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SELECTION AND MODIFICATION OF CONNECTIONS

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1. Introduction

The overall challenge of product development should be to create products

- which fulfill the required functions with the highest possible reliability;
- which are as attractive as possible for the customer;
- which have the lowest negative impact on the environment; and
- which require minimal financial resources for producing and recycling.

In this paper these challenges are addressed through optimizing connections.
The aim is to improve the functionality of connections as well as the process of (dis-) connecting. In this context the complexity of connections is also considered. The function of a connection has a direct impact on product reliability [Bauer 1983], [Bonenberger 2000], while the (dis-) connecting process directly affects the (dis-) assembly effort and therewith the production, maintenance and recycling costs. Product reliability and costs, in turn, have a direct impact on product attractiveness.
However, at present no established systematic approach for designing connections exists which leads to the assumption, that connections are usually selected in an unsystematic manner. To improve the connections and thus the product, a systematic approach should be developed for systematically selecting and modifying connections.

2. Methods

Developing an approach for selecting connections, not only requires considering the connection function and the (dis-) connecting process. For preventing that connections will get to complex, also their structure has to be regarded.

2.1 General description of the function of connections

A product function can only be fulfilled, if the components are and stay in the required position. This is realized using connections. The main function of every connection is to provide a defined *degree of freedom* (dof) through blocking undesired movements between components to be connected. [Roth 1996] defines for every axis of the three-dimensional coordinate system two movement types: translation and rotation. For each of these movement types he specifies a positive as well as a negative direction. According to this scheme, a component can move in 12 different ways, if not connected with any other component. In the upper half of Figure 1, the dof is represented using gray arrows (unblocked movements). Black arrows indicate blocked movements. Arrows labeled with (F) indicate movements blocked through friction forces compared to movements which are blocked through geometry. Prerequisite for blocking movements through friction forces is, that the forces are high enough to provide static friction.

To select the most suitable connection, the dof which should be realized between the components must be known. In many cases, connections should block all movements, but in some cases movements should be left unblocked. A door hinge, e.g., blocks the movements between the door and the door frame in all directions except for the rotation around the door hinge axis.
Other very important requirements are the preload which is required between the components as well as the accuracy of the preloading force.

2.2 General description of the (dis-) connecting process

Investigations were made into the creation of a general scheme for describing (dis-) connecting processes [Neubert 2000], [Klett 2003a]. The sub-states in which a connection can be between being "disconnected" and "connected" were defined as "positioned" and "joined" (see Figure 1). The processes for reaching these states were defined as the sub-processes "positioning", "joining", "locking", "unlocking" and "unfastening". Components are connected by means of connecting features [VDI 2232]. In line with the terminology for the sub-processes, the connecting features were classified in "joining features" and "locking features".

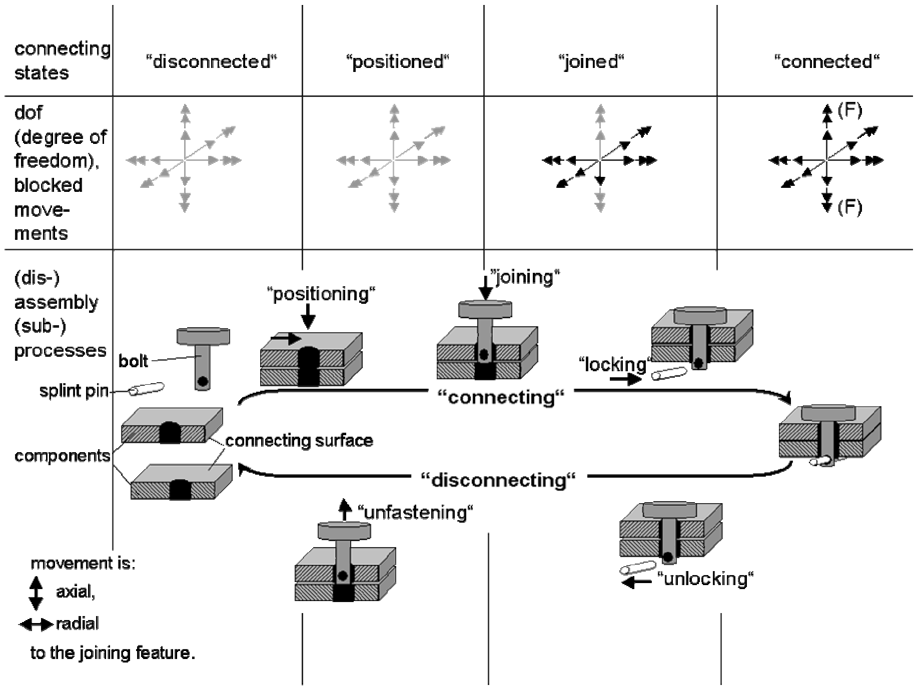

Figure 1. Dof, (dis-) connecting process, sub processes, connecting features

Using these definitions, the connecting and disconnecting processes can be described as follows:

