INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 03 STOCKHOLM, AUGUST 19-21, 2003-02-11

THE DIRECTOOL SOFTWARE – TOOL DESIGN ON FACET GEOMETRIES WITH DECISION SUPPORT

Dieter H. Müller, Claus Aumund-Kopp, Robert Weitzel, Axel Selk

Abstract

The paper describes the development and validation of a robust, easy-in-use and comprehensive software system for tool design. In contrast to existing CAD systems the described software is a solid modeller for tool design using triangulated facet data instead of the more complex mathematical surface descriptions. This brings a lot of benefits for the daily work with geometry data which is explained in this paper in detail. In order to make the whole approach more comprehensive the software has been complemented by decision support components which support the tool designer in design decisions related to the envisaged application of the mould. A strong emphasis has been put on metal casting applications. The tool designer is enabled to search for reference design solutions in a database. As mould design heavily depends on process and material considerations the tool designer is provided with suitable information on the one hand and a structure to store his design decisions on the other hand. In this way it became possible to end up with a protocol of the tool design decisions in addition to the pure geometric description of the tooling and thus obtaining a more comprehensive tool design.

Keywords: Solid modelling, tool design, decision support, case based reasoning

1. Introduction

The manufacture of dies and moulds forms a significant part of the economy and community activities as there are more than 5000 foundries and injection moulders in Europe. In 1999 the European tool making business reached an annual turnover of more than 8 billion Euro [1]. Small and medium size foundries have to keep their processes competitive, when it comes to design and data management.

The implementation and use of 3D CAD systems involve a lot of problems for small companies. In today's industrial practice tooling is predominantly designed as a surface model within specialised CAD systems. In the initial stage of using the component data for the generation of the geometric shape, inaccuracies of the data format and interface often occur. The reason is the simple fact that the customer and the tool maker are working with different CAD systems. As a result of the mathematical complexity of a surface model and the different geometric kernels between CAD systems, the model geometry is often transferred incomplete or with a lot of errors. Beside this issue most 3D CAD systems are very expensive and far too overloaded with geometric design functionality. The companies have to pay a lot of money for a CAD software of which they only use a fraction of functionality in their daily work. In addition CAD systems only support the generation and manipulation of geometry data while process and material data and knowledge is not considered at all. Tool making companies have a big need for a comprehensive covering of all tooling related aspects.

Within the European Community funded GROWTH project GRD1-2000-10866 DIRECTOOL (www.direct2tool.org) the Bremen Institute of Industrial Technology and Applied Work Science (BIBA) along with partners from the castings and moulding industry has developed a software solution which overcomes the limitations mentioned above.

2. Approach

With regard to the exchange of CAD data the transmission of discrete geometric data in the form of triangulated facet models using the STL (**ST**ereolithography **L**anguage) interface, which is supported nowadays by almost all CAD/CAM systems, provides much better results than the surface models currently used for this purpose. Compared to the transfer of surface models, errors are much more seldom. Moreover, potential model errors can easily be fixed with automatic repair functions based on faceted geometric data. The reason for using surface models for the tool design is justified by the strict requirements for the surface quality of the mould. To obtain a high surface quality on curved surfaces with an approximated geometry like a triangular mesh, a very high amount of data is required. However, this is no longer a problem for the current computer generation with abundant memory at very low costs. Furthermore, the more simple mathematical representation of facet models enables the development of substantially more flexible design tools with an increased degree of automation. The deduction of mould inserts based on a precise STL file could therefore be seen as an easier and more secure way of tool design with a substantial time reduction compared to surface based systems.

In order to make the whole tool design process more efficient the designer also needs to be supported in process and material considerations as those are of fundamental importance for the resulting tooling in metal casting applications. Therefore it would be helpful to determine all relevant considerations and to determine their influence on the resulting tooling design. The designer has to be provided with relevant information such as material properties and has to be guided through all relevant design decisions. Finally a protocol of all decisions has to be generated which captures the design information. In this way the whole tool design gets more comprehensive and can be communicated to the shop floor much easier than today. The design protocols could also help retrieving previously solved tooling designs form a database as reference for new tasks.

