ c_l \end{array} \end{array} \tag{5}$$

Where F_j is a component of $F(c_i)$ that constitutes element c_i, then $b_{i(j)}=1$.

Assuming that any node can only be filled with a particular color, there is and only one element $c_{i(j)}=1$ in the line ***i*** of the Boolean matrix of the node, and the other elements are 0; if the Boolean matrix of the edge has the same case, the corresponding graph is monochromatic. If the nodes and edges of a graph can be filled with multiple colors at the same time, there are corresponding elements $c_{i(j)}=1$, $b_{i(j)}=1$ in the Boolean matrix of the nodes and edges, and the corresponding graph is polychromatic. Taking the AHGD model in 0 as an example, the corresponding assembly connection matrix and assembly priority matrix are:

$$\boldsymbol{G1}=\left[e_{ij}\right]=\begin{bmatrix} 0 & 1 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 1 & 0 \end{bmatrix} \qquad \boldsymbol{G2}=\left[d_{ij}\right]=\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

The polychromatic set matrix $\left[E\times DE\right]$ of the sample model is constructed with assembly connection matrix $G1$ and assembly priority matrix $G2$:

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$$\left\| c_{ij} \right\|_{E,DE} = [\,E \times DE\,] = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

When there is assembly connection $e_{ij} = 1$ and assembly priority $d_{ij} = 1$ between parts nodes, the corresponding element $c_{ij} = 1$ in the polychromatic set matrix; conversely, $c_{ij} = 0$.

2.4.2 Assembly Compatibility Analysis Based on Polychromatic principle

Generating assembly sequence according to AHGD model is a process of merging constraints for each part node, which requires larger constraint space and more complex relational semantic representation. The disassembly process of assembly is the process of removing constraints according to assembly semantics, and the solution process is better. At the same time, without considering the disassembly damage in sequence planning, the disassembly sequence can be inversed to obtain the feasible assembly sequence based on the principle of disassembly and assembly.

According to the construction process of AHGD, the topology structure is determined by the assembly priority constraint relationship (disassembly sequence) of nodes. However, the assembly priority constraint relationship cannot fully guarantee the rationality of the topology structure. In the whole assembly semantic model, the compatibility of assembly semantics should be guaranteed and there is no loop, so compatibility analysis is essential.

The compatibility analysis of assembly model mainly involves the correctness and sequence compatibility of logical relationship. For logical relations, assembly semantics have met the logical relationship between meta-problems when building AHGD model. The compatibility of sequence can be combined with the polychromatic set matrix to divide the assembly priority constraints step by step, so as to determine whether the existing loop and the correctness of the model are satisfied.

In the form of graph, different colors can be used to fill the disassembly source points of different levels in the graph theory model, and the assembly priority relationship and the corresponding parts node are represented in the same color. The polychromatic image of the sample model in 0 is shown in 0.

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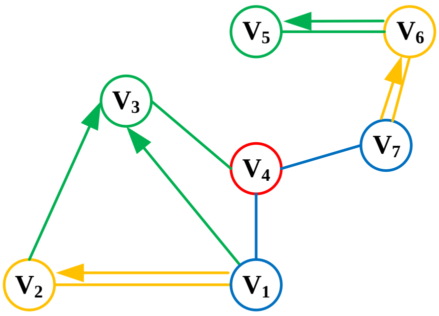

Fig 4: Example AHGD model polychromatic diagram

It can be seen from the figure that from the perspective of assembly connection, only one connection part is easier to be disassembled. The initial disassembly source points of the example model can be selected as $\mathbf{V_2}$, $\mathbf{V_3}$, and $\mathbf{V_5}$, but $\mathbf{V_2}$ must be assembled before $\mathbf{V_3}$, so $\mathbf{V_3}$ should be disassembled first from the perspective of disassembly priority. Therefore, $\mathbf{V_3}$ and $\mathbf{V_5}$ become the first batch of disassembly source parts that can be directly disassembled, part nodes and related semantics are labeled green at the same time. After removing nodes $\mathbf{V_3}$ and $\mathbf{V_5}$, $\mathbf{V_2}$ and $\mathbf{V_6}$ become new disassembly source parts, part nodes and related semantics are annotated in orange at the same time. After removing nodes $\mathbf{V_2}$ and $\mathbf{V_6}$ again, $\mathbf{V_1}$ and $\mathbf{V_7}$ become new disassembly source parts, part nodes and related semantics are labeled in blue at the same time. Finally, after removing nodes $\mathbf{V_1}$ and $\mathbf{V_7}$, the isolated node P4.

