Computer aided process planning based on ontology and rules system applied to forging domain

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Abstract

In order to reduce product and process plan design time and cost, the integration of the relations that exist between product data and manufacturing data is essential. This paper proposes an original approach to support this integration, mix of rule based and classification approaches with ontologies. This approach has been implemented in a computer tool which allows the formalization and the use of manufacturing knowledge, particularly to aid the design of process plan in the forging manufacturing domain.

Keywords: ontology, rules, computer aided process plan, forge

1. Introduction

The study presented in this paper takes place in the framework of product process plan integration. That means design the product, the associated process plan, determine the manufacturing processes and the resources that are used, considering the links that exist between these four kinds of element. The aim of this approach is to design more rapidly, and with as less as possible drawbacks on previous choices. In order to reach this goal, it is necessary to get, store and exploit the knowledge concerning the links cited before. This study is for the moment limited to the links between part parameters and process plan parameters (and thus manufacturing processes), resources are not considered. There are two ways for the exploitation of this knowledge:

- The first one consists in determining the constraints on the process plan due to the choice of certain values for the part characteristics (see for instance [1]);
- The second one is the inverse, i.e. determining which constraint some part parameters have to respect in order to let some process plan parameters possible (for example the use of certain manufacturing processes).

This paper is limited to the approach proposed for the first one: a computer aided process planning that is supported by ontologies and rules.

The first section of this paper concerns the choices that have been made for the treatment of the links between part parameters and process plan parameters, the third and the fourth ones describe the two part of the proposed approach. Finally some conclusion remarks and prospects are evoked at the end. This study is applied to the forging manufacturing process, thus some choices are made considering the specificity of this manufacturing domain.

2. Different ways for product process integration

There are several ways to process the links between part parameters and process plan parameters; among those ways, three of them are particularly interesting for our issue: group technology approach, rule based reasoning and case based reasoning.

- Group technology: this method consists in classifying objects into families, function of their similarities. In the context of this study, it is used for classifying the parts according to their characteristics into part families. Each part family is associated to consequences on the process plan parameters and typically a more or less general process plan. Some examples can be cited for this approach such as [2-3]. This approach is similar to the blacksmith reasoning when he recognizes a part of a certain type and he knows the process plan associated to this kind of part.

- Rule based reasoning: the rule based reasoning method consists in using a set of rules which queue is relative to the part parameters and head to process plan parameters. The consequences on process plan parameters can be inferred from some part parameters (see examples in [4-9]). This reasoning is similar to the manufacturer's one when he recognizes some characteristics on the part and associates directly to them some consequences on the process plan, for example if the part is bent, then there must be use of a bending process in the process plan.
- Case based approach ([10-13]): the principle of case based approach is to find one or more similar parts that have been processed (i.e. their associated process plans have been determined and validated) to the current one. The associated process plan of this part is derived from the process plans of the similar parts, function of the differences between those ones and the current one.

First remark: in this paper are not considered any feature approach (geometrical decomposition reasoning) [14-15] due to the considered manufacturing domain: forging. Indeed the forging process cannot be linked to any particular feature on a part. A part must be considered globally, with part parameters such as complexity ratio, general class of shape, rectangularity ratio, bending presence, etc…

Some remarks on the three presented approaches: the case based approach presents some difficulties overall to be booted because of the hard competition between forging companies. Then it's impossible to get a sufficient number of real cases and to fill a case base. Moreover the user can be a designer, client of a forging manufacturer, the interest would be certain if the case base could be shared but due to evident confidentiality problem, this is impossible.

The problem of group technology approach could be the proliferation of the families: indeed to cover a large panel of parts and to have process plans not too general, the part families must be more precise and thus numerous.

The problem of rule based approach could be the fact that rules are not contextual with a process plan, they bring consequences on the process plan without considering this one globally. It can lead to some inconsistencies.

A good compromise would be to combine group technology and rule based approaches. The aim of this combining is to limit the proliferation of the part families, conserve a certain level of precision of them, and limit inconsistencies of rules thanks to their adjunction directly associated to each family. The idea is first to associate a process plan with some degrees of freedom to each part family (here is the use of group technology approach) and second: for these degrees of freedom, a set of rules is associated. The proposition presented in this article is to realize the first part (classification in part families) thanks to an ontology. This is presented in the next section.

