RESEARCH AND APPLICATION OF FUNCTIONAL ELEMENTS AND NEWLY DEFINED FUNCTION SYMBOLS FOR MECHANICAL HANDLING SYSTEMS

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Abstract

The assembly and handling technology guideline VDI 2860 mentions concepts, definitions and symbols in a handling technology. However, in this document there are limitations which make it more difficult to describe and outline a handling flowchart. The method of this study is based on assembling and manufacturing equipment, parameters and functions effecting the handling process, as well as methods used in assembling techniques to establish new concepts. The introduced function symbols are checked by application examples in a virtual assembly line. As the result of this study, necessary parameters are added to the existing elementary and compound functions. Moreover, new function symbols are formed and gathered in new function symbols of handling. The theoretical concept and the final application of these elementary and compound functions can be used for computer-aided planning (CAP) of handling systems.

Keywords: CAP, Functional elements, Function symbols, Handling equipment, Handling flowchart, Handling functions, Handling sequence, Handling symbols, VDI 2860

Introduction

The handling flowchart is very important and must be formulated carefully and illustrated clearly. It is also intended to describe the sequence of what's being done to the handling objects. The assembly and handling technology guideline VDI 2860 [1], which contains concepts, definitions and symbols for handling technology, is the guideline for handling functions and handling equipment.

Handling functions and handling symbols can be linked to particular assembly lines, when they are used to describe the given handling objects. Therefore, each handling function is defined by VDI 2860 and classified into five groups: storing, quantities changing, moving, securing and controlling. They are applied for handling object in a handling flowchart. To make a simple handling flowchart, each handling function in the VDI 2860 is symbolized. These function symbols of handling include both handling functions and handling symbols; they are used for installing a handling flowchart.

However, a graphical description of these handling symbols provides no information about the used equipment or devices, because these handling symbols are the independent tools. On the other hand, [2] and [3] show a technical data of handling equipment; function symbols of handling are used to explain a working principle and build a handling flowchart. If there is no explanation or picture of equipment, the handling flowchart cannot depict a manipulation of handling object clearly.

The mentioned guideline is limited in its application field because it only writes on general manipulations, such as an assembly chip into a chip holder. This task can be done with a revolving machine (Figure 1).

Chip holders (yellow handling objects in Figure 1) are arranged storing and contained in a hopper. A chip holder is allocated from the hopper and transferred to the round table. The chip holder is rotated 22.5 degrees, and then the light sensor checks the position of the chip holder. The chip holder is then rotated 22.5 degrees to the assembly location, where it is kept by the chip holder clamp. Chips (red handling objects in Figure 1) are contained on the vibratory bowl feeder and fed in sequence to the chip feeder. A chip is grasped and assembled into the chip holder. After being assembled, the chip and chip holder are both rotated 22.5 degrees to the presence checking of the chip. Finally, they are rotated 22.5 degrees to the chip holder rejection where the chip holder is transferred to the groove and is slid into the lower hopper.

The function symbols of VDI 2860 are used to describe the transfer of the chip holder from the allocation to the round table (Figure 1). Therefore, three function symbols (clamping, sliding and releasing) only show three actions in this process. However, to describe this process in more detail it requires more handling information (e.g. direction and distance of movement, gripping force, moving time, etc.). Due to a lack of information in the function sequence, such as the handling objects, handling equipment, the handling flowchart is not clear enough to interpret; therefore, it is difficult to use in assembling and manufacturing lines.

