Integrated Approach to Design and Manufacture of Gas Turbine Components Based on Group Theory

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ABSTRACT

This paper deals with a new method that provides an integrated approach to design and manufacture of gas turbine components by using the group theory and customising standard computer aided design and manufacturing system. With this approach time consuming and iterative design procedure and process planning are automated and become more efficient. Due to the intricate and diverse nature of gas turbine components, grouping them is not easy as in other industries. A possible way of grouping the gas turbine components based on design and manufacturing attributes on a broad basis is presented. A case study of high pressure turbine disc is included with illustrations for design and process planning of this component. The proposed system is implemented on a personal computer and offers an alternate solution to sophisticated and expensive main frame based systems.

1. INTRODUCTION

A gas turbine engine is made up of more than 15,000 components of which about 150 are major components. Computers are extensively used to meet most of the design and manufacturing problems. But, merely using the sophisticated computer systems with renowned software packages will not yield expected results if proper approach is not developed. Such an approach should be very specific and encompass all the fields, from design to manufacturing.

A new approach has been under development to group all the major components of gas turbine engine based on design and manufacturing attributes and it has already been implemented for turbine discs. This approach makes use of the theory of group

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technology and offers a method to customise any computer aided design and manufacturing system to derive the maximum benefits.

2. GROUPING OF GAS TURBINE COMPONENTS

Using the grouping theory, all the similar parts are identified and grouped together to take advantage of their similarities in design and manufacturing. This stage is critical for it involves indepth study of design and manufacturing attributes.

2.1 Design Attributes

Design attributes generally concern with geometric shape, size etc. These design attributes are valid in a mass production environment but, in a research and development organisation, where iterative design procedure in combination with engineering analysis is carried out, additional parameters are required to make the design procedure more effective. Geometric entities which may require frequent dimensional changes after engineering analysis are identified and added to design attributes.

2.2 Manufacturing Attributes

Manufacturing attributes concern with process planning activity. Information about typical sequence of operations and tooling for machining part families are carefully decided at this stage.

2.3 Classification

The major components of gas turbine engine are turbine and compressor discs, blades, casings, shafts etc. They can be broadly classified as suggested below :

(a) Rotating components without a hole with respect to the axis of symmetry. Example : Shaft type of components

(b) Rotating components (surface of revolution) with the hole with respect to the axis of symmetry. Example : Discs, sealing rings, seal drums etc.

(c) Housing type of components. Example : Casings

(d) Components with complex profile (aerofoil shape). Example : Blades

(e) Flange type of components.

This classification is conditional and may not cover all the components. But, this classification can definitely be a guide line in grouping all the components. In some cases it may be possible to find that parts from the same family can have different design and manufacturing attributes. In such cases, sub groups could be formed. Also a group for sheet metal components could be formed.

Both compressor and turbine discs are classified as a rotating component with a hole with respect to the axis of symmetry. Though they operate under different conditions their similarities in design and manufacturing attributes make it possible to evolve an integral approach. A software using the techniques of parametric programming has been developed to accelerate the design process for this type of components.

3. PARAMETRIC PROGRAMMING

This technique is generally used for designing components with the same shape but, with different dimensions. This method is widely used for designing standard components. But, this method could be more efficiently used for designing even components with little shape variations, if proper logic and expertise is built into the program. Such an approach has been adopted for designing the discs in the software.

3.1 High Pressure Turbine Disc (HPT) Parameterisation

High Pressure Turbine Disc is a machined forging and it has around its perimeter provision for the attachment of turbine blades. It operates at high rotational speeds and the highest direct stresses are in the bore of the disc where the temperature is the lowest. The disc rim operates at the highest temperatures but with relatively nominal stresses.

Analysing these aspects, it is found that there are not many design changes to be made through out the disc but at specified critical places. These are web thickness and bore thickness. But, while making dimensional changes at these places the interconnecting entities have also to be changed suitably. In the manual method, designer creates a finite element mesh of the disc, performs analysis and based on the results, makes modifications at these critical places. Then the same procedure is repeated till an optimum design is arrived at. At every iteration there can be such changes and incorporating modifications in the design every time is time consuming and cumbersome.

The parametric program developed in Gas Turbine Research Establishment (GTRE) has completely eliminated this procedure. As soon as the designer specifies the dimensions, the program immediately displays the disc on the graphics terminal in a form suitable for finite element modelling. If there are design changes designer specifies new dimensions and the disc is again ready for further analysis.

4. THREE DIMENSIONAL MODELLING

When the designer wants to visualize the disc, he has to choose an option to do that and a three dimensional wire frame model of the disc is created automatically. This is done using the surface modelling facility of the available design software. Designer can choose suitable colours and angle for better visualization. There is also a provision for shading the model. This could be used by others such as process planning engineers for checking tool fouling.

5. PART DRAWING GENERATION

When the design is finalised, the designer chooses an option and a part drawing is generated automatically. For clarity, an isometric view of the object can also be provided with the part drawing. The part drawing can be plotted and released for manufacture.

Since the system is integrated and uses a single data base, the process planning engineer can access the drawing, wire frame and shaded model for manufacturing activities.

6. PROCESS PLANNING MODULE

This module makes use of a database where information about the sequence of operations, tooling etc. are stored for every group of components based on manufacturing attributes. This database also has a library of standard tools, fixtures and resources.

