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INFORMATION EXCHANGE ALONG THE PRODUCT DEVELOPMENT PROCESS USING THE EXAMPLE OF BIMETALLIC CORROSION

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ABSTRACT

The reduction of the overall manufacturing costs and time-to-market is one of the biggest strategic goals for many companies. Both factors (time and costs) are incurred during the production but mainly determined during the design phase.
At the example of bimetallic corrosion the information exchange along the Product Development Process (PDP) is shown. Therefore this paper presents a concept and a prototype for detecting bimetallic corrosion in a CAD-System and describes a general way for storing information in a neutral data format, e.g. in a PDM/PLM-System. Thus the data could be used not only by designers but also by other departments, e.g. process planning.
Thereby this concept generates (nearly) no overhead for the involved departments. Though it still offers a real value added by presenting the information in a prepared and consumable way. This way the approach can scale down the "wall" still existing between product development and process planning.

Keywords: bimetallic corrosion, information management, early design phases, product lifecycle management

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1 INTRODUCTION AND MOTIVATION

The reduction of the overall manufacturing costs and time-to-market is one of the biggest strategic goals for many companies. Both factors (time and costs) are incurred during the production but mainly determined during the design phase. Therefore the integration of product development and assembly process planning is especially crucial in this context. (Bley and Franke, 2004), (Petzelt et al., 2009)
One example for this circumstance is bimetallic corrosion which occurs when two metals with different electrode potentials come in contact. One way to prevent bimetallic corrosion is to apply an insulating layer of lacquer or coating powder on the relevant parts or contact surfaces. Although this work has to be done during production and assembly (and therefore planned by the process-planning department), the contact surfaces are defined (consciously or unconsciously) by the product development department.
To obtain a competitive advantage through a shortened time-to-market and a reduction of production costs it is important that those two departments work together and share their information along the whole Product Development Process (PDP). But today in many companies the flow of information is often hindered by a systemic and personnel break between those two departments. This break can be described as a “wall” at which (planning) information gets lost (see straight line in Figure 1).