These considerations lead to a tool design system, which is based on the STL format (a discretised triangular facet representation of the geometry). It visualises the progress of tool design and offers the possibility to easily return to certain stages. From the process point of view the system offers a database application which is capable of retrieving a best match solution for a previously performed tool design. This is done through the technique of Case Based Reasoning (CBR). CBR is a method for designing intelligent systems. It solves new problems by retrieving similar problems which have already been solved successfully [2]. The acquired solution is adapted to solve the new problem in a second step. This technique has already been applied to several CAD engineering problems, such as the design of stamping parts [3] and the failure analysis of mechanical units [4]. Taking into account the reference tooling the tool designer is assisted in all steps of design. This support is provided using a multimedia environment, which provides all functionality required.

3. Development of the decision support

In the first support step Case Based Reasoning is applied to determine a tool design solution which best matches the current problem. Cases are represented by a set of significant attributes. For the envisaged application these attributes must accurately describe the casting as they are the means of comparison. Therefore the attributes describing the casting's geometry as well as material and process requirements need to be determined. A large variety of tool designs for sand casting and gravity die casting has been analysed with regard to the relevant tooling characteristics. The results have been used to develop a reference model which is capable of mapping tool designs relating their relevant features. These attributes enable the tool designer to describe a casting in such a way, that a best matching die design solution can be provided by Case Based Reasoning. An important outcome of this research is that all factors influencing tooling design can be assigned to the main influences, geometry and material. These two categories each comprise a set of attributes, which together form a complete case description for a casting as illustrated in Figure 1.

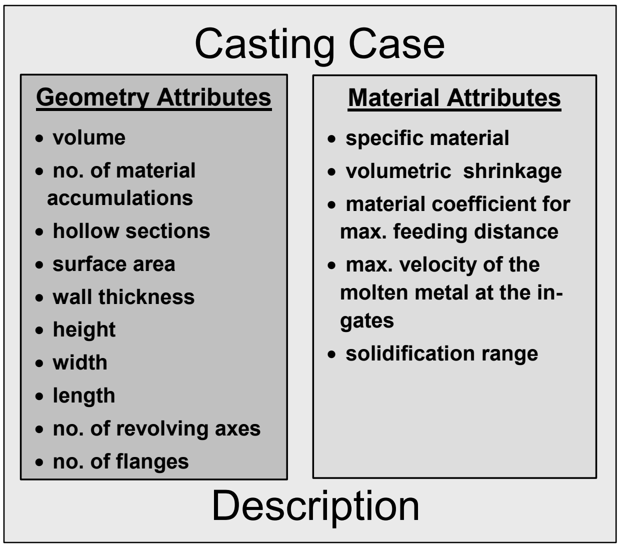


Figure 1 Characteristic attributes for the casting case description

It is important to mention that for a CBR comparison of two castings it is not sufficient only to take the specific material into account. As shown in Figure 1, there are casting specific properties such as the maximum gate velocity and the solidification range of a material. While the specific material might not be the same for two compared castings, those casting specific material properties might nevertheless be very similar. This is often the case, when slightly differing alloys are used. In this case the casting performance of the two materials is very similar and so is the resulting tooling.

In order to determine the degree of similarity between two castings with regard to the tooling, formulae are needed for the computation. Therefore three formulae have been applied to determine the overall degree of similarity between two castings following the paired comparison of single attributes.

$$sim[a_n;b_n] = 1 - |a_n - b_n|$$

$$\begin{aligned} &a_n : value\ for\ attribute\ n\ in\ case\ a; \\ &b_n : value\ for\ attribute\ n\ in\ case\ b; \\ &sim : degree\ of\ similarity\ between\ the\ two \\ &cases\ a\ and\ b\ regarding\ the\ attribute\ n \end{aligned} \qquad (1)$$

Numerical attributes are covered by the following equation:

$$sim[a_n;b_n] = 1 - \frac{|a_n - b_n|}{a_n + b_n} \qquad (2)$$

The overall degree of similarity gets determined using the following formula:

$$DS = \frac{\sum_{i=1}^{n} W_n * sim[a_n;b_n]}{\sum_{i=1}^{n} W_n} \qquad (3)$$

$$\begin{aligned} &W : Weighting \\ &DS : Overall\ degree\ of\ similarity \end{aligned}$$

The application of [1] to [3] provides the overall degree of similarity between two cases. Applied in a database software application an actual tooling design task can be compared to all previously solved cases and the one providing the highest degree of similarity will be suggested for reference.