The functional elements of the VDI 2860 are not adequate to explain clearly and distinctly a function sequence. Although some new symbols and functions have been defined and applied for handling equipment, further considerations are required to support symbolically the plant design by additional information and parameters through function symbols. Therefore, a handling flowchart can be applied for:

- designing a new machine or equipment of assembling or manufacturing line
- searching and selecting technical data on internet or catalogue
- ordering a maker to manufacture a machine or equipment

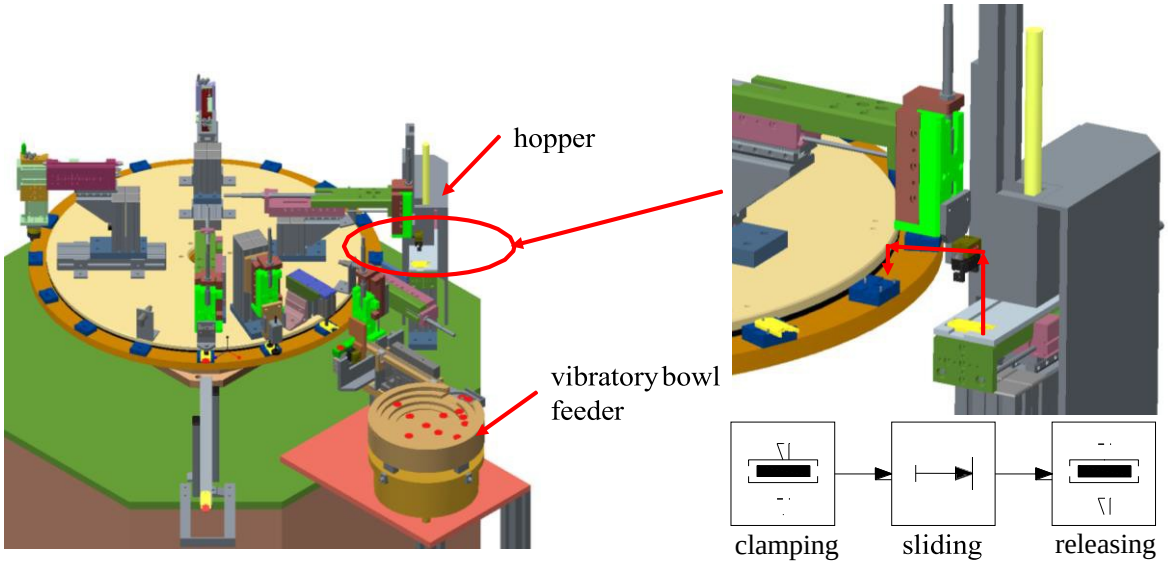

Figure 1. Model of a revolving machine for assembling a chip into a chip holder

Literature Review

It is useful to construct a handling flowchart with a planning of handling sequence. This handling flowchart serves as the description and comprehension of the handling task. The handling

flowchart must be completed and included all handling functions inside and outside of the manufacturing line. Thereby, the advantage of handling functions has been proved by using symbols for the description of the individual process in assembly machines [4]. With these function symbols, the handling object flow is designed and displayed clearly as a block diagram. Other function symbols are contained in *Handhabetechnik* [5]. These symbols and functions are generally incomplete. However, these concepts, definitions, and symbols in the VDI 2860 are already well developed. This guideline is supposed to act as a basis for computer-aided planning (CAP) of handling systems.

The manipulation is divided into 5 groups: storing, quantities changing, moving, securing and controlling. The corresponding function symbols of handling are summarized in Table 1.

Table 1. Function Symbols According to VDI 2860

Storing - Group 1							
Function	**Symbol**	**Function**	**Symbol**	**Function**	**Symbol**	**Function**	**Symbol**
Arranged Storing		Partially Arranged Storing		Unarranged Storing			
Quantities Changing – Group 2							
Dividing		Amalgamating		Separating		Allocating	
Branching		Combining		Sorting			
Moving – Group 3							
Rotating		Sliding		Swivelling		Orienting	
Positioning		Arranging		Guiding		Forwarding	
Conveying							
Securing – Group 4							
Holding		Loosing		Clamping		Releasing	
Controlling – Group 5							
Presence Checking		Identity Checking		Form Checking		Size Checking	
Colour Checking		Weight Checking		Position Checking		Orientation Checking	
Measuring		Counting		Orientation Measuring		Position Measuring	

Methodology

Theoretical Foundations

Manipulation is a partial function of material handling. Material handling is defined the Material Handling Institute (www.mhi.org) as the movement, storing, control, protection of materials and products throughout the process of their manufacture, distribution and consumption. The five commonly recognized aspects of material handling are: movement, time, place, quantity and

space [6]. Material handling means providing the right amount of the right material, in the right condition, at the right place, at the right time, in the right position, in the right sequence and for the right cost by using the right methods [7]. In the manipulation, the handling object must be controlled and different parameters, such as its orientation, position, quantity, its path of movement and the demand of handling time, should all be supported in the new function symbols. However, all function symbols described by concepts and definitions do not contain the same parameters because each function has its own task.