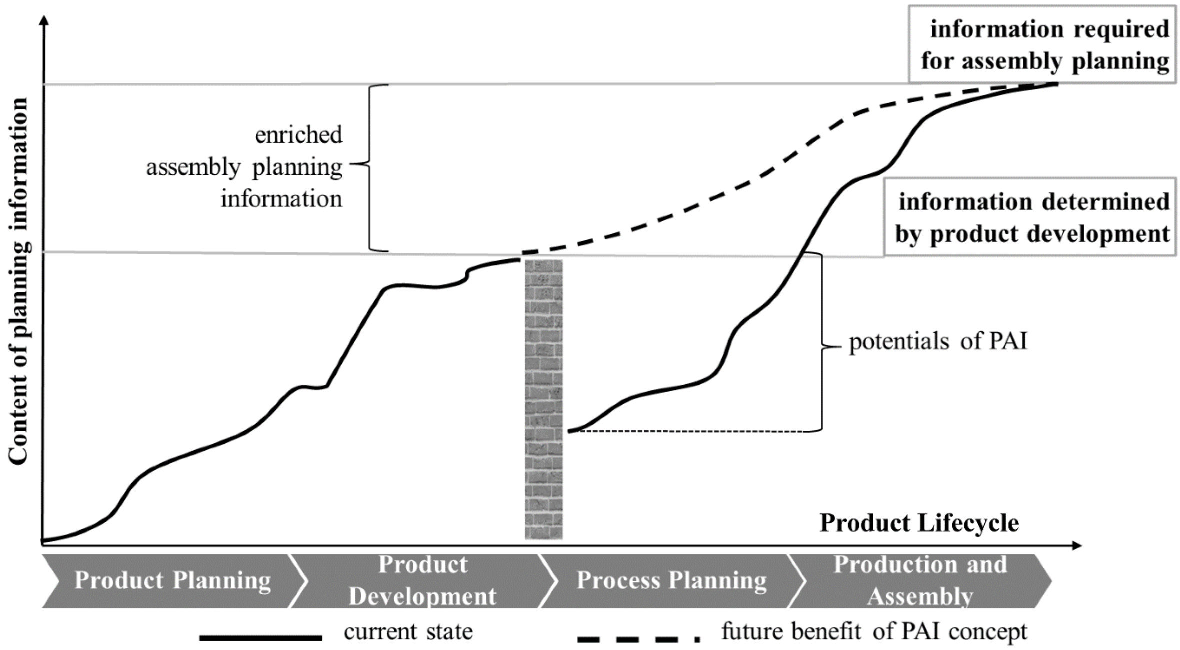

Figure 1. Information transfer along the Product Lifecycle is often disrupted by a systemic and methodically wall between Product Development and Process Planning (Eigner et al., 2013)

In the presented example of bimetallic corrosion this information would be the contact surface of two parts with different metal. Therefore, this paper presents a concept and a prototype for detecting bimetallic corrosion in a CAD-system and describes a general way for storing information in a neutral data format, e.g. in a PDM/PLM-system (Product Data Management-/Product Lifecycle Management-System). This way the information can be used not only by designers but also by other departments - especially the process planning department. By realizing this concept the content of (planning) information can be conserved as described with the dashed line in Figure 1.

2 STATE OF THE ART

2.1 Bimetallic Corrosion

In the integral design different materials are used to satisfy requirements as weight or cost reduction. An important material for a mechanical industry is metal. When two metals with different electrode potentials have an electrical contact (through the surfaces and an electrical conducting liquid) this can increase the probability of bimetallic corrosion. Even though there are some applications where bimetallic corrosion is deliberately used, like in the ship industry where donor anodes are used to prevent corrosion on the hull, it is most likely an unwanted phenomenon with dramatic consequences. (Schreckenberger et al., 2010)

Table 1. Standard electrode potentials of metals (25°C) (ICT, 2013)

Metal	**Positive metal ion**	**Standard electrode potential [V] bei 25 °C**
Li	Li+	-3,01
K	K+	-2,92
Ca	Ca2+	-2,84
Na	Na+	-2,71
Mg	Mg2+	-2,38
Al	Al3+	-2,34
Mn	Mn2+	-1,05
Zn	Zn2+	-0,76
Fe	Fe2+	-0,44
Cd	Cd2+	-0,4
Co	Co2+	-0,28
Ni	Ni2+	-0,23
Sn	Sn2+	-0,14
Pb	Pb2+	-0,13
H2	2H+	0
Cu	Cu2+	0,34
Ag	Ag+	0,8
Hg	Hg2+	0,8
Au	Au2+	1,36
Pt	Pt2+	1,6

The electrochemical processes of bimetallic corrosion have three partners, two different metals and an electrolyte. To start the process an electrical connection is required as well as a potential difference between the two metals. Thereby the conducting liquid acts as a bridge for the flowing electrons between those two metals. During this process the metal with the more electronegative potential works as anode and is destroyed by the bimetallic corrosion process. The other metal works as the cathode and is either completely protected against this corrosion type or at least profits from a slower corrosion process.

Figure 2 shows the bimetallic corrosion for a Copper-Iron-Couple.

On the right side the dissolution of iron (anode) is shown:

$$Fe \rightarrow Fe^{2+} + 2e^{-} \quad (1)$$

On the copper side (cathode) reduction of dissolved oxygen takes place:

$$O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-} \quad (2)$$

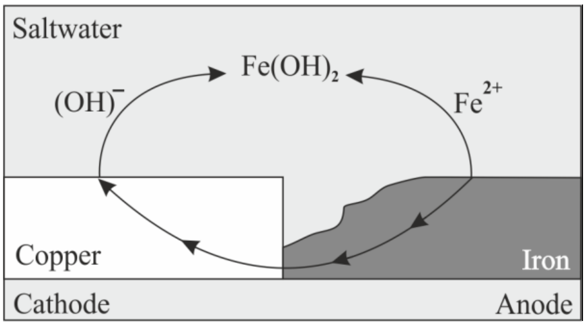

Figure 2. Corrosion process (Schulze, 2010)