Beside the Case Based Reasoning a software system has been developed which supports the designer in adapting the reference solution for the new tooling design. The detailed derivation of tooling features is a complex task which involves a lot of knowledge of parting strategies, feeder and gating design, only to name a few. For this task the designer has to look up certain material and process figures from charts and to calculate additional figures, such as the fill rate and gating cross-sections. The support system covers a lot of these aspects. Casting-relevant material properties are retrieved directly from a tooling database. Furthermore feeding distances and fill rates are calculated automatically.

With regard to the field of gravity die casting the partners agreed on a die design process structure comprising 10 stages (see Figure 2). A large variety of aspects influencing gravity die design has been taken into consideration for this development. Initially the casting is specified with regard to the material, the envisaged casting process and the quality requirements. Subsequent stages comprise the parting strategy as well as the feeder and gating design for the die. Beside the pure mould-flow-related considerations also the machine interface for the die has also been introduced to the structure.

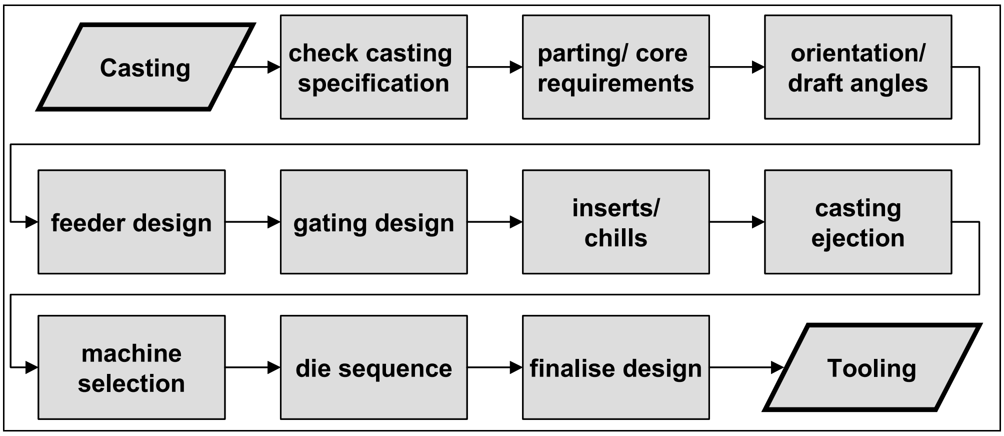


Figure 2 Gravity die design: Schematic sequence of design decisions

A component for sand casting patterns comprises 6 stages of support and works according to the same principles as for the gravity die component.

The software provides charts, tables and 3D models for reference purposes. After completion of a tool design all relevant design decisions regarding the new tooling are stored in a database. For communication and reference purposes a short design protocol can be printed. In this way a more comprehensive description and documentation of the tooling design is achieved than in today's practice where the designer only archives the CAD data.

4. Software implementation

Based on an existing CAM software for Rapid Prototyping/ Rapid Tooling processes which is based on the triangulated facet format STL (**ST**ereolithography **L**anguage) design functionality for mould derivation has been implemented.

The tool design component visually represents the progress of the design process and offers the possibility to easily return to certain states of the design which are saved on the hard drive. To improve the performance of saving and reloading these tool design states and furthermore to improve the handling of faceted geometries like moulds, parts and standard assemblies in general a new file format (VFX) has been developed and implemented to store faceted geometries. This file format supports fast reading and writing of large geometries whereas the file size remains comparably small. This is an important feature since the accuracy of RP machines is constantly growing which makes it necessary to handle more detailed and therefore larger faceted geometries in the data processing. Figure 3 gives a comparison of the VFX file size to the STL file size for three different parts indicating the number of triangles which define the geometry.

