INTERNATIONAL DESIGN CONFERENCE - DESIGN 2008
Dubrovnik - Croatia, May 19 - 22, 2008.

DESIGN 2008

IDENTIFYING FEATURES IN CAD-MODELS FOR POWDER METALLURGY COMPONENT EVALUATION.

R. Stolt

Keywords: feature, CAD, rule

1. Introduction

Designing parts for production by the powder metallurgy (PM) pressing and sintering process require detailed knowledge about the process, since the product and the manufacturing process are closely related. The parts geometry can not be established without knowing the limitations of the pressing equipment and the manufacturing process in general. Since designers do not always have sufficiently elaborate knowledge, the aim of the research presented here is to explore how a tool to aid the designer in designing the PM parts so that the production issues are taken into account should be constituted. The assumption is that the designer has some rudimentary PM manufacturing knowledge but is not familiar with the details. The designer is supposedly able to create a design suggestion in CAD, and the idea is to provide feedback on the manufacturability of the suggestion by evaluating the geometry against rules and recommendations for pressed and sintered PM parts.

In order to analyse the geometry directly its purpose has to be known, giving it an engineering meaning. A common and well known way of providing such meaning is subdividing the model into features which are portions of the geometry that have meaning such as hole, slot, thread or pocket. Each feature can then be evaluated from various aspects. The features of a CAD model can be defined either directly while defining the geometry (design by features) or after the geometry has been defined by letting the user point out the features in the geometry. The features can also be retrieved automatically in a process known as feature recognition. (Shah and Mäntylä 1995) give an elaborate view on features and feature recognition. Feature recognition is mostly used in machining applications where it can be integrated into CAD-systems and used to plan machining operations (Nasr and Kamrani 2006). Other purposes have also been explored such as the decomposition of the geometry into features when automatically meshing the geometry for FEA (Dabke, Prabhakar et al. 1994). Naturally, features do not have to be limited to only machined features. Processes such as injection moulding also contain characteristic shapes that can be identified by feature recognition.

The automated evaluation of neutral format CAD-models for their manufacturability has been explored in the recent PhD thesis of Helen Lockett (Lockett 2005). She has developed a feature recogniser tailored for the injection moulding process. The aim is making an advisory aid for designers of plastic parts. To recognise features such as ribs and bosses regularly appearing in plastic parts, she first extracts the mid-surface of the part. Removing one dimension will simplify the recognition process by not having to consider the third dimension when creating the rules that distinguish the different features. Topology graphs of the mid-surface are used to aid the rule-based feature recognition process After identifying the features, an evaluation is made to determine how well suited for manufacture the identified features are. The rules used for the evaluation are mostly based on experience and heuristics and have been gathered from suppliers of plastic materials and tooling technology.

For the PM pressing and sintering process (Smith 2003) have customized a CAD-system allowing the designer to select among a number of standardized features that all can be produced by the PM process in a design by features approach. The system, called IDA (Interactive Design Advisor), works by building the model in the CAD-system by combining such features. When a feature is added to the design, a rule-based check is made to secure that the dimensions of the feature itself, that was set by the user, and the combination of features are feasible from a manufacturing point of view.

These two systems both make a manufacturability evaluation based on heuristic rules and recommendations. The rules are general considering all types of products and materials. Consequently, the precision in these rules cannot be particularly high. The rules need to be refined to consider the specific equipment and materials as well as the particular type of products being designed. All this have to be reflected in the system, so there clearly is a need for the users of the system to be able to revise, add or delete rules. A way of letting the content and number of rules vary but still keeping them computer executable is to use rule-based systems see e.g. (Hopgood 2001). Rule-based systems that involve geometry are sometimes referred to as Knowledge-based engineering systems, KBES. Facilities for defining such systems are nowadays sometimes integrated into the CAD-systems allowing the definition of rules and checks to evaluate the geometry. Further, the CAD programs possibly also allow the automation and user programmable access to the functions in the CAD-system. The work presented here has been carried out in such CAD-system complemented with the necessary application programs.