As mentioned above the corrosion rate depends on the difference of the electrode potentials. With a rising potential difference between two reactants the corrosion rate increases. The values in a galvanic potential table are generally measured with respect to Standard Calomel Electrode (SCE) as a reference electrode. Table 1 shows a table with different electrode potentials for some materials. The first part of the table shows materials with negative potential while the second part shows materials with a positive potential. In between hydrogen is listed with its neutral potential. This table is used for the calculation of electrode potential differences. (Schulze, 2010)

2.2 Protection against Bimetallic Corrosion

At the design stage it should be considered which kind of corrosion is possible and how the material can be protected. The solution for bimetallic corrosion protection results from the way bimetallic corrosion works.

The first way to solve the problem is to select the same metals or metals from the same galvanic series (with a small potential difference). But this is not always possible to do, because some physical and engineering requirements constrain the engineer to use one specific material or material pair.

The second possibility to protect metals is to use an electrical isolation between the metal pair. To achieve this non-conducting materials can be used (e.g. rubbers or plastics). For bolts and other connecting elements it is possible to use non-conducting washers, spacers or spoon pieces. For bigger parts it is possible to use non-conducting panels. These parts will avoid an electrical contact between metallic parts.

The third way is to avoid wetted parts. It must be ensured, that no conducted liquid closes an electric circle between two metals. With painted or lacquer coated parts the adequate protection can be reached.

The fourth way is to optimize the relation between anodic and cathodic surfaces. The anodic surface should be minimized to minimize an electrical current flow. If an anodic surface is kept small, then electrons cannot be discharged or are discharged slower and electrical current flows slower or stops. This way the rate of bimetallic corrosion slows down or stops. Therefor “noble” (less negative) metal parts should be reduced or covered with paint or lacquer. (Schulze, 2010)

2.3 Classical Product Design Process

The product development process is quiet complex. To control this complexity many product development process models were developed over the time. Even though those processes have a number of differences they also have many things in common. By taking a look at the VDI 2221 guideline (1993) or the two models developed by Pahl and Beitz (2006) and French (1998), it can be recognized that all divided the development process in four phases (see Figure 3). They are an example for classical product design models. Each phase consists of several steps which are described in the following paragraphs.

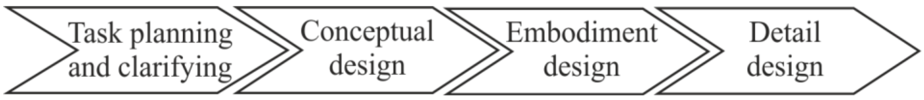

Figure 3. Four phases of product development (VDI, 1993)

The first step is the analysis and specification of the task. The result of the first step is a product specification. Based on the specification first concepts of the product are designed. During this phase

the whole product is planned. The preliminary design includes a first product structure, rough implementation of parts, materials, cost calculation, etc.
In the third phase (which uses the conceptual design as an input) the product will be divided in functional groups. In parallel there is a search for possible function implementations. Also first drafts of parts or assemblies are designed. The preliminary concepts and solutions are analysed and assessed. Until this point the models are quite similar.
The first differences take place at the middle of the third and in the fourth phase. As soon as the geometrical product information is elaborated, the process planning department gets the first production relevant information (Pahl and Beitz, 2006). In the other two models (VDI, 1993) and (French, 1998) the information exchange between product designer and production planner happens one phase later. It takes place as soon as the definitive product and product documentation are complete and all product requirements are fulfilled (see Figure 4). It cannot be excluded that some companies perform the test (e.g. corrosion test) as soon as a real prototype is created without performing a virtual test. (Schreckenberger, 2010)