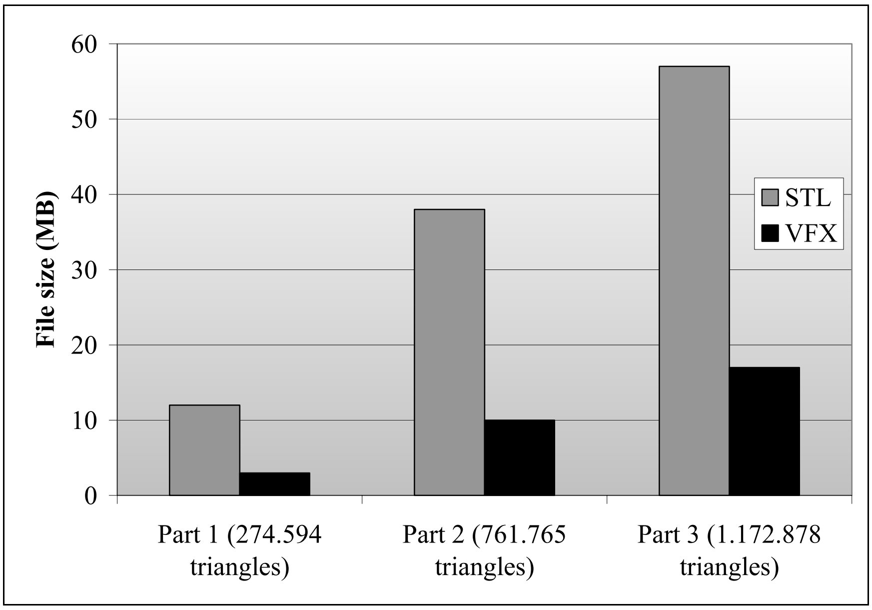
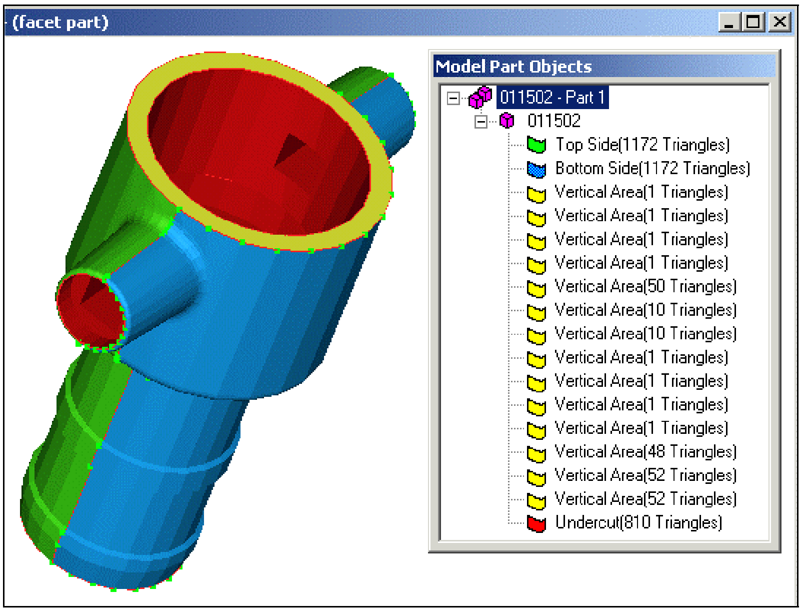


Figure 3 Compression capabilities of the new VFX file format compared to the existing STL standard

Regarding the mould derivation the software determines the split line according to a given direction of de-moulding and automatically detects occurring undercuts. Vertical sections have to be assigned to either one mould half. The assignment can easily be done through a "pick and assign" feature. All regions are listed in an object tree (see Figure 4). The high degree of automation has been achieved due to the simple facet representation of the geometry.



- 011502 - Part 1
  - 011502
    - Top Side(1172 Triangles)
    - Bottom Side(1172 Triangles)
    - Vertical Area(1 Triangles)
    - Vertical Area(1 Triangles)
    - Vertical Area(1 Triangles)
    - Vertical Area(1 Triangles)
    - Vertical Area(50 Triangles)
    - Vertical Area(10 Triangles)
    - Vertical Area(10 Triangles)
    - Vertical Area(1 Triangles)
    - Vertical Area(1 Triangles)
    - Vertical Area(1 Triangles)
    - Vertical Area(1 Triangles)
    - Vertical Area(48 Triangles)
    - Vertical Area(52 Triangles)
    - Vertical Area(52 Triangles)
    - Undercut(810 Triangles)

Figure 4 Mould derivation: Split line and detection of undercuts

Once having defined the parting a mould frame can be defined and additional tooling features such as ejector pins and plugs can be added to the mould frame until the final mould is achieved.

