Towards Automated Identification of Functional Designations of Components Based on Geometric Analysis of a DMU

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Abstract

With the increasing interest to automatically simplify products' 3D models to cope with varying engineering demands, the identification of functional designation of components has become an insistent need.

In this work, we suggest a method to classify elementary components of a product into a taxonomy of functional designations. This is done based on information present in the product's digital mockup; that is the geometrical properties of different solids in the assembly. We argue that relative interactions between adjacent pieces reveal essential information that guides the identification of functional properties. We refer to such interaction as conventional interfaces.

To allow our reasoning we demonstrate the relationships between geometry and force, and between force and functional properties. These connections establish the link between the mere geometrical representation that we have as input to the desired functional designations of components.

1 Introduction

Digital Mock-Ups (DMUs) are key engineering elements during different stages of product's life cycle. They mainly represent the product as a 3D model comprising geometric properties of components, along with their relative positioning and constraints. DMUs are also collaborative means of information exchange throughout Product Development Processes.

Model's complexity reduction is essential to physics-based simulations, as numerous details present in the design model render resource intensive computation prohibitively expensive. Simplification methods already exist [14]. However, in most of those methods, the knowledge about functional properties of components is indispensable.

Despite its importance when adapting a model to specific engineering needs, we can only hope for few poorly standardised annotations about functional denominations of a component in a DMU, usually presented as features. Having such knowledge beforehand facilitates necessary simplifications to scale down DMU's complexity. This is usually done by replacing the geometrically detailed components (such as screws, nuts, etc) by functionally equivalent and geometrically consistent elements (such as line segments), allowing for simulations to take place through simpler tessellations.

The aforementioned motivations actuate bridging the gap between the mere geometric representation of a model and a comprehensive functional classification of its components. Literature has tackled this problem in different ways. Efforts as early as [8] have been paid to form features recognition in solid models. In their work the geometric model is transformed into a graph representation, then graph matching techniques are applied to extract form features, also represented as graphs.

Falcidieno and Giannini in [4] addressed the problem of functional features extraction out of geometric models, and classified existing solutions back then into human assisted approaches, feature based modelling, and automatic feature recognition and extraction. Their proposed method falls in the last category and suggests a three stage solution that builds a hierarchical structure of part's shape in accordance to the level of details.

In [1], the author advocates an expert sys-

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tem approach to recognize application-specific features given the product's solid model as B-Rep.

A survey on recent techniques of feature recognition is presented in [2]. Those techniques address a wide range of features, in participation to the Computer Aided Process Planning (CAPP) automation.

In this work we aim at establishing a method to denominate components present in a product's DMU with discriminative functional labels based on the geometric description of the model. The classification is based on the relative positioning of a component with respect to its neighbours and potential interactions between adjacent solids. The reasoning is then done with the help of certain hypotheses and axioms that relate concepts of geometric configurations, internal forces, objects' mobility, and functional properties together.

This work is an exploratory effort toward an automated identification of components designation, trying to establish the basis for robust algorithms in this direction. A direct application to such approach is structural and thermal analyses and computational fluid dynamics simulations to assess product's fulfillment to functional requirements. Another application would be the immersive environment simulation for training, testing and other purposes[11, 3, 12].

In the remainder of this paper, we establish the theoretical background of our research, defining basic concepts, and formulating axiomatic hypotheses in section 2. Having formally introduced our problem and related concepts, we present ourapproach walking through basic examples, and showing how the inference process can be conducted on simple components in section 3. We finally conclude in section 4 to summarise what have been demonstrated so far.

2 Definitions and Axioms

In this section, concepts that are central to our work and hypotheses essential for the reasoning are defined and highlighted.