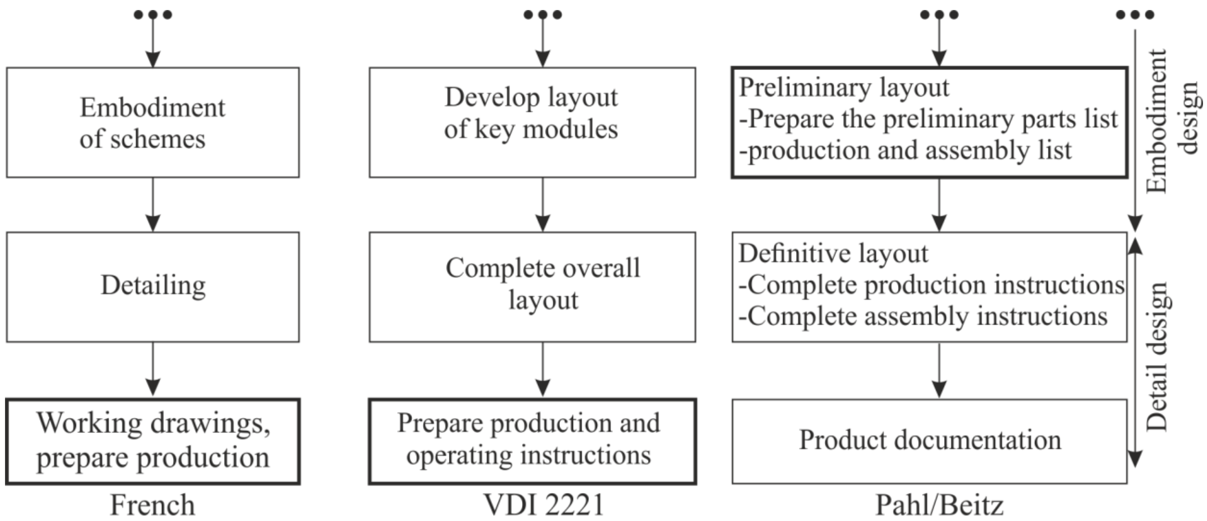

Figure 4. Comparison of product design processes

The aim of the concept, which is presented in this paper, is to bring the production relevant information exchange and the virtual tests with a preliminary geometry into earlier phases. The main benefits of the concept are earlier detection of corrosion problems and earlier, integrated information exchange between product development and product planning. Nevertheless it is possible to make the information available for other departments, if the information is stored in a PDM/PLM-System.
In these three development processes the production relevant information is exchanged between product development and production planning in late stages in PDP. The later changes are made, the more expensive they are. Therefore it is important to detect errors, in our case bimetallic corrosion, as early as possible (Eigner and Stelzer, 2009). Concurrent and Simultaneous Engineering address those challenges, but these methods do not sufficiently describe which information should be exchanged and how it should be supported by IT-Systems. (Pennel, 1989) (Bullinger, 1997)
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3 CONCEPT

Bimetallic corrosion can be avoided in many different ways (see chapter 2.2). To apply these approaches, it is in any case necessary to firstly identify where bimetallic corrosion can occur. With that information either the designer or the process-planer can decide which approach to pursue. This results in three steps for the concept described in the following:

- Detection of bimetallic corrosion
- Data storage

- Visualization in CAD
- Additional reuse

Because the effort and cost for the prevention of corrosion (as with many other changes) increase dramatically in later stages of the product development process the concept focuses on a preferably early detection. Unfortunately the tested CAD systems (Catia, NX and Creo) do not offer functionality for the detection of possible corrosion areas. Therefore the following chapters describe a prototype for a fast and easy detection in a CAD-system based on the material and the constraints between two parts.
To make the detected positions of bimetallic corrosion available for every department along the PDP the information has to be stored in an adequate way. A neutral, lightweight and easy to access format is thereby preferred. As described in chapter 3.2 there are many possible ways to do so. Because many producing companies are using Product Data Management (PDM) or Product Lifecycle Management (PLM) systems in their relevant departments (design and process planning) we recommend to store the data in those systems.
If the data is stored in a PDM/PLM-system this offers many possibilities for the usage of the information. As a first approach we developed and implemented an intuitive and comfortable add-on to a CAD-system. This prototypical tool (see chapter 3.3) is especially useful for designers and other CAD users.