In each manufacturing and assembling process, semi-products, materials, parts/ assemblies are required for a continuous manipulation. Many products contain multiple components and they all must be assembled for their particular process. In addition, the location of the manufacturing and assembling lines and the orientation and position of the handling objects should be defined in a handling sequence. In this paper three corresponding coordinate systems are established: a body coordinate system ($X_BY_BZ_B$), a reference coordinate system ($X_RY_RZ_R$) and a world coordinate system ($X_WY_WZ_W$). All of them are Cartesian coordinates (Figure 2).

The world coordinate system (WCS) is established to define all of the reference coordinate systems (RCS) in the plant design. The RCS is used at the beginning of each function sequence. The body coordinate system (BCS) is put inside the enveloping surface of the handling object and moves together with it.

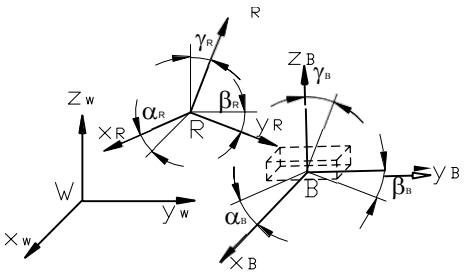

Figure 2**.** Coordinate systems for manipulation

Time is an essential factor of material flow. Each function of the manipulation is controlled by time and defined firmly in the time schedule. All handling sequences will be described clearly by this parameter. A start time t_{start} and an end time t_{end} of each function should be added to the function symbols.

Moving is also a main function of the manipulation. The changes in movement of the handling object are defined by the accurate information of the orientation and position. These parameters, as well as different tolerances, will be represented by function symbols. The movements of the handling object are defined by the translation (x, Δx; y, Δy; z, Δz) and the rotation (α, $\Delta\alpha$; β, $\Delta\beta$; γ, $\Delta\gamma$) in function symbols.

In addition, indications of quantity in the handling sequence also play an important role. Among the symbols in Table 1, there are only two function symbols (the separating and allocating) which define the quantities changing. The quantity of handling objects is essential information for a concept of plant design and also for the selection of exact storing size or the cycle time of the forwarding function.

Other parameters, such as a checking result, an arrangement, are based on the respective functions and are also added to an elementary or a compound function.

Handling Equipment

Handling equipment is a partial function of manipulation, e.g. devices, equipment or machines and used in assembling and manufacturing lines [2], [3]. For the planning of new handling equipment, it should be considered to outline the basic statement of physically functional principles (e.g. mechanical, pneumatic, electric, etc.), criteria of application and operation or requirements of special functions. Handling equipment is used to carry out a handling flowchart. Therefore, the name and technical data of the handling equipment are added to a function symbol.

Results and Discussions

New Function Symbols

The basic symbols in Table 1 are developed into the new function symbols and a new group 6 **"**assistant processes" is formed as the results of this research. The assistant processes are: a handling object feature, an actuator, a body coordinate system, a control signal of handling equipment, etc. The distinction of the function symbols between the VDI 2860 and the research are shown in Figure 3, 4 (Example of function symbol: identity checking). A new function symbol is generally formed according to the following structure (Figure 4).

- Input signals: used to define a suitable interface with previous function symbol.
- Output signals: used to define a suitable interface following function symbol.
- Name of function
- Symbol of function
- Predefined parameters: the quantity of parameters depends on the definition and the concept of each handling function.
- Information of implementation: value/ method will be selected or entered and they should be appropriate to the handling task.
- Control signals (e.g. results of checking and measuring): used in the following function symbols.