3. Classification with ontologies

3.1 Presentation

The first part of our approach is to classify a part into one or more part families.

Table 1 gives an example of parameters that allow the classification of a part in a family.

Table 1
Example of classification parameters

Name of the parameter	Type
Existence of a central boss	Boolean
Bent part	Boolean
Existence of an opening	Boolean
Part with slender shapes	Boolean
Existence of a plate	Boolean
Revolution part	Boolean
Complexity ratio	Real
Diameter/height ratio	Real
Diameter/Height of the boss (if exists) ratio	Real
Rectangularity ratio	Real
Section variation ratio	Real

After filling the parameters in, the classification can be done to get the part family to which the part belongs.

3.2. How can it work with ontology ?

After explaining what is an ontology and what can be expressed with, we'll see how we can formalize the knowledge for our needs.

3.2.1 What is an ontology?

An ontology is defined as a specification of a conceptualisation of a knowledge domain [16].

More technically, an ontology is a set of:

- classes organized in a hierarchy (based on the relation is-a : taxonomy)
- instances of classes
- properties (that are also called relations) that can be applied to instances and may link several instances between each other
- restrictions on relations defined for one or more classes.

An ontology enables [17-19]:

- To describe a knowledge field (ex: to belong to a certain part family, the part must have certain characteristics and this family implies some recommendations about the manufacturing process).

• To store a data structure and also the data (ex: in the ontology can be described a class named « Machine » that have for attributes: "name", "power", "availability", etc. and the user can fill in the fields with the corresponding data for his workshop).

• To define a common vocabulary for the field (in the form term/definition) in order to favour interoperability between several applications.

We must observe that the reasoning applied on the ontology rests on the open world assumption, i.e. all that is not asserted isn't assumed to be false.

3.2.2 Automatic classification

After having defined the taxonomy as well as the relations between the classes, it is possible to assert some restrictions on those. These restrictions are used to define necessary and/or necessary and sufficient conditions to be instance of a class.

For instance, the Part class is a primitive class, i.e. it has only necessary conditions. Other classes like part family classes are defined classes: there exists for each of those ones at least one necessary and sufficient condition. Thanks to that, the classification in those classes is conceivable.

3.3 Structure of the ontology

The structure set to realize the classification of the part is presented on figure 1. As it can be seen, there are two kinds of parameters with a different structure for each one:

- List parameter: the range is simply expressed with classes that represent the possibilities, the affectation is realized with the linking of the considered part (samplePart in that case) to an instance of the desired property (sample-Part_Bending_absent).
- Float parameter: for this type of parameter, interval classes must be created; example for the complexity ratio: three interval classes representing different ranges have been created. The affectation is realized with the linking of the considered part to an instance of the right interval class that corresponds to the value to fill in.

Finally, the class Part_Family1.1 is a defined class: it owns some restrictions on part parameters (not represented on figure 1) that allow the classification of a part.

The interest of the classification is that the defined class in which a part can be classified, is linked to a kind of process plan with degrees of freedom that can be developed in several process plans according to the respect of some contextual rules. This is the matter of the next section.