2.1 Functional Designation and Taxonomy

In the remaining of this paper, we refer to the identifying denomination of a component that unambiguously describes its functionality and role in an assembly by its *Functional Designation.* Examples of functional designations are cap-screw, tubular rivet, locknut, stud, spur gear... etc. A functional designation can be regarded as a class of components. This is not to be confounded with component's function, as one component belonging to one functional designation class may contribute to more than one function. For instance, a tubular rivet can play both roles of fastening and of pivot point at a time. Moreover, one function can be performed by members of different classes of functional designation. An example is a cap-screw and a solid rivet which both do the job of fastening. However, members of the same functional designation class provide all the same set of functionalities.

Based on this discriminative classification of components, we build a hierarchical taxonomy represented as a tree structure, where leaves are the functional designations, and nodes are their generalisations (e.g. fastening component, screw, rivet, gear... etc).

2.2 Solid Model of a Product

A *solid model* is an unambiguous geometric representation of an assembly in terms of its solid constituents. Solid modelling can be achieved using different schemes, the most important of which in the world of Computer-Aided Design (CAD) systems are Constructive Solid Geometry (CSG) or history trees and Boundary REPresentation (B-REP).

CSG and history trees represent solids as trees where leaves are primitive object shapes (such as spheres, cuboids, prisms, pyramids, cones, cylinders, etc.), nodes are boolean operators (union, intersection, and subtraction) or extrusion, pocket, revolution, etc. operators, and the root of the tree is the modelled solid. These approaches are used to keep track of the construction process of the product. These methods, however, don't guarantee a unique representation of the solid, that is, different construction trees exist modelling one and the same solid.

Alternatively, solids can be modelled using B-REPs. In this case, objects are represented by means of their boundaries. Solids thus are defined as the interior of closed surfaces. Unlike CSF, this method partially hides the history of construction. However, when combined with the generation of maximal surfaces and curves [10], it provides a a unique representation of a solid. We hereafter adopt this representation, as in our research we are only concerned about the final geometry of the product. Thus, we consider DMUs to be presented as B-REPs with maximal curves and surfaces.

Here, it is also hypothesized that analytical surfaces, i.e. planes, cylinders, cones, spheres, are tagged to address specific algorithms when identifying interfaces between components.

The International Organization for Standardization (ISO) defines the protocol ISO 10303, collectively known as STEP (Standard for the Exchange of Product Model data). The protocol is meant to propose means of data exchange and representation throughout a product's life cycle. To this end it defines some data structures for boundary representation. Generic topological and geometric aspects are defined in Part 42 [7], while application protocols such as AP204 [6] suggest structures to model solids in B-REP.

In this work, we consider the geometry of the product to be represented as a STEP model, in accordance with ISO 10303 specifications to conform to model exchange processes. This is often the case at different stages of a product development process. Such a model contains the identification of analytical surfaces that often act as functional surfaces between components. In the current scope of our work, functional surfaces are restricted to planes, cylinders, cones, and spheres.

2.3 Conventional Interfaces

Definition 1. A *component* is a solid bounded by closed surfaces.

According to this definition and the hypotheses of the section refsub:modelling, the components processed are completely independent of their construction tree that may group more than one solid in one entity. Moreover, components are three-dimensional manifolds, that is, no non-manifold configuration entry point is considered when analysing components.

This assumption gains its ground from the fact that real components are 3D objects that do have volume. However, simplified object presented as non-manifold or less than three-dimensional objects (e.g. plates represented as surfaces, or strings as curves) are out of the scope of our analysis.

Definition 2. A *conventional interface* between components in a solid model is the relative positioning of adjacent surfaces of different components involving functional surfaces. This can be one of three configurations:

- Clearance;
- Contact; or
- Interference.

Conventional interfaces are the result of the intersection between components' interiors (in the case of interference), components' boundaries (in case of contact) or components' dilation by a specific structuring element (in the case of clearance) over a subset of each component boundary.