In order to create the KBES rules and checks the geometry and topology need, as aforementioned, be given an engineering meaning so that the KBES can interpret it. Therefore, a key issue for the work presented here is if it is possible to establish a modelling procedure using the features provided by the CAD-system such as extrude, revolve, and loft so that all or most of the shapes that can be manufactured can be modelled in a standardized way. The structuring and parameterization of the model in a predefined way will mean that the sought geometrical elements and parameters easily can be retrieved and evaluated by the KBES.

In order to keep the number of features and feature combinations on a manageable level so that the KBES will not be overly complicated, the number of permissible features needs to be limited. However, this not necessarily preferred from the designer's point of view. The CAD developer has put in much time and effort into developing modelling commands for the efficient definition of the geometry and the designer has often developed a personal proficiency in using them. Instead of restricting the modelling procedure the intent is to automatically construct the desired construction history afterwards by evaluating the low level entities in the model: edges, faces and vertices. Doing so is known to be difficult involving feature recognition, but it turns out that given the strict geometrical restrictions of the process it is feasible, at least if some simplifications are made and will be shown in this paper. This will also have the added advantage that neutral files such as STEP or Iges originating from arbitrary CAD- system also can be processed. It should be noted that construction histories may in the future become interoperable between CAD-systems but this for the time being this is not possible (Kim, Pratt et al. 2007).

To summarize, the aim of the work is to explore how a system to prepare CAD-models for geometric evaluation of their manufacturability should be built. The actual evaluation follows the industrial practice by defining rules and checks in the construction history tree of the parts. The rules will then be transparent and accessible for the user allowing the contained knowledge to be refined, rather than hard-coding it into the system. Consequently the contribution of the paper lies mostly in the preparation of the models i.e. finding a standardized way of modelling all pressed and sintered PM parts and automatically reconstructing the predefined construction history from arbitrary CAD-models. The reason for adopting this unexplored approach is primarily the user refinement of the knowledge but also to be independent of modeller and modelling procedure. Further, it enables the automated evaluation of a large number of existing PM-parts which perhaps will contribute to refining the general rules and recommendations of PM-parts.

The industrial benefit of the system is allowing designers to evaluate their design suggestions so that mistakes hopefully can be avoided. This will increase the process knowledge of the designers and thereby facilitate the communication with the PM part suppliers, reducing the number of redesign loops required before the parts geometry finally can be established.

2. Methods and tools used

A number of parts produced by PM pressing and sintering have been studied. The modelling method is established by modelling the parts in the commercial CAD-system Catia V5 (www.3ds.com) using a limited number of CAD-features. This establishes a modelling procedure by which the geometries can be defined using primarily linearly extruded convex and concave features.

A simple feature recognition technique is developed to find the PM features in neutral files. The feasibility of the method is tested by creating an automated experimental system using the application programmable interface (API) of the CAD-system complemented with software programmed in visual basic. A number of in production PM parts are processed in the system to verify the accuracy of feature recognition and geometry evaluation.

3. Deriving a construction history of PM parts

A brief description of the PM pressing and sintering process is given to aid the understanding of the feature structure and feature recognition procedure. The feature recognition procedure is described as well as the construction of the parameterised model in the receiving CAD-system. It is also shown how the parameterized model is evaluated for its manufacturability using a rule-based system defined in the CAD-system.

3.1 The PM manufacturing process

The PM pressing and sintering process is limited in terms of what shapes can be manufactured. The primary reason is that in order to press the powder to an even density, the compression rate must be equal everywhere in the part. This is mainly because, unlike fluids, the powder has very little possibility to redistribute itself inside the die during pressing due to the high internal friction in the powder and against the die walls. Consequently, the part must be designed with a limited number of levels in the pressing direction, each formed by a separate punch in the tooling assembly. Minor features can be formed by indenting the faces of the punches, called face-forms.