3.1 Detection of Bimetallic Corrosion

The detection of bimetallic corrosion is in a proof of concept stage and relies on accessing the application programming interface (API) integrated in a typical and sophisticated 3D CAD tool. Actually for this paper the prototype is implemented in PTC Creo 2.0 using its J-Link API and Java code. The implementation is straightforward and maps the logic presented in Figure 5 to the Creo API functionality. This approach is feasible for all kinds of CAD tools offering proper API support.
The test environment consists of an assembly structure containing three parts which are assembled using constraints. The detection tool is started independently from Creo and connects to the active session of the CAD software. To start the checking procedure the engineer can press a button especially created in Creo. In a real life environment automated checks will most likely be used to replace manual activities.
During the checking procedure a number of tests and checks are executed starting with the active model which is scanned for all its contained parts. For each part the included constraints are collected and checked for their type. Constraints are described by their constraint type, an offset and a reference to a second part.
To detect possible bimetallic corrosion checks are executed as described in Figure 5 for each constraint. A textual interpretation of the flow chart in Figure 5 could look as follows:

- The offset value of the constraint is retrieved.
- If the offset is greater than zero there is no possible bimetallic corrosion and we can stop, else we have to proceed.
- With an offset of zero the two parts are touching and their materials are retrieved.
- If material of part 1 and material of part 2 are equal, there again is no possible bimetallic corrosion and we can stop, else we proceed.
- With two different materials on two touching parts we detected a possible bimetallic corrosion.
- The two involved parts, their touching surfaces and the two materials are stored for later use.

To enhance check results and improve data quality for downstream processes the material comparison step can be enriched with numerical tests instead of checking only for equality or inequality. For this purpose tables containing materials and their electrode potentials (see Table 1) can be digitally stored and included during the comparison procedure by comparing both electrode potentials and storing their difference.

Basically there are two possibilities to handle the gathered information of a detection process:

- Storage for later analysis and evaluation (see chapter 3.2)
- Immediate visualization in the CAD tool (see chapter 3.3)