Contacts are very common in assembly models, as they reflect the physical interaction between solids. In a real product components often lie on each other through contact surfaces, which are functional surfaces. Clearances, however, are less common in a DMU, but they still closely reflect reality when components are kept close enough, though not in contact. As its description entails, interferences are non-physical configurations, as solids matters do not intersect in a real functional product. However, the use of interferences is widespread in products' DMUs, as they represent idealisation of highly detailed parts of the real components, such as toothed or threaded connections. In this case also, threaded connections use cylindrical surfaces in the idealized representation as the envelope of positions of a screw. Therefore, this cylindrical surface is regarded as a functional surface. They may also stand for a deformed object configuration, as for rivets. More generally, at least one functional surface of a component takes part to an interference boundary. The location of these functional surfaces over an interference reflects properties of the idealisation, which is not detailed here.

Next, we formally define aspects such as interference, contact and clearance. To this end, we will apply topological concepts[9] such as solid interior $int(S)$ which is the set or interior points of S in the Euclidean space $\mathbb{R}^3$, and solid closure $cl(S)$ which is the union of the solid interior and its boundaries. We recall that a solid is called an open set if it is equal to its interior, and it is called a closed set if it is equal to its closure.

We also borrow the morphological concept of dilation[5], where the dilation of a solid S with respect to a structural element A is denoted $S \oplus A$. In our case, the structural element is a closed sphere of radius ρ, and the dilation returns the extension of the solid by ρ over a subset of the solids boundary.

Definition 3. Two solids C_1 and C_2 are said to be at *interference* if and only if

$$Z_i(C_1, C_2) = cl(int(C_1) \cap int(C_2)) \neq \emptyset.$$

We call $Z_i(C_1, C_2)$ the *interference zone* between solids C_1 and C_2.

The definition states that two solids interfere if and only if their interiors intersect, resulting into a non-empty set. In fact, the use of closure in the previous definition is unnecessary to define the intersection itself. However, we define the interference zone to be a closed set to enable its reuse in later definitions. The above definition contains all the interferences over a solid, i.e. $Z_i(C_1, C_2)$ has n disconnected components $I_{1,2}k,\ k \in \{1, 2, \ldots, n\}$. Each component $I_{1,2}k$ is not necessarily defining an interference from a functional point of view. If several components $I_{1,2}i, \ldots\ , I_{1,2}m$ belong to the same functional surface (a maximal surface) of either C_1 or C_2, indeed they define the same conventional interface.

Definition 4. Two solids C_1 and C_2 are said to be at *contact* if and only if

$$Z_c(C_1, C_2) = (cl(C_1) \cap cl(C_2)) - Z_i(C_1, C_2) \neq \emptyset.$$

We call $Z_c(C_1, C_2)$ the *contact zone* between solids C_1 and C_2.

The definition states that two solids are in contact if and only if their boundaries intersection is a non-empty set that is not contained in the boundaries of their possible interference zones. The fact that the interference zones are a closed set allows us to exclude boundaries intersections that are the result of an interference (when boundaries cross each others). Here also, $Z_c(C_1, C_2)$ contains m disconnected components, $T_{1,2}k,\ k \in \{1, 2, \ldots, m\}$. All surfaces involved in contacts are functional surfaces of C_1 and C_2. Disconnected components $T_{1,2}i$, , $T_{1,2}m$ can be merged together to form a conventional interface if they share either of the functional surface of C_1 or C_2.

Definition 5. Two solids C_1 and C_2 are said to be at *clearance* with respect to a distance ρ over an area A_c if and only if

$$\begin{aligned} &Z_j(C_1, C_2) = \\ &(C_1 \cap (C_2 \oplus A)) - (Z_i(C_1, C_2) \cup Z_c(C_1, C_2)) \\ &\qquad\qquad\qquad\qquad\qquad\qquad \neq \emptyset. \end{aligned}$$

Where A is a closed sphere of radius ρ. We call $Z_j(C_1, C_2)$ the *clearance zone* between solids C_1 and C_2 defined over the area A_c.