For the Case Based Reasoning a database application has been set up using the Java programming language. The tool designer describes the new casting defining its geometrical properties and the desired material. The designer does not need to fill in the process-related material properties as those are directly retrieved from the database. Furthermore the CAD/CAM system, which is applied within the project, transfers some of the geometry information such as volume, surface area and bounding box dimensions, automatically to the CBR system. Once all information has been given for the new casting, the system performs the comparison between this case and all cases stored in the database. For each comparison the degree of similarity is computed through the formulae (1) to (3) presented in the previous section. The CBR search engine provides a hit list comprising the five cases which have shown the highest similarity to the actual case. Information on these five proposals can be viewed on a spreadsheet. Furthermore a link is provided to the corresponding CAD file of the tooling. The tool designer then decides which of the proposals to choose as a reference solution for the actual tool design task.

The equations (1) to (3) are standard formulae for the computation of similarities. First test runs of the system confirmed that the set of attributes describing a case, seems to satisfy the CBR requirements best.

For detailed assistance in the adaptation of the proposed solution the multimedia support tool is invoked by the tool designer. This software has been implemented using the multimedia authoring system Macromedia Director 8.5 Shockwave Studio©. This environment allows the implementation of all the media which is needed, such as:

- Images, showing tooling features,
- Viewing of 3D models,
- Database interaction,
- Interactive formulae for automatic calculations.

The program is an executable, that can be run in the free-of-charge Macromedia Shockwave Player©. This player is already integrated in most web browsers.

5. Case study

The system was validated by the introduction of a new casting case. The part is a female coupling for fire fighting equipment as shown in Figure 5.

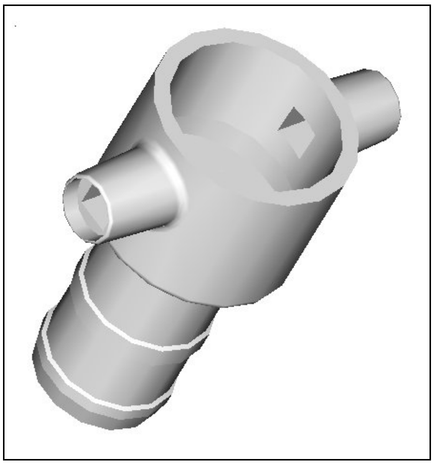
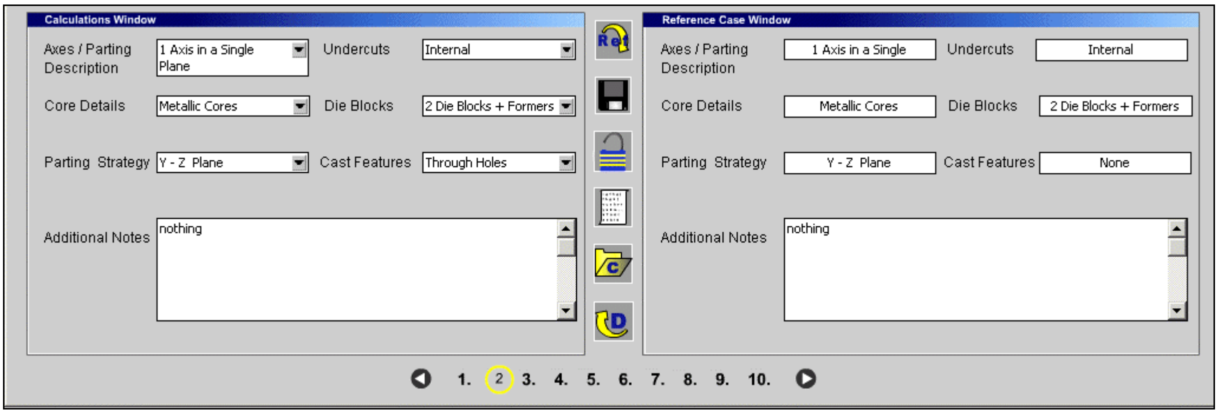