The disassembly priority constraint is constructed on the basis of assembly priority constraint. Thus, the AHGD model has no loop and the assembly priority constraints are compatible, which are feasible for disassembly and assembly processes.

2.5 Case Study and Results

Taking the milling fixture as an example, the assembly diagram of the three-dimensional model and the explosion diagram of the parts are shown in 0.

The AHGD-F model is constructed with the milling fixture as the description object, as shown in 0. Node 6 to node 9 are undirected edges, indicating that there is assembly connection between part 6 and part 9. Node 13 to node 4 is a directed edge, indicating that part 13 must be assembled before part 4. Node 2 to node 13 have both directed and undirected connections, indicating that there is an assembly connection between Part 2 and Part 13, and Part 2 must be assembled before Part 13.

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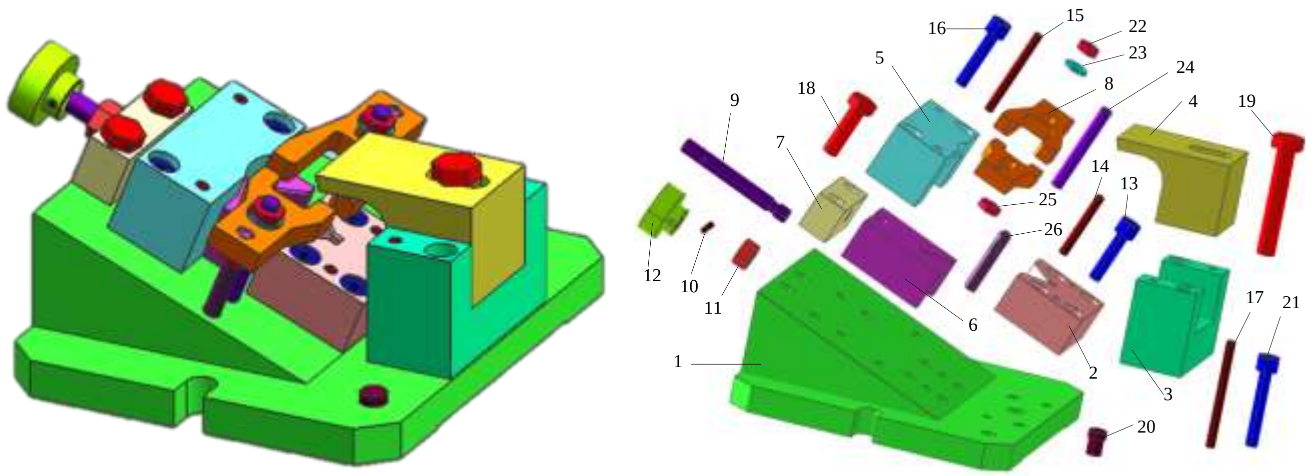

1-Body 2-V block 3 - Guide plate 4 - Pressing block 5 - Guide plate 6 - Pressing plate 7 – Plate 8 - Pressboard
9 - Screw CM10x80 10-Cylindrical pin A4x20 11 - Nut M10 12 - Nut BM10 13 - Screw M8x35 14-Cylindrical pin A6x45
15 - Cylindrical pin A6x60 16 - Screw M8x40 17-Cylindrical pin A6x70 18 - Screw M10x50 19 - Screw M12x90
20-Cylindrical pin 21 - Screw M8x50 22 - Nut M8 23 – Cushion 24 - Bolt M8x60 25-nut M8 26 - Adjustable support M8x45