The definition states that two solids are at clearance if the ρ-thick shell covering A_c on the solid C_2 intersects with the other one, resulting in a non-empty set. The notion of disconnected components applies also here likewise contacts and interferences and clearance relates to at least one functional surface of C_2. This definition can be applied symmetrically to C_1.

We refer to the generalisation of interference zone, contact zone, and clearance zone as an *interaction zone* for components of these zones defining conventional interfaces.

It is worth mentioning that while interference zones are 3-dimensional (with possible non-manifold configurations) contact zones are either surfaces, curves or points.

As seen above, for each maximal connected component related to a single functional surface of each interaction zone, a conventional interface is said to exist joining both components involved in the interaction. The interfaces is then said to be either interference, or contact, or clearance in accordance to the interaction zone type. This can be regarded as a more formal definition of the conventional interfaces.

A conventional interface, thus, has as property a geometric object which is its interaction zone. In its turn, the interaction zone has its own properties as well; it can have length in case of curvilinear contact, area in case of surface contact, or volume, either positive in case of interference or said negative in case of clearance.

In the general case, the interaction zone can be of an arbitrary shape. However, in the majority of cases, shapes defining interaction zones are limited to geometric primitives such as line segments, circular, as curves, and planes, spheres, cones, and cylinders as surfaces. Faces are usually formed by one of the above-mentioned surfaces, since they fall into the category of functional surfaces,. Volumes then are formed by a closed set of functional surfaces and other free-form surfaces.

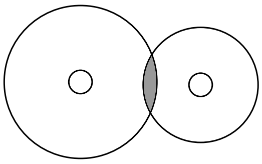

Figure 1: Cross section of idealized toothed connection represented as an interference.

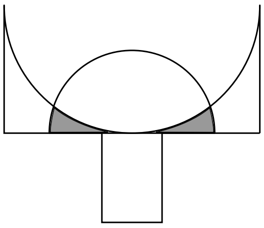

Figure 2: Cross section of an idealised deformed body represented as an interference with non-manifold configuration.

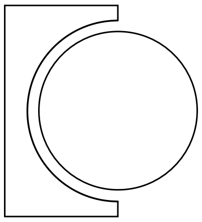

Figure 3: Cross section of a clearance example.

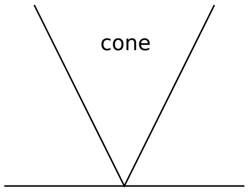

Figure 4: Cross section of punctual contact.

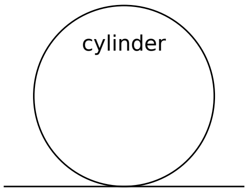

Figure 5: Cross section of linear contact.

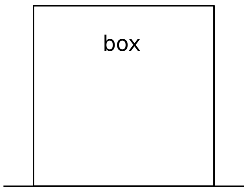

Figure 6: Cross section of surface contact.

In our study, we attribute the conventional interfaces by their functional surfaces. This allows for the introduction of many geometric constraints and relations to enrich the reasoning, such as symmetry, concentricity, coaxiality, parallelism, and perpendicularity. For instance, we call “mono-axial cylindrical interference” an interference whose interaction zone is bounded by two coaxial cylinders, we call the common axis of the two cylinder the interference axis. We also call “planar contact” a contact whose interaction zone lies on a planar functional surface. This generalises to conic, spheric and cylindric contacts. We then can refer to a planar contact to be perpendicular to an axis if the plane its contact zone lies on is.

2.4 Reference States

Here we define the concept of the state in which the product is studied and the digital mockup is analysed. We refer to this state as the *reference state*. This is accomplished through a set of hypotheses and axioms that we assume to hold true on the model at hand.

Hypothesis 1. The digital mockup is consistent.

We are only interested in consistent DMUs, that represents a functional product and contain no contradictory information. This assumption allows us to derive reasonable conclusions.