Figure 3. Old function symbol

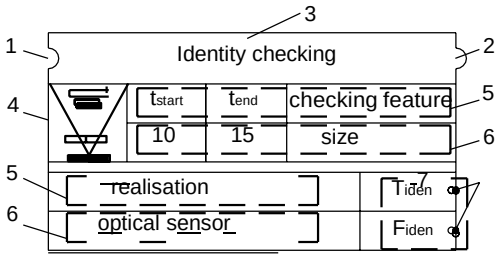

Figure 4**.** New function symbol structure

According to the definition of "identity checking", it decides whether handling objects fulfil the predefined features. It is difficult to use this function symbol of VDI 2860 in a handling flowchart. To apply this handling function in a handling flowchart, it requires more information and parameters. This will be clarified in the new function symbol.

The new function symbol of identity checking contains a start time, an end time; checking feature; realisation, result of checking (T_{iden} (true), F_{iden}(false)). The start time and end time show when this function symbol in a handling flowchart will be executed. A cycle time of a handling flowchart will be measured and used to calculate the efficient productivity. Handling object consists of many different features, e.g. size, colour, shape, weight. It depends on an assembly line, how many features of handling object will be checked. Each checking feature requires a suitable equipment or machine. For this reason the "checking feature" and "realisation" are added to the "Identity checking". The following manipulation of handling object will be decided by the result of checking (T_{iden}, F_{iden}). For example, if the result of checking is T_{iden}, the handling object will be continuously handled, if the result of checking is F_{iden}, the handling object will be transferred to a container of wrong products.

Example of Application

Figure 5 shows the manufacturing line of shaft collars and figure 6 displays the symbolic handling flowchart of the manufacturing line. The differences between the function symbols of the VDI 2860 and the new function symbols are demonstrated in the following example and shown in Figure 6 and Figure 7. These differences are also analysed in the below group 1, 2, 3, 4, 5, 6.

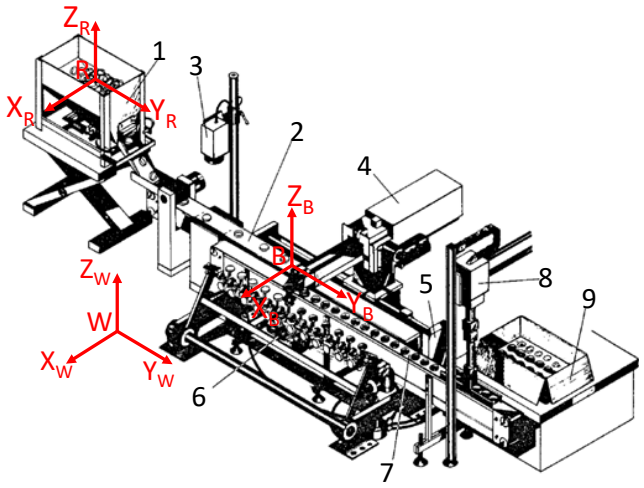

Figure 5. Principle of a manufacturing line [1]

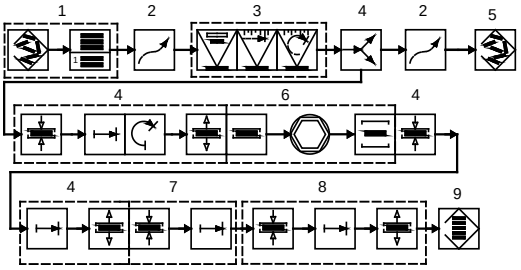

Figure 6. Symbolic handling flowchart

1. Hopper with isolating equipment; 2. Conveyor belt; 3. Optical sensor; 4. Industrial robot; 5. Hopper for wrong shaft collars; 6. Shaft collars holder for coating equipment; 7. Magnetic conveyor belt; 8. Industrial robot; 9. Hopper (shipping carton with pallet)

Shaft collars are located in the hopper 1 (unarranged storing) and isolated from the hopper 1 to the conveyor belt 2. During the movement on the conveyor belt, the shaft collars are measured and checked by the optical sensor 3. If the results of "identity checking" of the shaft collars are wrong, the wrong shaft collars will move continuously on the conveyor belt to the hopper 5 (unarranged storing).