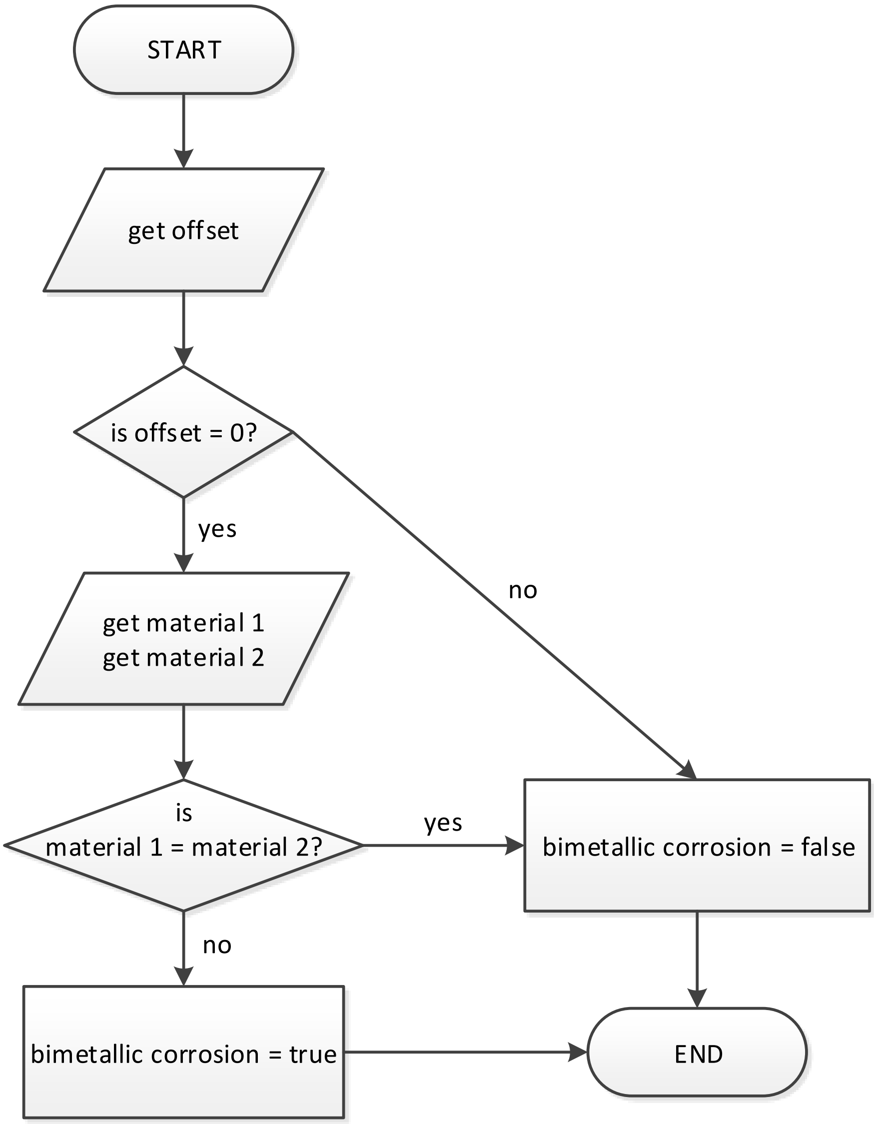

Figure 5. Flow chart of the detection procedure

3.2 Data Storage

The gathered information regarding bimetallic corrosion is not only displayed to the engineer during the assembly procedure but also saved for later usage. Preserving the information is vital for quality enhancements and a continuous improvement process since both are based on analyzing actual processes and detecting mistakes currently made during the product engineering and assembly.
Data can be stored in a number of ways depending on corporate specific requirements:

- in a file (Human or machine readable ASCII text with reference to the CAD file)
- in the CAD file (Annotation, markup or attribute)
- in the PDM (Attribute or document with reference to the CAD data)
- in a standardized format like STEP (Anderl and Trippner, 2000)

During the prototype phase a minimal set of information has been detected as relevant data which is at least required to reconstruct the corrosion alert and its detection:

- The two parts assembled by the constraint (Part 1 and Part 2)
- The touching surface of each part (Surface 1 and Surface 2)
- The Constraint Type
- The two materials of the constrained parts (Material 1 and Material 2)

Depending on the use case and predefined corporate environments the syntax for storing the bimetallic corrosion data can vary significantly. Though some basic information should be present in most cases and will most likely include data fields similar to the example in Figure 6.