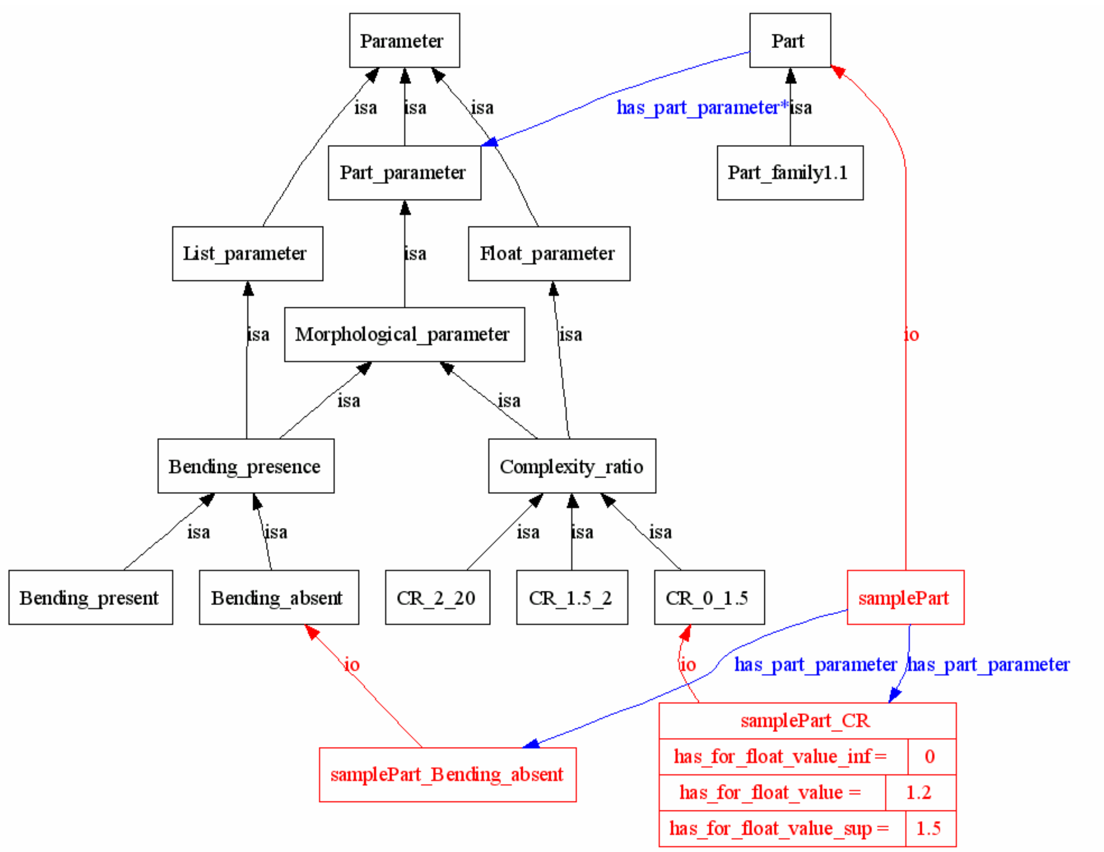

Fig. 1. Structure of the ontology

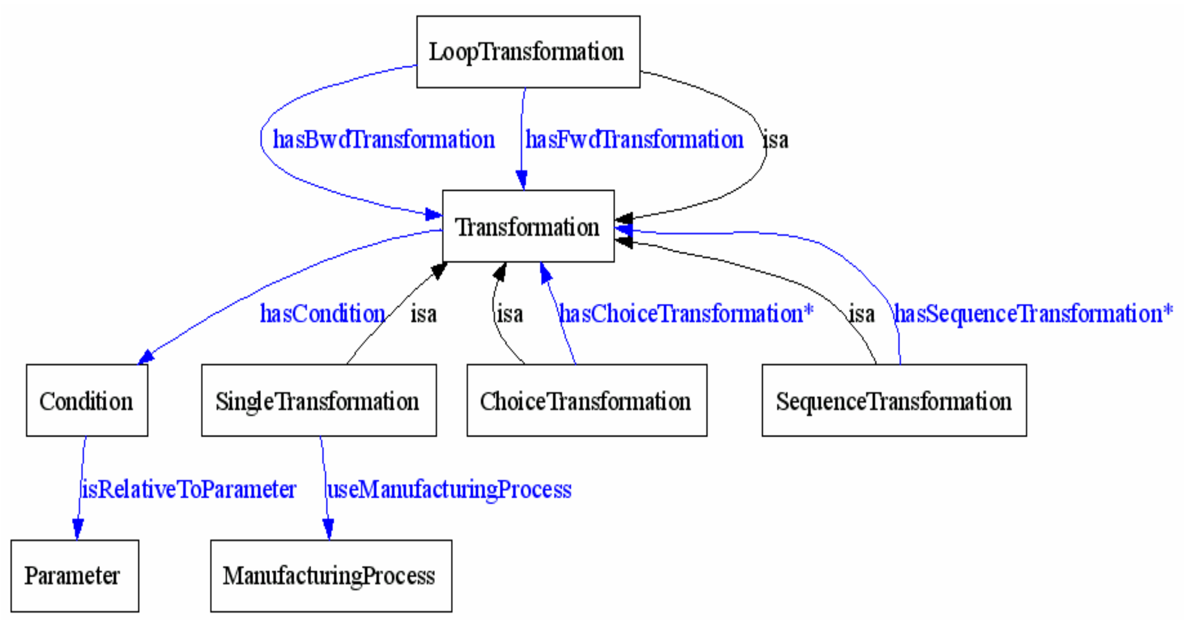

Fig. 2. Ontological representation of Transformation structure

4. Use of contextual rules – process plan schema

The set consisting in a process plan with degrees of freedom and associated rules is called a process plan schema. In order to clarify ideas, here is a summary of the objects employed in the framework of our study.