The industrial robot 4 grasps the right shaft collar and slides directly the correctly orientated shaft collar to the shaft collars holder 6. If the orientation of the shaft collar is not correct, the industrial robot 4 will at the same time rotate the orientation of the shaft collar to the correct orientation and slide it. After coating, the shaft collars will be taken down by the industrial robot 4 to the magnetic conveyor belt 7. Finally, the industrial robot 8 will transfer the finished shaft collars to the hopper 9 (arranged storing).

Group 1 - "Storing": Storing keeps the solid object, such as workpiece, assembly, semi-finished product, and product in the spatial arrangement.

Storing is classified by the arranged orientations and positions of handling objects in a store. If the orientations (three rotary degrees of freedom) and positions (three translational degrees of freedom) of the handling object are defined in the store, it is the arranged storing. If all of the orientations and positions are not defined, it is the unarranged storing. In the other cases, it is the partially arranged storing.

The "storing" function symbols in Figure 5 are the "unarranged storing" symbol (the hopper no. 1 and no. 5) and "arranged storing" symbol (the hopper no. 9). The VDI 2860 defines the arrangement state of handling objects. However, the quantity, position and orientation of handling objects must be indicated in the handling sequences. Therefore, these indications are integrated in the new function symbols. The position and orientation of the handling objects will be represented by the realisation parameter in these function symbols, e.g. pallet, box, round shelf, etc.