Hypothesis 2. Conventional interfaces are time-invariant.

From a kinematic stand point we differentiate between mechanisms and structures when analysing a products model. As mechanisms are supposed to provide a method of transmitting motion between different components of the product, the model is presumed to have at least two different kinematic classes. For instance, a body that is considered stationary, and an axial arm with associated components that possess a rotational movement.

Structures however are motionless, that means that all components in the model belong to the same kinematic class and thus are considered stationary.

Due to the immobility of structures, the whole system is considered time-invariant, including its conventional interfaces. In a mechanism, however, the product model contains relatively mobile parts with respect to each others. That is, the model potentially changes its state over time. We here assume that no matter how the different parts move, the conventional interfaces between those parts, along with their attributes, remain the same. That is, the relative movement of parts doesn't add any new interfaces, nor remove old ones, neither does it alter their types (contact, interference, or clearance).

An example would be a four-stroke internal combustion engine, where although the model shows high mobility, components tend to maintain their conventional interfaces unchanged. For instance, the piston stays only in a cylindrical contact with the combustion chamber, despite the translational motion.

This assumption, however, doesn't hold in the general case, one counterexample could be the Maltese cross (Figure 7), where conventional interfaces are added and suppressed while wheels rotate.

The time invariance property of conventional interfaces limits the relative movement of components in the model, allowing us to deduce the existence of internal forces that keep those components together. This hypothesis is realistic, as components in a function product are indeed held together to form an assembly, and it is only the mechanical stresses exerted between components that keep them assembled.

Hypothesis 3. The product is an isolated system.

This hypothesis is meant to define a reference state in which the product is in mechanical equilibrium. That is:

- no external force is applied to the product,
- no external moment is applied to the product [13].

This assumption allows us to exploit lows of conservations to derive more conclusions.

A second reference state can be of interest for mechanisms. This state refers to a kinematic point of view where the mechanism representing the product is analysed in working conditions. The purpose of this state is the specification of the kinematic equivalence class of each component to define the kinematic chain of a mechanism.

Based on the functional surfaces and conventional interfaces, relative movements between components fall into three categories:

- translations,
- rotations, and
- helical movements.

This depends on the meaning of idealisation configurations, e.g. threaded connections are often idealised as cylindrical surfaces with interference and they express helical movements between the components.

Kinematics is not explicitly available in a DMU because contact interfaces can be associated with either positive or negative clearances enabling or preventing a relative movement between components, i.e. whether or not the corresponding components belong to the same kinematic equivalence class. Moreover, a DMU is only an instantaneous configuration of a product and, from a purely geometric point of view, there is no information available to generate the relative movements between components.

Here, the invariance of interfaces and the type of interfaces enable the generation of relative movements between components as infinitesimal displacements. Finite displacements would require checking the consistency of displacements over their whole amplitude. Because a DMU is a still configuration of components and clearances parameters are not available, it is mandatory that the user provides input to specify kinematic equivalence classes of an input movement, i.e. a still component and a moving one like crankcase and shaft.

The corresponding state of the DMU solely relies on kinematic equivalence classes and, hence, it is independent from the previous one based on internal forces only. Currently, preliminary work has shown that users input can be propagated to generate a kinematic equivalence class for each component as input of a reasoning process.

Other DMU states can be connected to the reasoning process. It is particularly the case for deformable components where their deformation process is associated with different shapes. Here again, the conventional interfaces of components is the source of inferences for deformable components.