Figure 5 New casting: Female coupling from Al-Si7Mg

It is to be cast from Al-Si7Mg in a quantity of 2.000 using gravity die casting. Its rough size is 52 mm * 102 mm * 108 mm and it has a weight of 0.5 kg. First of all the part geometry was loaded into the tool design system. Then the Case Based Reasoning was invoked. The tool design system automatically transfers geometric information to the CBR system. The designer completes the case description by assigning a material and further job information. Then the CBR retrieved a hit list indicating the five cases from the database providing the highest similarity to the actual case. The description for each of these proposed cases can be viewed. It contains all the CBR attributes. Furthermore a link to the corresponding CAD file is given and the design protocol of the solution can be retrieved as well. Having a reference solution, in this case another female coupling from Al-Si7Mg provided the highest degree of similarity and has consequently been chosen for reference, the designer entered the decision support component for tool design. This component guides the designer through the ten design stages given in Figure 2.



Calculations Window

Axes / Parting Description: 1 Axis in a Single Plane
Undercuts: Internal
Core Details: Metallic Cores
Die Blocks: 2 Die Blocks + Formers
Parting Strategy: Y - Z Plane
Cast Features: Through Holes
Additional Notes: nothing

Reference Case Window

Axes / Parting Description: 1 Axis in a Single
Undercuts: Internal
Core Details: Metallic Cores
Die Blocks: 2 Die Blocks + Formers
Parting Strategy: Y - Z Plane
Cast Features: None
Additional Notes: nothing

Figure 6 Interface of the design support component: The decisions for the actual case can be made on the left hand side while the design protocol for the reference case is displayed on the right hand side.

Figure 6 shows part of the interface provided by the decision support component. This interface provides the same structure throughout all stages of design. On one panel the tool designer can set all tooling features and perform all calculations for the actual tool design while the system provides him with corresponding information for the reference case in another panel. Using the navigation bar the designer can step through all stages and complete the tool design. All data is stored to the database resulting in a design protocol for the new tooling. Completing the tool design requires multitasking between the decision support system and the tool design system. The tool design CAD file does not occupy a lot of memory due to the high compression of the VFX file format. By the time the design was completed in the described way the designer not only obtained the CAD file of the tooling as usual, but he furthermore generated a design protocol containing all relevant design decisions. This protocol can be used for failure analysis in case first castings fail. Once the die will produce sound castings the design will be promoted to the reference status. In this way it will serve as a potential reference solution for future die designs. The resulting CAD file can easily be transferred without any errors to the tool shop as an STL file. In this way it can be used for generating tool paths for CNC machining or Layer Manufacturing techniques in order to manufacture the die. The following figure summarizes the whole case study in brief.