- "positioning" the components, i.e. moving the components in the desired position;
- "joining" i.e. reducing the dof of the components by means of joining features (in Figure 1 these are the holes in the components and the bolt);
- "locking", i.e. using locking features (in Figure 1 these are the hole in the bolt, the surface of the component to be connected and the splint pin) preventing the components and the connecting features from moving in the inverted joining direction which would initiate the unfastening process. The locking process realizes the required dof between the components;
- "unlocking": i.e. releasing at least one blocked movement and so enabling the components and the connecting features to move;
- "unfastening": i.e. disengaging the components and any connecting features.

Subdividing the (dis-) connecting process allows to identify the constituent movements of the complex movements in this process and the comparison of the order of the sub-processes regarding consistency of movements. The direction of the sub-process movements of the (dis-) connecting process are represented two dimensionally: axial and radial to the joining feature.

2.3 Structure of connections

The complexity of a connection is determined, among others, by the number of separate connecting features. This number depends on the *degree of integration* (doi) of the connecting features into the components to be connected. The doi thereby refers to the complete connection including its components to be connected and its connecting features. The doi does not refer to itemized components.

The advantage of a high doi is, that the number of separate connecting features decreases and therefore less parts have to be handled, reducing time and cost.

The following five degrees of integration were defined (see Figure 2):

- No integration of connecting features in the components, doi = 0, e.g.: a vise.
- Components contain some joining features, doi = 1, e.g.: the hole through which a bolt can pass through the components.
- Components contain some joining and locking features, but the positioning process is not influenced, doi = 2, e.g.: the hole through which a bolt can pass through the components, the thread for the bolt in one of the components.
- Components contain some joining and locking features, the positioning process is influenced, doi = 3, e.g.: the bolt in one of the components, the hole through which the bolt can pass through the other component.
- Components contain all joining and locking features, doi = 4, e.g.: the inside thread at one and the outside thread at the other component.

In general, for all connections with a doi larger than 2, the positioning movement has to match with the joining movement (see Figure 2). If the space available for installation is small, this could be disadvantageous.

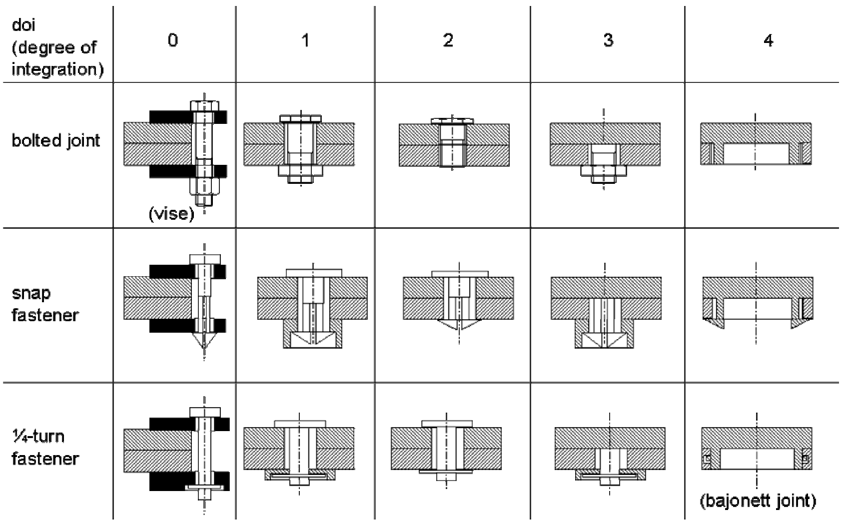

Figure 2. Connections with different Degree of integration (doi)

3. Results

For a connection to meet the requirements, the required function of a connection and the (dis-) connecting process have to be optimized. In addition, the doi plays an important role. A *table of connections* was created containing this information for different types of connections (Figure 3). For lack of space, the figure only shows an extract of the whole table. The function parameters are covered by the first two columns: the dof and the preload option. If existing, the preload always works in the direction of the joining feature axis. The connecting process parameters are covered by the third

(positioning process), fourth (joining/unfastening process) and sixth column (locking/unlocking process). Column 5 contains the dof after joining and before locking. Column 7 contains possible concrete solutions with their degree of integration (doi). Column 8, finally, indicates with “inv” (invert) whether this connection can be disconnected by inverting the movements. Each possible sub-process is shown with the components, the connecting features, the movements with their directions and the resulting degree of freedom.
The next sections describe how, using this table of connections, the most suitable connection can be selected (3.1) and how these can be modified (3.2).