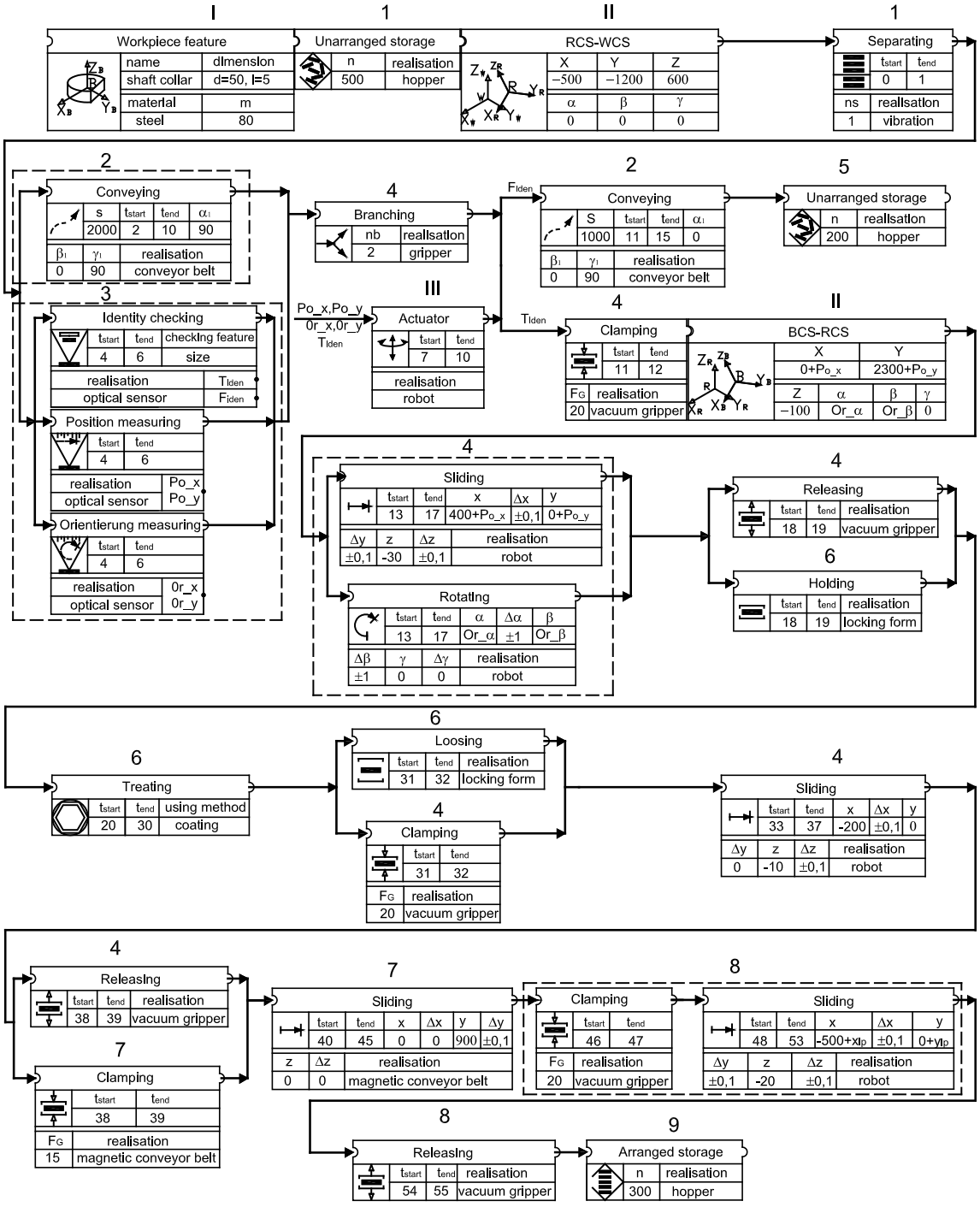

Figure 7**.** Handling flowchart with new function symbols

Group 2 - “Quantities Changing”: Quantities changing are the formation of subset from quantities by splitting or the formation of quantities from subsets by combining. The “branching” function symbol in Figure 5 stands at the robot no. 4. The VDI 2860 defines the splitting of a partial flow from a main flow. The quantity changing of handling objects in the manufacturing line should be suitable with different requirements, e.g. unloading of checking and measuring handling objects, branching of excess handling objects in storing, etc. The number of branches and the types of equipment are necessary for choosing the handling equipment. Therefore, they will be used in the function symbols.

Group 3 - “Moving”: Moving changes the orientations and positions of handling object. The “moving” function symbols in Figure 5 consist of the “conveying” symbol (the conveyor belt no. 2), the “sliding” and the “rotating” symbol (the robot no. 4 and no. 8). The VDI 2860 defines the moving types of handling objects. According to these definitions, the moving of a handling object is a change in spatial arrangement of the handling object. The sliding is the movement of the handling object from a given position to another predefined position by a linear translation and the orientation of the handling object is unchanged. To define clearly the movement of the handling object in the handling sequence, the information of the start time (t_{start}) and end time (t_{end}), the position and orientation of the handling object from the beginning to the end, must be used in these function symbols. This data is necessary for the parameters to calculate velocity and acceleration of the handling object. The appropriate equipment can be selected quicker through these indications.

Group 4 - “Securing”: Securing maintains the defined conditions of handling object in the spatial arrangement. To maintain the spatial arrangement of handling object, the operating principle of securing can be: force, shape, material. The “securing” function symbols in Figure 5 are the “holding” symbol and “loosing” symbol (the shaft collars holder no. 6); the “clamping” symbol and “releasing” symbol (the gripper of the robot no. 4 and no. 8, the magnetic conveyor belt no. 7). The VDI 2860 defines the securing of a handling object in spatial arrangement by gripping force, locking material or locking form. To make the indications of clamping and releasing clear, the gripping force, gripping method, cycle time of opening and closing should be added to these function symbols.

Group 5 - “Controlling”: Generally controlling makes the determination,

- whether the defined properties or conditions of handling objects are acceptable. It is referred to “Checking”. The checked components are: Information reception, comparison with defined properties or conditions and decision about the checking results (good/bad or yes/no).
- the properties or conditions of handling objects are compared with the given reference value. It is referred to “Measuring”. These properties or conditions are described as variety of defined references through a value.