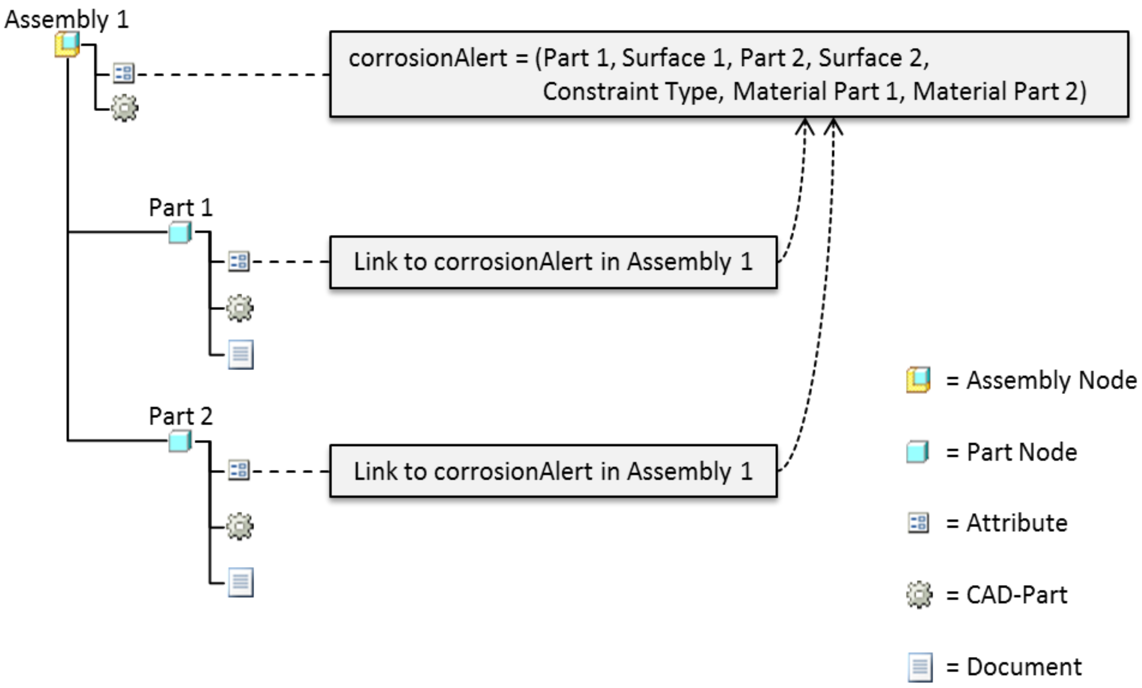

Figure 6. PDM Assembly Structure based on PTC Windchill

The attribute *corrosionAlert* in Figure 6 contains the following data:

- Part 1 = Reference to Part 1
- Surface 1 = Reference to constrained surface of Part 1
- Part 2 = Reference to Part 2
- Surface 2 = Reference to constrained surface of Part 2
- Constraint Type = Type of the constraint connecting Surface 1 and 2
- Material Part 1 = Material of Part 1
- Material Part 2 = Material of Part 2

3.3 Visualization in CAD

With the results of the detection procedure in chapter 3.1 immediate feedback to the engineer is provided through a pop-up window as shown in Figure 7. It displays a list with each entry showing the two involved parts and their materials. By popping up a warning message any unintended use of two different materials is pointed out to the engineer.

The geometry of the parts included in the constraint is highlighted in the 3D workspace by flashing green lines. This allows for easy tracking of the relevant parts and quick correction of the problem if required. In case of multiple detections the user can choose from the list of issues to highlight the respective corrosion in the 3D workspace.

3.4. Additional Reuse

For additional evaluation purposes the stored information can be analyzed. This might preferably be done from a PDM/PLM system to benefit from cross-links and a more detailed data basis.

Involved parts can be highlighted in the bill of material while the respective surfaces of the parts can be colored or marked in a 3D environment.

Simply running the tool again will also show up the desired information with direct access to the CAD model and the possibility to change materials.