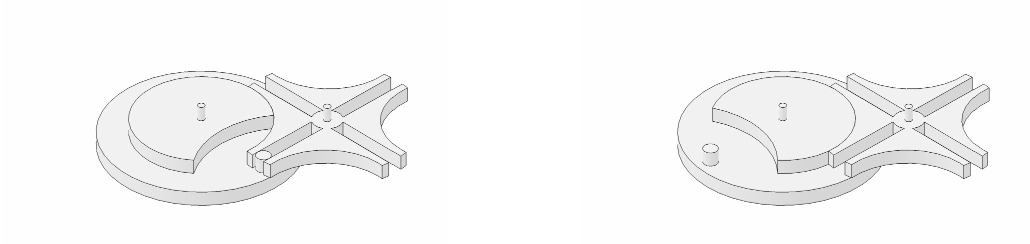

Figure 7: The Maltese Cross at two different stages of its rotation, showing how conventional interfaces change.

2.5 Conventional Interfaces Graph

We consider one conventional interface to be a binary relation between components. That is each conventional interface binds exactly two components, having their interaction zone as attribute. Initially, this assumption is not globally valid, as for some cases more than two components can be at the same interference. Nevertheless, such anomalies can be solved by treating those interferences as two or more conventional interfaces, having only two components each.

To have a general perception of how different components in a DMU interact, we represent the above-mentioned relation as an undirected graph.

Definition 6. The *Conventional Interfaces Graph* of a product's DMU is an undirected graph with components as graph vertices and conventional interfaces as graph edges. Graph edges hold interfaces' attributes.

Further analysis of the graph enables the inference of more information about the functional designation of components. It also permits making grounded assumptions about the relative mobilities of different parts in the assembly consistently set with respect to internal forces between components. Such assumptions are based on physical properties, which are in turn deduced from the geometry of the system, and the assumption of reference states, that implies the consistency of the model and the isolation of the assembly.

3 Reasoning Elements

After establishing the theoretical framework, we describe in this section the proposed inference process that leads to the identification of component functional designations using the reference states described in section 2.4.

As mentioned before in section 1, the inference is highly dependent on the tight relations between geometry and forces, and between forces and mobilities. We refer to these relations as geometry/force and force/kinematic dualities, respectively. Duality means that there is a bijective mapping between configurations of the first aspect and those of the other.

3.1 Geometry/Force Duality

When conducting the geometric analysis of a DMU, the system is considered to be at the reference state of isolated mechanism mentioned in section 2.4, which implies tight coupling between geometric configurations and internal stresses. This is a result of the assumptions of model consistency and isolation, and conventional interfaces time invariance. An example would be a planar contact between two solids: following the time invariance assumption, the two solids remain in planar contact over time, that is, they are held tight together. Since the product is assumed to be an isolated system, only internal forces can be presumed to hold the two solids. Thus, the deduction of the exertion of reciprocal stresses between the two solids. Then, this elementary reasoning process can be propagated to another solid up to the validation of isolated state of the DMU, i.e. no component should be left non-equilibrated to avoid the generation of movements. If not equilibrated, the resulting movements should be rotations.

Another example would be a cylindrical interference. In this case the mere information about the interface itself is not enough. More geometrical analysis has to propagate to the neighbouring objects in order to deduce the internal stresses. However, only a threaded connection, a tight assembly, or a spline coupling combined with a snug fit can be hypothesized to exist between the two solids, reducing the number of possibilities to reason about.

3.2 Geometry/Kinematic Duality

Geometric configurations –reflected as conventional interfaces– determine objects' mobilities to a great extent, that must conform to the kinematic working state specified at section 2.4. For instance, two parallel cylindrical contacts on a solid yield a translation between the objects, causing null-mobility along the normal to each cylindrical contact.

The constraints that geometry applies on objects mobility lead us to the classification of those objects into mobility equivalence classes. Objects belonging to the same mobility class are stationary with respect to each others, that is, they all enjoy the same mobility, if at all mobile.

A snapshot of the product, as presented by its DMU, cannot provide more information rather than that. In this stage, minimal users intervention is essential as stated at section 2.4. This piece of information propagates the rest of members. At this point, it has to be noticed that the lack of indication about positive/negative clearances may create a fair amount of internal mobilities.