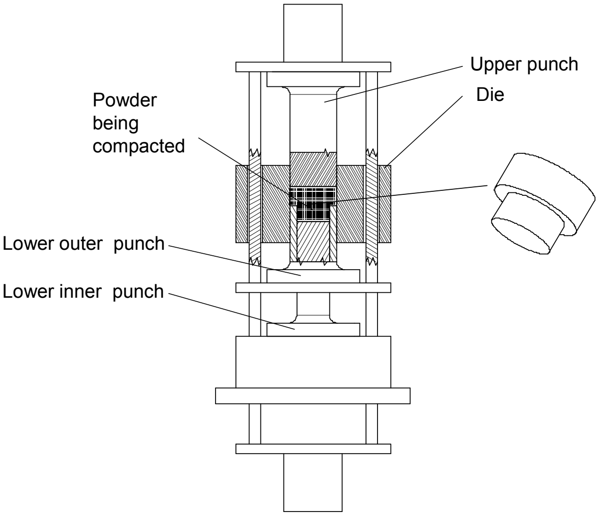

Figure 1. Compaction tooling assembly.

They will inevitably introduce a distortion in the density distribution and should be avoided, especially in areas where high mechanical properties are needed. The reason for wanting a high and evenly distributed density is that the residual pores between the powder grains have a very detrimental effect on the mechanical properties of the final part, see e.g. (Beiss and Dalgic 2001). Consequently, when designing PM parts used as loaded structural elements care should be taken to place low density areas where the part is least stressed.Following from the above, the freedom of shape and the accuracy of tolerances are quite low in the pressing direction (~IT13) whereas, in the radial direction, complex shapes with high dimensional accuracy (~IT9) can be formed. Further, to avoid making an overly complicated and expensive tooling the number of punches must be limited to typically two upper and three lower.

The figure 1 on the next page show a part pressed in a tool with two lower and one upper punch. Note that the outer lower punch could possibly have been replaced by a step in the die. The punches must move separately creating a uniform pressure distribution in the powder. This is realized by attaching the tooling elements to plates sliding on rods. The plates are moved by hydraulic actuators. The individual movements of the actuators are, in newer presses, guided by CNC.

3.2 Feature recognition

The features in the neutral file CAD model needs to be found to derive a construction history in the receiving CAD-system. In order to do so a simple feature recognition procedure has been developed. Feature recognition is, as mentioned, a well established area that have been studied for a long time. In the case of PM pressed and sintered parts and for the purpose needed here, it can be widely simplified. The PM parts are dominated by one type of feature namely what is here called a powder column. A powder column has a uniform section and represents one pressing height. A PM-part can in many cases be seen as a number of such columns stacked or placed side by side. Thus, the feature recognition process only has to find the flat areas, the levels, perpendicular to the pressing direction marking the ends of the powder columns. This is done by searching the neutral model for edges that form loops that are located in planes perpendicular to the pressing direction. When such loop is found parameterized lines and arcs are fitted to it. The reconstructed loop can subsequently be extruded in the pressing direction to form a solid feature with the same height as the original. An example to illustrate the procedure is given in next section. The PM parts may also contain other features such as drafted sections and chamfers and rounds located on planes perpendicular to the pressing direction. It may also contain minor features that have been formed by face-forms. These have been disregarded for the time being.

3.3 Creating a construction history tree and evaluating the part.

In the neutral CAD-file the loops of edges forming the flat faces can be distinguished from the model by extracting edges that form loops in the model staying at a constant level in the parts pressing direction. It is also determined at what side of the loop that the material in the model is located. The figure 2 on the next page shows a part that have edges forming ten closed loops in the pressing direction. Parameterised sketches are formed in the receiving CAD-system by fitting lines and arcs to these edges (1). The closed loop sketches are linearly extruded to a distance corresponding to the full height of the part in the pressing direction (2). Since it is known which side of the loop the material is located, the loops located between the end levels are used to remove material from the model in the opposite material direction (3). Now a part with a construction history tree and parameterized sketches has been constructed in the receiving CAD-system.

The observation that PM parts can be constructed by sketching sections that are extruded have been explored earlier. In the PhD work of (Dissinger 1995) an experimental system is presented where the user sketches the sections. A rule-based evaluation of the manufacturability of the sketched sections and the interactions between them is made prior to extruding it into a solid.