4.1. Employed objects

- Manufacturing process: it's a mean that can be used in a single transformation and that uses some resource, e.g. hot stamping, cold extrusion, sintering, rolling, bending, empty process…
- Single transformation: elementary block for the representation of the use of a manufacturing process in a process plan. A single transformation cannot be composed of sub-transformations; moreover it uses a unique manufacturing process.
- Process plan: a process plan (without any degrees of freedom) consists in a sequence of single transformations.
- Sequence transformation: represents a transformation that is composed of several transformations, in a defined order.
- Choice transformation: represents several possibilities of transformations. This choice is an exclusive choice.
- Loop transformation: represents a transformation that can be repeated.
- Transformation: a transformation can be a sequence transformation, a choice transformation, a loop transformation or a single transformation.
- Process plan with degrees of freedom: represented with a transformation (that can be decomposed if it's a sequence, loop or choice transformation into several other transformations).
- Process plan schema: it's a process plan with degrees of freedom with the possible adjunction on each transformation of contextual rules linked to part parameters that indicates in which case the transformation is impossible. These contextual rules are called conditions.

To facilitate the storage and exploitation of the process plan schema, we have designed a tree structure presented on the diagram on figure 2. In fact process plan schemes are stored in the ontology and directly linked to part families. Each node can be a loop, choice or sequence transformation, whereas the leaves are single transformations. Only single transformations can use a process.

Conditions may be of several types, for example conditions due to the limitation of a manufacturing process, or linked to the know-how of an expert, or to the limitations of some resource, but until now, we impose to express these conditions only function of the part parameters, e.g. not indicate the tool type but translate this property into conditions on part parameters. In fact conditions are relative to part parameters but are detailed with metadata. We can see on figure 3 a representation of a process plan schema with some conditions.

To summarize, a process plan schema is the process plan with degrees of freedom and rules on transformation. It is associated to a part family that impose some criteria on part parameters to be respected. Conditions are particularly used in the processing of the process plan schema, processing that is presented in the next subsection.