3.1 Selecting connections

First of all, the connection function parameters have to be defined, i.e. the dof and the preload option. If a preload is required, between a fixed and an adjustable preload has to be differentiated. The connections shown in Figure 3 block all movements between the components. They fulfill the function: “provide a dof of zero between the components” (column 1). Preloads can be fixed (abbreviation “fix” in column 2), which can e.g. be realized easily using springs. For an adjustable preload (“adj” in column 2), a thread is a possible solution.
After having determined the function parameters, the connecting process parameters have to be defined. This second step requires the possible directions of the positioning and joining movements to be determined. These mostly depend on the available installation space.
Once the function and connecting process parameters have been determined, the table of connections can be consulted to find suitable connections. The best connection is then chosen by selecting the locking parameters.

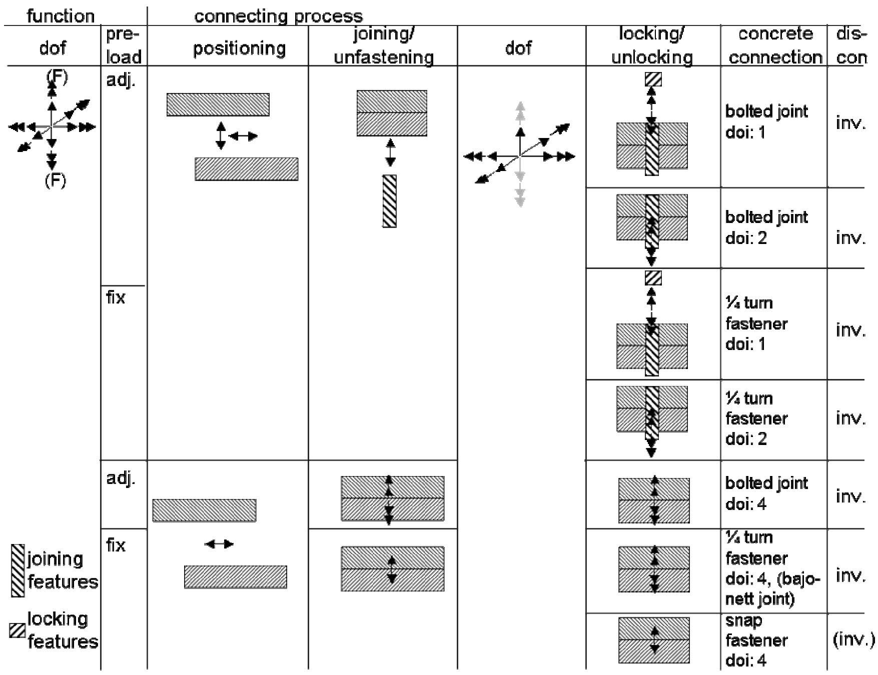

Figure 3. Table of connections (extract)

Choosing a suitable connecting process can be based on several criteria. A general criterion could be to choose a process in which sub-processes that are executed after one another, require the same connecting movement. In this way extra movements of the equipment could be saved. A snap fastener is an example of such a combined movement: only one movement is required for the sub-processes joining and locking.
Another criterion is to consider both connecting and disconnecting processes. Many connections need little effort for the connecting process but a large effort for the disconnecting process. Many connections can be disconnected by inverting the connecting process (see Figure 3, column 8

“discon”). The disconnecting process then involves the inverse movements of those movements in the sixth and fourth column in the table to realize the sub-processes of unlocking and unfastening.
To disconnect a bolted joint, e.g., the locking and the joining processes only have to be inverted. To disconnect a snap fastener, the unlocking process is dependent on the geometry of the locking features (hook and edge). In the best case, the process can be inverted. In the worst case, the hook has to be lifted over the edge. This could be very difficult, because once connected, the hook is often inaccessible. This would e.g. require adding extra elements with which a movement can be transmitted to the hook. For this reason, Column 8 of Figure 3 contains “inv” between brackets “(inv)”.
If none of the connections in the table of connections is able to fulfill the desired requirements, modifications should be made. The following section proposes a systematic modification process.