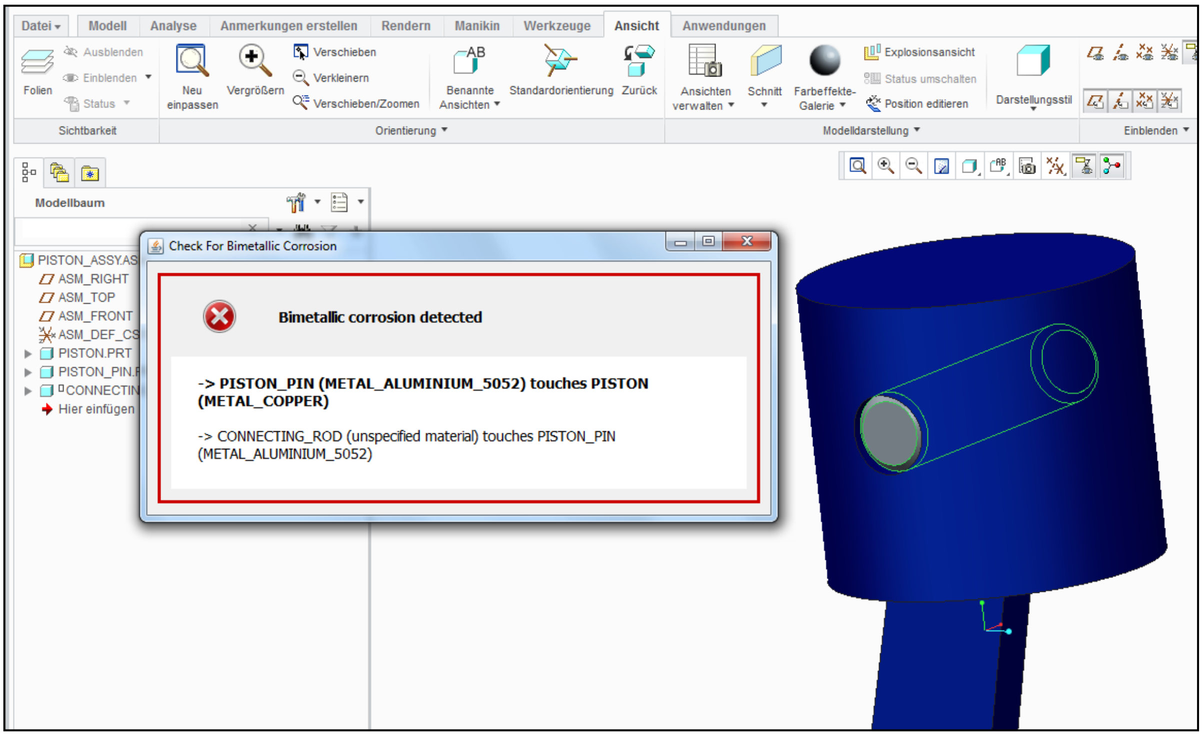

Figure 7. Pop- up window with warning message in PTC Creo 2.0

4 SUMMARY, FURTHER DEVELOPMENT AND SCIENTIFIC OUTLOOK

The described concept uses existing information (extracted from a CAD model) during the product life cycle and makes them available for different user groups, such as the designers themselves but also for process-planners and other departments located later along the lifecycle. Thereby (nearly) no additional information needs to be entered, neither by a designer nor by a process-planner. Though the concept still offers a real value added for both departments by presenting the information in a prepared and consumable way. Therefore this approach will scale down the "wall" still existing between product development and assembly process planning.

This paper presents a prototype for the detection of bimetallic corrosion which uses a minimum amount of existing information (material of two parts and the constraints between those two) and uses fairly easy detection mechanism based on this information. To improve the accuracy and reduce the amount of fail recognitions the prototype can be extended in many ways. Possible extensions include:

- Checking for surface finishes already avoiding bimetallic corrosion.
- Checking for unintentionally touching surfaces (e.g. Part A is assembled with Part B and unintentionally touches Part C which is not done on purpose by the engineer).
- Alternative materials or additional surface finishes are recommended to the engineer based on a corporate knowledge database.
- A threshold is defined for the potential difference (according to Table 1) of the two materials to allow uncritical combinations of different materials.

The exemplary data model in this paper shows that the so gathered information can be stored in a neutral and reusable format. This enables the possibility for further data usage. One way is presented in this paper by a fully functional tool for visualization in CAD. The implemented popup-windows and the additional (blinking green) highlight of the relevant surfaces in den modelling area of the CAD-system offers the designer an instant feedback. The usage of the tool is very intuitive and all relevant information is presented in a consumable way. The dialog is currently limited to visualization. Therefore further improvements should offer possibilities for interaction to directly solve the problem.

Besides this already implemented visualization in CAD-systems (and therefore manly for the designers) the storage of the information in a PDM/PLM-system offers further options for visualization and usage of the data. Involved parts can be highlighted in the bill of material while the respective surfaces of the parts can be colored or marked in a 3D environment. Simply running the tool again will also show up the desired information with direct access to the CAD model and the possibility to change materials.

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