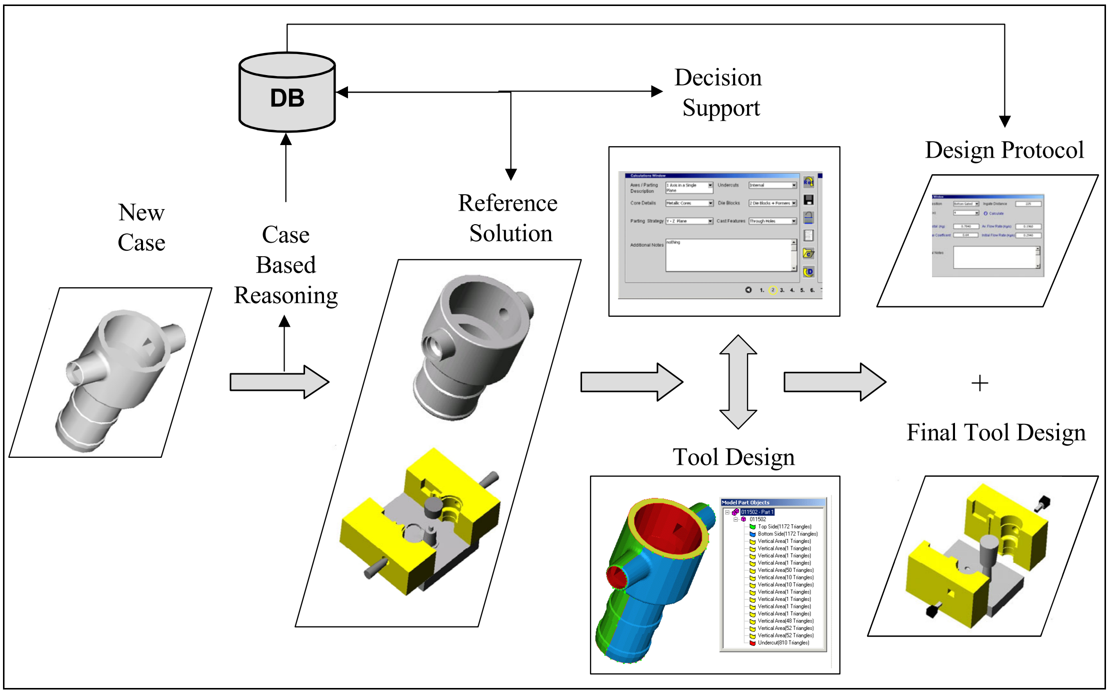


Figure 7 Summary of the case study

The whole design process started with the part description in STL facet format. In order to get a hint at how to design the tooling the designer retrieved a best matching tooling solution for the new case from a database through Case Based Reasoning. Taking this reference case into account the design work was done using the decision support tool for the casting relevant facts of the tooling on the one hand and the tool design system for generating the resulting tool geometry on the other hand. In this way the designer ended up with the final tool design based on the STL/ VFX facet format description and a corresponding protocol containing all calculations and settings which determine the different tool features such as gating and feeding.

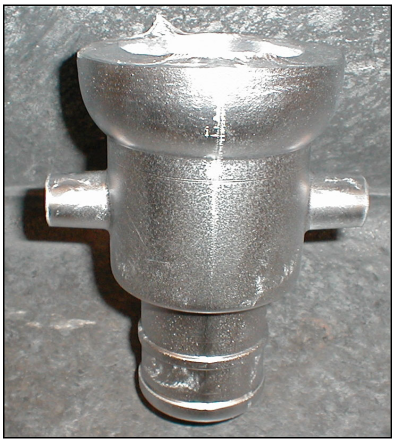


Figure 8 A casting of the presented case study from Al-Si7Mg, Source: Walter Frank & Sons Ltd., Barnsley, UK

The presented design case study revealed the whole potential this new way of tool design offers for foundries and tool makers in the metal casting business. The participating companies are now adopting this new methodology for their daily design work.

6. Conclusions

Within the Directool project it has been achieved to develop a tool design system which works on triangulated facet geometries. The simple facet representation allows the automatic detection of split line and undercuts as well as the automatic derivation of mould halves.

Beside the pure geometry manipulation a decision support for material and process considerations in tool design has been developed. Through the technique of Case Based Reasoning the designer can retrieve a best matching solution from previously solved tool designs and therefore benefit from previous work.

Having selected a reference solution the designer gets support in adapting this solution to the requirements of the new design task. A multimedia environment guides the designer through a framework of ten design stages. This framework offers panels for setting and calculating tooling features. A database connection provides the capture of all design decisions in a tool design protocol. In this way the design ends up with the tool's geometry and a protocol comprising all design decisions which lead to the resulting tool geometry.

References

[1] VDMA: "Statistik zur Situation des europäischen Werkzeug- und Formenbaus im globalen Umfeld", Branchenstudie im Auftrag des VDMA, 2000

[2] Aamodt, A.; Plaza, E.: "Case-Based Reasoning: Foundational Issues, Methodological Variations and System Approaches", AI Communications, Vol.7 No 1, 1994, pp.39-59.

[3] Leake, D.; Birnbaum, L.; Hammond, K.; Cameron, M.; Hao, Y.: "Integrating diverse information resources in a case-based design environment", Engineering Applications of Artificial Intelligence, 12 (1999), pp. 705-716.

[4] Liao, T.W.; Zhang, Z.M.; Mount, C.R.: "A Case-Based Reasoning System for Identifying Failure Mechanisms", Engineering Applications of Artificial Intelligence, 13 (2000), pp. 199-213.

For more information please contact:

Dieter H. Müller, BIBA PPC, Postfach 330560 D-28359 Bremen, Germany

Phone: +49-421-218-5531, Fax: +49-421-218-5551, E-mail: ml@biba.uni-bremen.de ,
URL:http://www.biba.uni-bremen.de