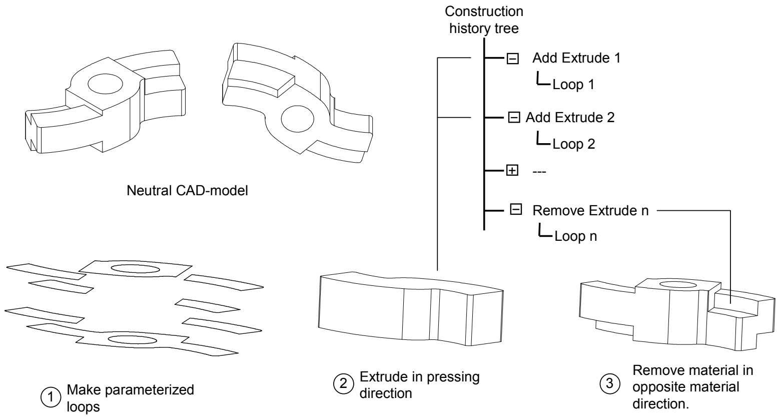

Figure 2. Deriving the construction history

3.3.1 Limitations of the method

Having a levelled part with the levels perpendicular to the pressing direction is a prerequisite for the proposed recognition process and is also ideal from a manufacturing point of view. However, there are examples of PM parts that do not fulfil this requirement. These parts often require specialized tooling technology and are therefore not very common. The figure 3 below shows two examples of parts that will cause problems. In the left part the levelling is not perpendicular to the pressing direction in the protruding "wing" features and consequently they are not recognised. The wedge shaped part on the right cannot either be processed for the same reason. A more elaborate discussion on the principles of the underlying tooling technology for compacting parts like these examples are given in (Beiss 2007).

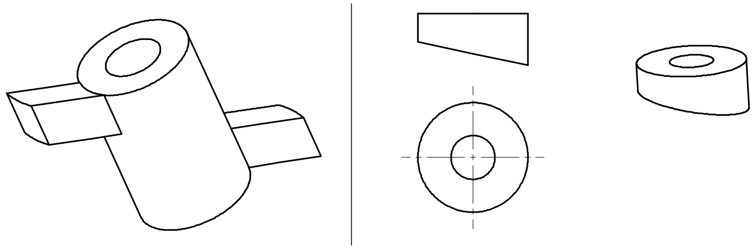

Figure 3. Exception parts

However, having examined a number of in production parts it seems like the most PM parts can be processed. This is supported in Höganäs handbook chapter 8 (Höganäs 2007) where 35 examples of PM parts from 9 different difficulty categories are given. Among these only 9 contained spherical, sloping and other that cannot be identified by the prototype system. Note that most parts contain in chamfers and rounds that where disregarded. The successful modelling of the parts using simple features indicated that the PM process is well suited for the proposed method. Other process, such as machining can create complex feature interactions making the individual features difficult to identify.

3.3.2 Evaluating the parameterised model

The derived construction history tree is far from being practical if the geometry was to be defined interactively by a designer. The designer would perhaps have used the parts antisymmetry and created only half the part and constructed the other half by copying and rotating the copy half a turn. However, the parameterisation has provided a structuring of the geometrical elements of the model that have made them available for manufacturability evaluation using a rule-based system. The rule-base to evaluate the part contains a number of geometrical recommendations on how the PM part should be designed to enable the creation of a reliable tooling. These recommendations are found in handbooks such as (Mosca 1984; Metal Powder Industries Federation. 1998) and are based on experience from PM parts production. The recommendations are aimed at securing that a reliable tooling, that can compact the powder to as uniform density as possible, can be manufactured. In order to check that the parts comply with the recommendations, a number of checks have been defined in the CAD-system. The CAD-system supports the definition of such checks through an integrated KBES shell. The checks are formulated as production rules of the type IF <Condition> THEN <check pass> ELSE <check fail>. A few checks are shown in figure 4 below. It is e.g. checked that there are no angles in the geometry that are less than 30° or else the tooling elements that form the edge will become fragile and will probably break in the production. Further, it is checked that there are radii at the inner corners of the loops to facilitate the flow of powder in the tooling. It is also checked that the tooling elements does not become too thin to avoid that they deform unacceptably much due to the high compacting pressures. The compacted, but not sintered, part is quite delicate and can easily break as it is being ejected from the tool. Therefore it must not have any long protruding sections that are susceptible to fracture. Due to the high friction within the powder and against the die walls the ratio between the diameter and the height in each section must be kept within limits or else the density will become too low in the area furthest away from the punch faces. This condition is also checked.