In some cases, the absolute lack of mobility indicates deformation that took place to assemble the object. As the example of retaining rings, where the only solution to a consistent model (where assembling and disassembling components are feasible) is the existence of elastic transformation. Another example is a rivet, where the null-mobility, the possible interference and non-dismountability of objects indicates plastic deformations. Other reference states for specific components have not been described for the sake of conciseness.

3.3 Inference Locality

The complete Conventional Interfaces Graph CIG has as order the number of solids in its corresponding DMU. This can range from few tens to few thousands or more, rendering the reasoning over modestly large graphs inefficient. However, the identification of a component's functional designation shouldn't require the reasoning over the whole graph, but only over the neighbouring solids to a certain degree (immediate neighbours, neighbours of neighbours..., etc). We call $CIG|_C$ the smallest subgraph of CIG that matters to the inference of the functional designation of component C.

$CIG|_C$ is first initiated by component C as one-node graph, it is then iteratively augmented by interfaces that involve at least one component belonging to $CIG|_C$ nodes as graph edges, and their respective components as graph nodes, as long as such interfaces add up to the inference of functional designation of C. The iterative process stops when all candidate interfaces are irrelevant to the identification process.

As all $CIG|_C$ nodes are also nodes of CIG (the set of all solids in the DMU), and all its edges are as well edges of CIG (the set of all conventional interfaces), it logically follows that $CIG|_C$ is a subgraph of CIG. Moreover, and according to its iterative definition, $CIG|_C$ is a connected component of CIG.

The missing piece now is to know how to determine whether an interface participate to the inference process or not. A precise answer to this question will helps pruning the subgraph down to exactly what is needed, no more, no less.

To demonstrate how the construction of $CIG|_C$ is propagated, we consider the example of a cap-screw holding several components together. Obviously, the fact that the component is a cap-screw is not available initially, as it is what we are looking for. However, we have the whole CIG of the DMU containing the screw besides other components, along with conventional interfaces between them. We refer to the cap-screw as C from now on. Thus, we're aiming to construct $CIG|_C$. First, we initiate $CIG|_C$ with C and all its adjacent components as nodes, and the conventional interfaces between those components as graph edges. The addition of immediate neighbouring component is justified by their clear participation to the identification process.

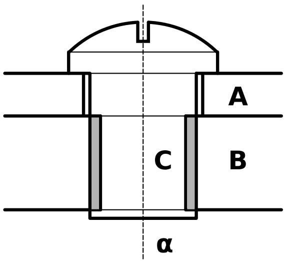

Figure 8: Cross section of an idealised representation of threaded connection in a cap-screw, showing the interference zone in grey.

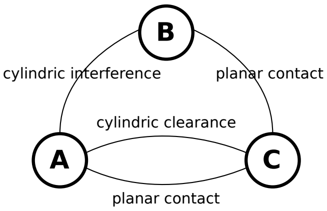

Figure 9: The CIG generated of the simple cap-screw model.

The existence of the cylindrical interference between C and B suggests –among other possibilities– the existence of a threaded connection. Following this hypothesis, internal stresses are assumed to exist collinear to the axis of the cylindrical inference α_I, alongside the threaded zone. In the case of fastener components, this forces should propagate creating a loop that ties at least two other components together. However, and since those forces are coaxial to the threaded connection, the propagation can only occur through contact zones that have an average normal that is parallel to the cylindrical axis as well. Examples of such surfaces are:

- Planar surfaces orthogonal to α_I;
- Spherical surfaces with a centre coincident to α_I;
- Conical surfaces with an apex coincident to α_I.

Finally, the force is propagated to the assumed thread through a planar contact in case of cap-screw, that is, the contact between the upper most component and the head of the screw.