The “controlling” function symbols in Figure 5 are the “identity checking” symbol, the “orientation measuring” symbol and “position measuring” symbol (the optical sensor no. 3). The VDI 2860 defines functions of checking and measuring. In respect to quality requirements, it is crucial for subsequent processes to define the results of checking and measuring at the plant design. These results will be used to planning and controlling the subsequent processes.

New Group 6 - “Assistant processes”: VDI 2860 supports the function symbols for Assembly and Handling Technology. However, when the new function symbols are formed and used in a handling flowchart, the function symbols of Table 1 are not enough.

The most important function symbols are group 3 “Moving”. The movements of handling object are defined by the translation ($x, \Delta x; y, \Delta y; z, \Delta z$) and/or the rotation ($\alpha, \Delta\alpha; \beta, \Delta\beta; \gamma, \Delta\gamma$). To determine these movements, it is necessary to establish the coordinate systems and define them in a handling flowchart. These coordinate systems (BCS, RCS, and WCS) are not supplied in the VDI 2860. Other function symbols, such as workpiece features, actuator, and cleanness, are needed to add into the function symbols of handling.

Function symbols of this new group are defined in Figure 7 as the “feature handling object” symbol (no. I), “RCS-WCS” symbol, “BCS-RCS” symbol (no. II) and “actuator” symbol (no. III (the robot no. 4)). The “handling object feature” function symbol shows the basic parameters of the handling object. Therefore, the handling function can be installed more suitably from the “handling object feature” symbol and the handling equipment can also be chosen more accurately. The location of the manufacturing line in the plant is defined by the relationship between the RCS and the WCS (RCS-WCS). Moreover, the position and orientation of the

handling object within the manufacturing line are shown by the relationship between the BCS and the RCS (BCS-RCS). Additionally, handling equipment is an important part of a handling flowchart and it has a strong connection with a movement of a handling object. The implementation of handling equipment, e.g. the robot no. 4, in the handling flowchart is demonstrated by the "actuator" function symbol.

Symbols and Abbreviations (Figure 7)

d, l (mm): diameter and length of a handling object
m (g): weight of a handling object
n: maximal number of handling objects in a storing
s (mm): distant movement of handling objects on the conveyor belt
X, Y, Z (mm); α, β, γ (degree): distance and angle between coordinate systems
α_1, β_1, γ_1 (degree): angle of conveyor belt in comparing with the RCS
ns: number of separated handling objects
nb: number of branches
T_{iden} (true), F_{iden} (false): the results of identity checking
Po-x, Po-y, Or-α, Or-β: the results of position and orientation measuring
F_G (N): gripping force
t_{start}, t_{end} (s): start time and end time
x, Δx; y, Δy; z, Δz (mm): translation and tolerance determined by starting and ending movement according to the BCS
α, $\Delta\alpha$; β, $\Delta\beta$; γ, $\Delta\gamma$ (degree): rotation and tolerance determined by starting and ending movement according to the BCS
x_{ip}, y_{ip} (mm): offset of point ip
Note: the values or parameters given in the figure 7 are only examples.

Conclusions and Future Works

- This paper shows the new function symbols of handling developed from the VDI 2860. Moreover, the new group of assistant processes is formed to complete the function symbols in the handling library.
- These new function symbols contain the additional descriptions of the selected function sequence. They make a logic connection between elementary or compound functions more transparent and comprehensive.
- A handling flowchart with new function symbols is useful for designing, ordering or searching a new machine or equipment in an assembling and a manufacturing line.
- In order to save time and make a handling flowchart easier, the new function symbols should be programmed for computer-aided planning (CAP) to apply in handling flowcharts. In the future, by using the application program, the handling flowcharts will be created by dragging and dropping the function symbols from the menu bar to the drawing area and connected together by arrows. The information of implementations (no. 6 in figure 4) will be entered or selected from the list.
- In comparison to the function symbols of the VDI 2860, these new function symbols are larger. Therefore, they need more area in the menu bar of the application program. To solve this problem, the different view and display format can be selected by implementing it in the application program.

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