Fig 5: Milling fixture

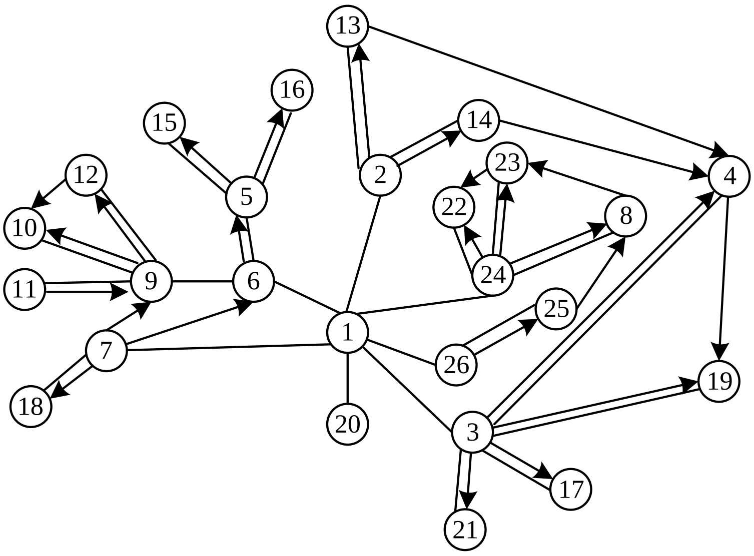

Fig 6: AHGD-F Model of Milling Fixture

In 0, node 1 connects the most undirected edges, corresponding to the basic parts of the milling fixture: Part 1-Body. The basic parts are generally regarded as the first installation according to the assembly requirements. The AHGD-F model no longer identifies the assembly precedence constraints between the base parts and their parts. The AHGD-F model takes the functional components as the main node to connect with each other. For example, the base component (functional component) 1 - Body and the functional component 2 - V block are connected with the connector 13 - Screw M8x35 and the connector 14 - Cylindrical pin A6x45. In the AHGD-F model, it is reflected that the base component node 1 is connected with the functional node 2, and the two connectors 13 and 14 are connected to the functional node 2, respectively. It only reflects the existence and constraint of the connector, optimizes its

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connections, and ensures the loop-free property of the AHGD-F model, which is convenient for subsequent assembly planning.

The assembly compatibility of milling fixture was analyzed based on the polychromatic principle, and the polychromatic graph of AHGD-F was constructed as shown in 0.

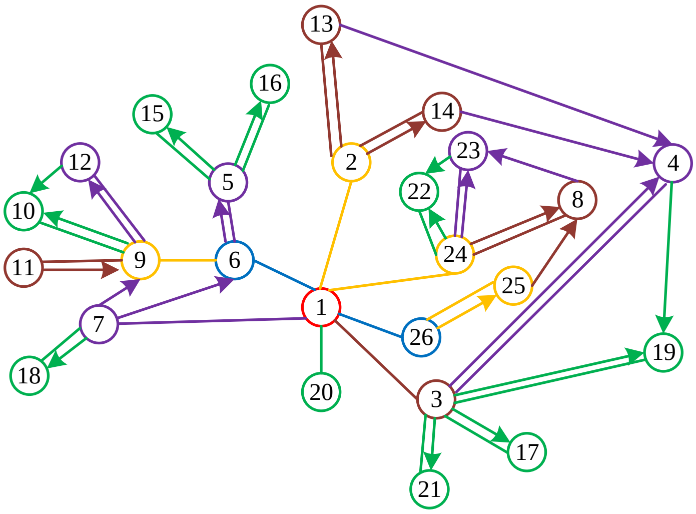

Fig 7: Multicolor graph of milling fixture AHGD-F model

A variety of colors are used to fill the disassembly source points of different batches in the milling fixture AHGD-F model, and the assembly priority relationship and the corresponding parts nodes are identified in the same color system. Theoretically, 0 shows:

The first batch of disassembly source points were identified as green, respectively: 10,15,16,17,18,19,20,21,22.

The second batch of disassembly source points were identified in purple, respectively: 4,5,7,12,23.

The third batch of disassembly source points were identified in brown, respectively: 3,8,11,13,14.

The fourth batch of disassembly source points are identified in yellow, respectively: 2,9,24,25.

The fifth batch of disassembly source points were identified in blue, respectively: 6,26.

The remaining base parts are identified in red: 1.

Therefore, the AHGD-F model of milling fixture meets the requirements of assembly feasibility. The logical relationship of the model is correct and the assembly sequence is compatible. The connection relationship has no loop and is feasible and effective.

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III. Conclusion

The Assembly Hybrid G-Diagram Based on Functional Components (AHGD-F) can not only meet the semantic expression of assembly connection relationship and assembly priority relationship, but also realize the corresponding data transformation. Under the premise of ensuring product function, it provides visual model and data basis for subsequent intelligent planning. The AHGD-F model is analyzed by polychromatic principle to meet the requirements of assembly feasibility, ensure the functionality of assembly semantic model, and verify the effectiveness of the model. Visual assembly semantic model can provide assembly relationship information in subsequent intelligent assembly sequence planning, and further realize the generation and verification of assembly sequence, which has broad application prospects in the field of intelligent manufacturing.

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