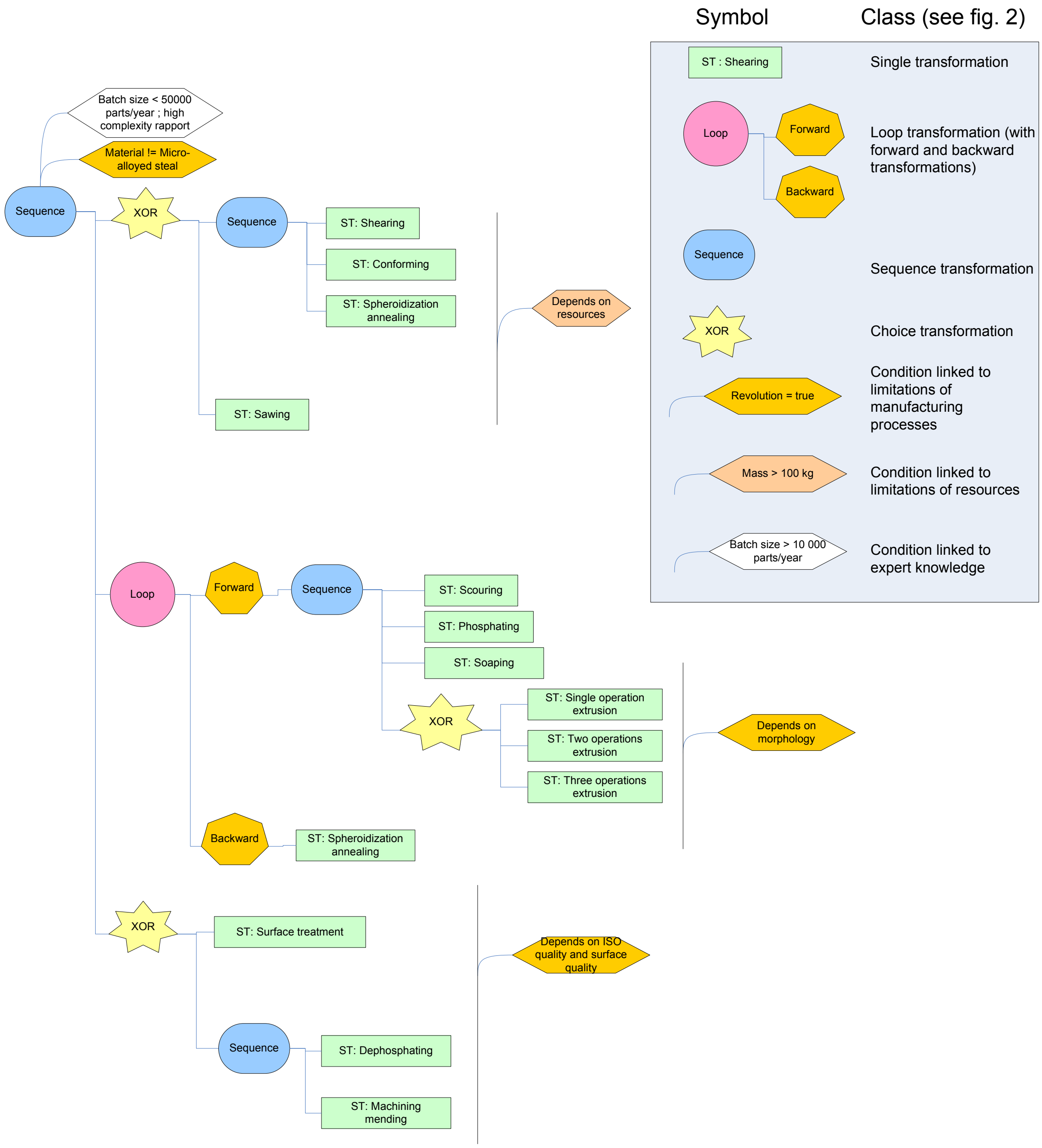

Fig. 3. Example of a process plan schema

4.2. Exploitation of a process plan schema

As it is said in the introduction, this approach has been designed for handling the first way of product process integration: knowing values of certain (not necessary all) parameters of the part (e.g. complexity ratio, shape class, bending presence…), what are the consequences on the process plan parameters (e.g. is hot stamping process possible?)? To achieve this way, we must first select the part families to which the part belongs (thanks to the classification), and for each associated process plan schema, determine which node has to be cutting away due to the disrespect of its condition.

Some remarks:

- As it's said before, there are different types of conditions, the pruning could use different types of conditions (e.g. conditions linked to limitations of processes) and not of other ones (e.g. linked to limitations of resources) according to the wishes of the user.
- To be consistent in all the approach, the choice of the open world assumption has been made: it means that all the parameters that aren't filled in are not taken into account in the conditions. Then a node cannot be eliminated due to a condition relative at a parameter that hasn't been filled in.

- An important thing is to show the pruned nodes and why they are pruned; the user can then come back on the parameters used in the false conditions and examine rapidly different possibilities.
- When the pruning is done, it could be then possible to deduct from the pruned process plan schema all the possible process plans (if they are not too numerous), of course possible according to the part parameters that are filled in until this moment.

5. Conclusion

The proposition in this paper is to realize the first way of product process integration with a mix between a rule based approach and a classification approach. With this way, the proliferation of families (problem of group technology) is avoided and we have a better control on rule consistency since they become contextual. Actually the discussions with forging experts permit us to elaborate the structure of process plan schemas, so they can express their knowledge into them. The main problem of this approach is to adjust the size of the process plan schemas: a too big process plan schema becomes unreadable, and the control of rule consistency becomes harder; on the opposite if knowledge is expressed in too small process plan schemas, the proliferation of families becomes reality. Then when filling the knowledge with process plan schemas, the forging expert has to be careful at the right size of a process plan schema. Further studies will be led to define some indicators that can give some help in the correct achievement of this important task. Note that some complementary information about our work has been presented in [20].

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