The structuring of the geometry mean that data can be collected from the model though the CAD-systems API. The data relevant for each check is collected. One example is when determining if the parts have any small angle edges. First all angles between the sketch-elements defining the loops are measured. From these measurements only angles less than 30° are sorted out. If such angles are found the check fails and the user is shown where in the geometry the small angles are found and is prompted to revise the geometry until it passes the check.

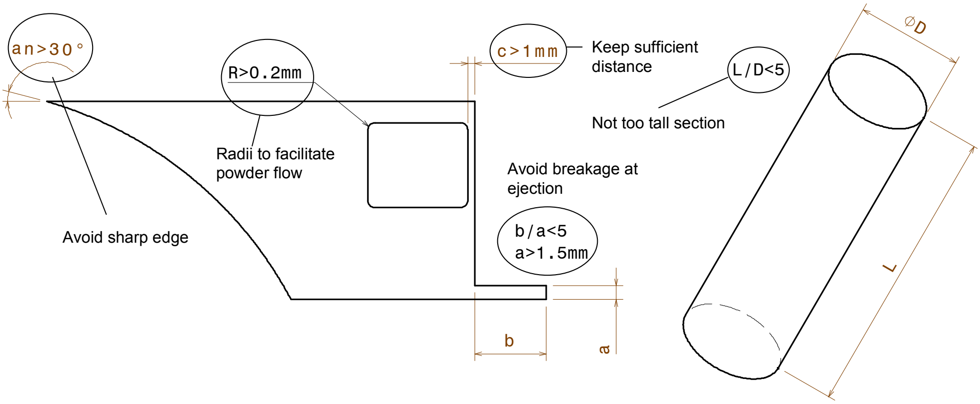

Figure 4. Geometrical conditions checked

This process continues until all checks are passed meaning that the part comply with the geometrical recommendations for PM parts. The reconstruction of the part in the receiving CAD-system means that the check becomes transparent to the user. If additional checks are needed then the elements of the model are easily accessed trough the API and evaluated by additional rules. It also becomes apparent to the user what has been evaluated since all sketches, sketch elements and positive and negative extrusions are available in the construction history tree of the part.

The figure 5 below shows three of the PM parts that have been evaluated in the system. They pass all checks except the rightmost part that was found to have a too small angle at the location indicated.

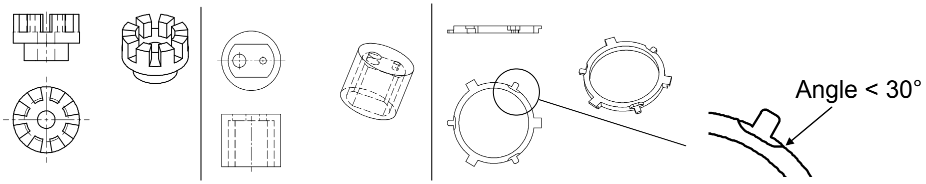

Figure 5. A selection of the PM parts tested

3.4 Possible uses of the described system

The system is intended as an advisory aid for designers of PM parts with the added advantage of allowing designers to incorporate their gathered knowledge in it. As an alternative, It could be ran on a web site to which the designers could upload their CAD-models and get recommendations on how to revise the geometry to make it more favourable from a manufacturing point of view. Further, it will encourage the designer to start thinking in terms tooling technology. Failure of the system to identify the features means that they deviate from the ideal levelling of the part then perhaps a design revision can be made to make the part more favourable from the manufacturing perspective. This will lead to an increased awareness of the pros and cons of the manufacturing process, enabling the designers to be more confident when communicating with the PM-part supplier.