3.2 Modification of connections

The first step in the modification process is the specification of the problems with those connections, that, using the process in 3.1, were found to fulfill some but not all requirements. In most cases, the problems arise through the locking respectively unlocking process, because the function, the positioning and joining processes are chosen one after another, based on the requirements, after which the (un) locking process follows based on these parameters. For example, the requirements are that the preload force should be adjustable and, for reasons of disassembly process efforts, that the connection should be unlocked using a translatory movement. It is decided to realize the adjustable preload by a thread. The unlocking process can be performed by inversing the locking process: transmitting a rotational movement, or by cutting the bolt – both processes cannot be performed through a translatory movement. To meet the two requirements, the connection has to be modified.
This leads to the second step, finding possible principle solutions for modification of the existing connection(s). The principle of task division could be used, which means to reduce the degree of integration. In the example, the joining feature is separated from the locking feature, and the locking feature is split into two locking features: one to provide the adjustable preload (e.g. a nut), the other to realize the desired unlocking process. This might involve the creation of new (un-)locking features [Klett 2003b], [Jones et al. 2002].
If the locking feature is to be modified or a new concept created, it is important to understand how movements can be blocked. Therefore it is important to look at the different kinds of working surfaces on which the locking feature is acting:

- working surfaces which are parallel to the connecting surface,
- working surfaces which are perpendicular to the connecting surface (see Figure 3).

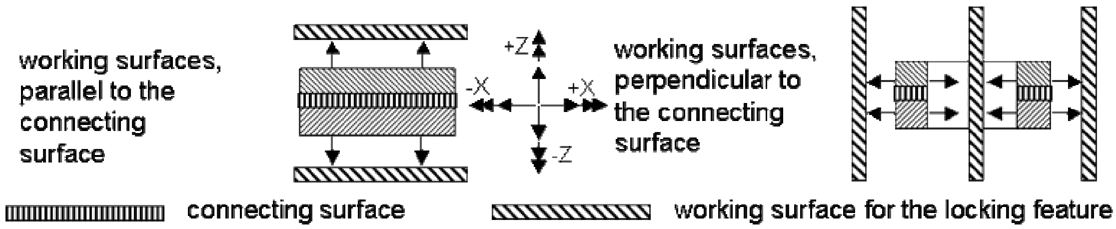

Figure 4. Working surfaces in dependence to the connecting surfaces

Movements between components to be connected which have a direction which is not in the plane of the considered working surface can be blocked through geometry. Movements between components to be connected with a direction which is situated in the plane of the considered surface, only can be blocked through frictional forces.
This means for the cases shown in Figure 4, that at the working surfaces, which are parallel to the connecting surface,

- movements in the direction of the Z-axis can be blocked through geometry
- movements perpendicular to the Z-axis only can be blocked through frictional forces.

At the working surfaces which are perpendicular to the connecting surface,

- movements in the Z direction only can be blocked through frictional forces

- movements perpendicular to Z-axis can be blocked through geometry.

Even if the function and the processes meet the requirements, it could be desirable to modify the chosen connections, e.g. because the connection consists of too many separate connecting features. The emphasis would then be on integration.

After connections have been modified or new features created, these should be entered into the table of connections to support reuse.

4. Conclusions

The challenge of developing products which are optimally adapted to their environment lies in optimizing their function and reducing the (dis-) assembly efforts. Thereby, connections are playing a decisive role, but no method to systematically develop connections exists.

In this paper a systematic approach for selecting and modifying connections is proposed. The starting point for this approach are the requirements regarding the function of a connection and sometimes the (dis-) connecting process. With these, the developed table of connections can be used to select the most suitable connection. This table contains information about the function and the (dis-) connecting processes of existing connections. In case none of these connections fulfill the requirements, the connections have to be modified. Some guidelines for this are given.

The proposed approach provides designers with a systematic procedure that should give them confidence in cases where decisions are difficult to make.

The additional effort needed for this systematic approach, compared to using intuition or experience, should be as low as possible and weighted against the benefits. We think that through a better process of selecting suitable connections in the conceptual stage, development time and costs could be saved in the embodiment design phase. This could lead to increased product reliability and decreased (dis-) assembly efforts (which has effects on production, maintenance and recycling), and might improve product attractiveness.

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