Intermediate contacts should not only be parallel (or have parallel global norms), but they also should be non-coplanar. Consider the example shown in figure 10, where two cap-screws assemble three plates. The geometric analysis of the model generates the graph depicted in figure 11. In this example, one may mistakenly consider two screw-head/upper-most-piece contacts as part of the same internal stresses loop, as both contacts are parallel to the thread axis. However, this conclusion is faulty, as internal efforts cannot propagate orthogonally to their direction, thus, contacts (parallel to efforts) cannot lie on the same plane.

If no such contacts exist (that are globally orthogonal to the axis α), and as long as the model is consistent, the original threaded connection assumption is invalidated, and another interpretation of the cylindrical interference should be investigated.

The closure of the internal forces loop confirms the initial assignment of “cap-screw” as functional designation to the underlying component. At this point, adding more interfaces to the $CIG|_C$ subgraph is pointless, as they are irrelevant to the inference process.

The previous examples show that the process of determining $CIG|_C$ and the process of identifying the functional designation of C overlap, and are dependent on each other.

The above description is a simple where interference meaning is uniquely set to threaded connections. Often, current DMUs may contain interferences or contacts having similar geometry but corresponding to different functional designations. In this case, complementary criteria are required to distinguish alternative possibilities of functional designations. As to the reference state of isolated mechanism, the criterion to distinguish between functional designations is the minimization of the number of functions of a component. Indeed, this criterion minimizes the complexity of components, hence of their cost, which is the usual purpose of industrial products. Similarly, in the working kinematic state of a DMU, positive and negative clearances cannot be distinguished. The criterion of minimization of the internal mobilities of the DMU is a means to select the appropri-

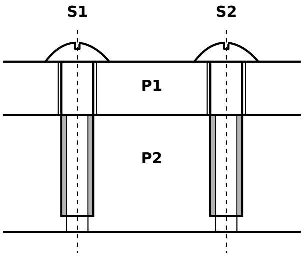

Figure 10: Cross section of an idealised representation of two threaded connections as two cap-screws binding two components.

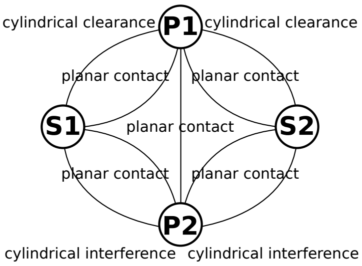

Figure 11: The CIG resulting from the two threaded connections configuration.

ate type of clearance consistently with the forces transmitted in the isolated reference state.

3.4 Iterative Process

At the beginning of the reasoning about the functional and kinematic properties of components, all components are assumed to be unknown. Little by little, this ignorance about their functionality and mobility clarifies. In many cases, the knowledge about functional designation or mobility class of one component is useful, sometime necessary, for the identification of another. This gives rise to the issue of identification priorities, that is, which component should we investigate next.

This suggests an iterative parsing to our model, where at each pass, we try to deduce as much functional and kinematics properties of the model's component as possible. The process of identification continues until no more information can be derived of the model. At this point, and in the lights of what has been identified so far, the algorithm either return the model, now annotated with functional designation and kinematic classes, or asks for users feedback to enable further reasoning, and launches the inference process again.

4 Conclusions

This work is a preliminary step towards an automated identification of components functional designation in a DMU. In this paper, we emphasized the motivation of our work, and formulated the theoretical framework upon which further algorithms and data structures will elaborate.

The integration of neighbourhood geometric information in the inference process was particularly suggested, presenting the concept of conventional interfaces that defines the geometric interaction between one component and its adjacent solids. We also advocate the exploitation of such geometric knowledge to deduce physical, kinematic, and functional attributes of the model. This suggestion is backed by the strong relationships between geometric configurations and internal forces at one hand, and geometrical configurations and kinematic properties at the other. We refer to those tight connections as dualities that form essential elements of reasoning in our approach.

Reasoning was demonstrated through simple examples, basic algorithms were also sketched that form the basis of future work.

The work done so far shows that the method proposed have significant potentials in enabling a fully automated procedure of identification. It also points out the merit of the efforts have and still being paid in this research.

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