4. Conclusions and future work

It is concluded that parts produced by the PM pressing and sintering process, as a result of having strict shape limitations in the pressing direction, lend themselves to be modelled using a limited number of simple features. These features can automatically be extracted from neutral format CAD-models by identifying the individual levels in the part which are planned to be formed by the tooling elements. Reconstructing the identified features in a commercial CAD-system will mean that the creation of a transparent and user revisable a rule-base for manufacturability evaluation is facilitated.

4.1 Future work

For the work presented it is assumed that most pressed and sintered parts can be modelled by simple extrusions. This seems to be a reasonable assumption since it is a prerequisite for the ideal levelling of the part. Nevertheless real parts also display other features: face-forms, chamfers, rounds and so on. The system must be further developed to recognise and evaluate these. One example is that chamfers and rounds should not be located so that the tooling elements need to be manufactured with sharp edges that are quickly worn out.

Here material suppliers and PM parts producers that participate in this research project can provide valuable help both by providing the needed test environment and a rich examples database needed. The expectation is also that this will lead to the further development and refinement of the rules and recommendations for pressed and sintered PM-parts.

Acknowledgement

The author of this paper wishes to thank Sven Bengtsson and Anders Bergmark at powder manufacturer Höganäs AB and Jan-Olof Krona, CEO of PM parts producer Callo sintermetall AB in Nässjö, Sweden for advice on powders and tooling technology. Further I wish to thank professors Staffan Sunnersjö at the University of Jönköping and Lars Nyborg at Chalmers University of technology for initiating and leading the research project "Regelbaserat system för sintergodstillverkning" financed by the participating companies and from the research grant "Effective product realisation" sponsored by Vinnova.

References

Beiss, P. (2007). Shape Capability in Powder Compaction. 2007 Powder Metallurgy Training Course. Kosice, EPMA Shrewsbury UK. 1: 535.

Beiss, P. and Dalgic, M. (2001). "Structure property relationships in porous sintered steels." Materials Chemistry and Physics 67(1-3): 37-42.

Dabke, P., Prabhakar, V., et al. (1994). Using features to support finite element idealizations, Minneapolis, MN, USA, ASME, New York, NY, USA.

Dissinger, Thomas E. (1995). A fully Integrated Design-for-Manufacture System for Powder Metallurgy. Department of mechanical Engineering, University of Maryland. PhD.

Hopgood, Adrian A. (2001). Intelligent systems for engineers and scientists. Boca Raton, CRC Press

Höganäs (2007). Höganäs Handbook for Sintered Components, Höganäs AB, Sweden (www.hoganas.com)

Kim, J., Pratt, M. J., et al. (2007). "Standardized data exchange of CAD models with design intent." Computer-Aided Design(On-line only, Volume and issue not decided).

Lockett, Helen L. (2005). A Knowledge based Manufacturing Advisor for CAD. School of Engineering, Cranfield University, UK. PhD: 206.

Metal Powder Industries Federation. (1998). Powder metallurgy design manual. Princeton, NJ, Metal Powder Industries Federation, USA (www.mpif.org)

Mosca, Enrico (1984). Powder metallurgy : criteria for design and inspection. Turin, AMMA

Nasr, Abouel Emad S. and Kamrani, Ali K. (2006). "A new methodology for extracting manufacturing features from CAD system." Computers & Industrial Engineering 51(3): 389-415.

Shah, Jami J. and Mäntylä, Martti (1995). Parametric and feature-based CAD/CAM : concepts, techniques, and applications. New York, Wiley

Smith, Lyndon N. (2003). A knowledge-based system for powder metallurgy technology. London, Professional Engineering

Roland Stolt
School of Engineering, Jönköping University
P.O Box 1026, SE 551 11 Jönköping, Sweden
Tel.: +46 36 101677
Fax.: +46 36 125331
Cell.: +701 709190
Email: roland.stolt@jth.hj.se