6.1 Process Design

This module prompts the user to specify the component name and the group to which it belongs. When this is done, it retrieves the model, suggests the first operation, say as turning. If this is agreeable, the process planner can confirm it and use the type of machine tool to be used, standard tooling etc. There are two reasons to keep this option open. First, even a new process planner can make proper decisions, since there is a suggestion based on the past experience. Secondly, there is a choice to change it if a situation arises and the database can be updated.

If standard tools and fixtures do not meet the requirement then new ones are to be designed and added to the library. The process planner can move the tool around the component to check tool fouling. Earlier it was done on a two dimensional model and now, it is possible to get a more realistic picture since, both the tool and component models are in three dimension.

6.2 CNC Part Programming

Based on the final process decided, cutter location data is created by the system for all operations and stored. A post processor has been written for two axis machining and by specifying the machine tool and cutting parameters a Computer Numerical Control (CNC) part program is generated automatically with necessary function codes to machine the component. A tape punch unit can be hooked to the personal computer through RS232 C serial port and a punched tape for CNC machines could be obtained. The CNC part program can also be directly transmitted to the machine control system.

7. SYSTEM CONFIGURATION

The suggested methodology can be customised to run on any system. In GTRE it has been implemented on a personal computer which is relatively inexpensive. Except for running powerful analysis programs, this system could be fully used for all other purposes. The configuration used in GTRE is given below :

(i) Hardware : IBM Compatible Personal Computer AT with Digitizer, Dot Matrix Printer and Plotter.

(ii) Software : Computer Vision's Microcadds Geometric Construction and Detailing (GCD), Personal Designer Finite Element Modeler (PDFEM), Microcadds Shade, User Programming Language (UPL) and Microsoft Quick Basic Compiler.

8. CASE STUDY

The component choosen for illustrating the proposed methodology is the high pressure turbine disc of a gas turbine engine. Figure 1 shows the lay out of this component, which is generated automatically as soon as the design attributes are keyed

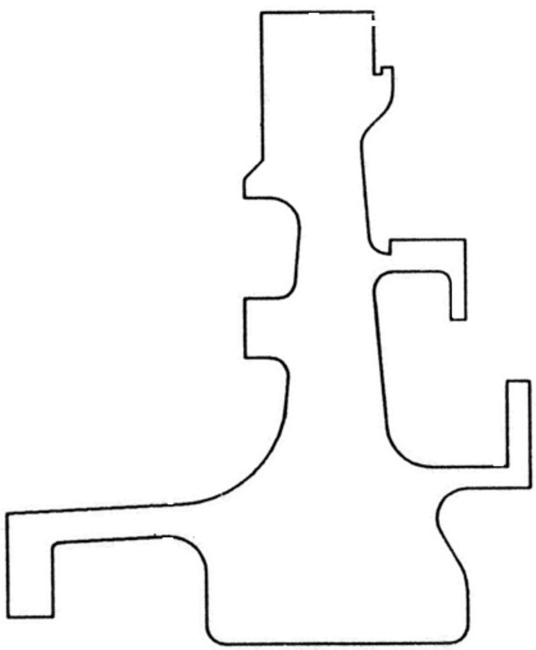
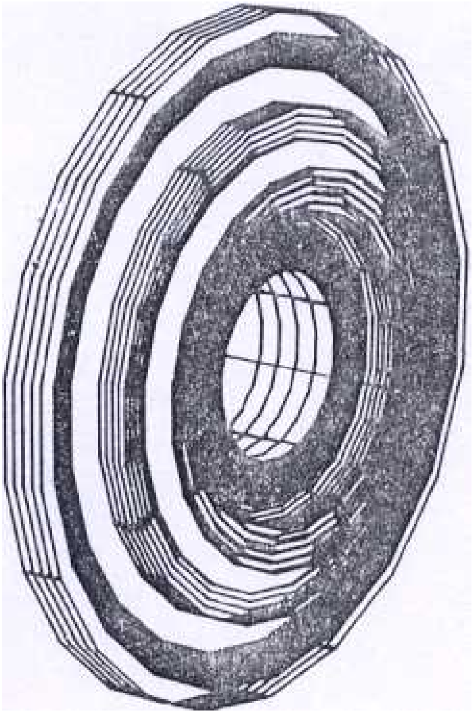
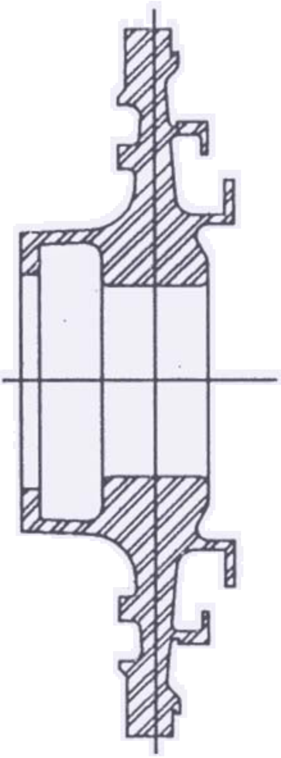


Figure 1. Turbine disc created by parametric program.

in. Figure 2 shows the wire frame model created by the system. This model is further used for shading for better visualization. The final part drawing created by the software is shown in Fig. 3 and a sample view of the tool library is presented in Fig. 4. A typical process sheet for machining the component is shown in Fig. 5. The listing of CNC part program generated by the system for one setup is shown in Fig. 6.



Figure



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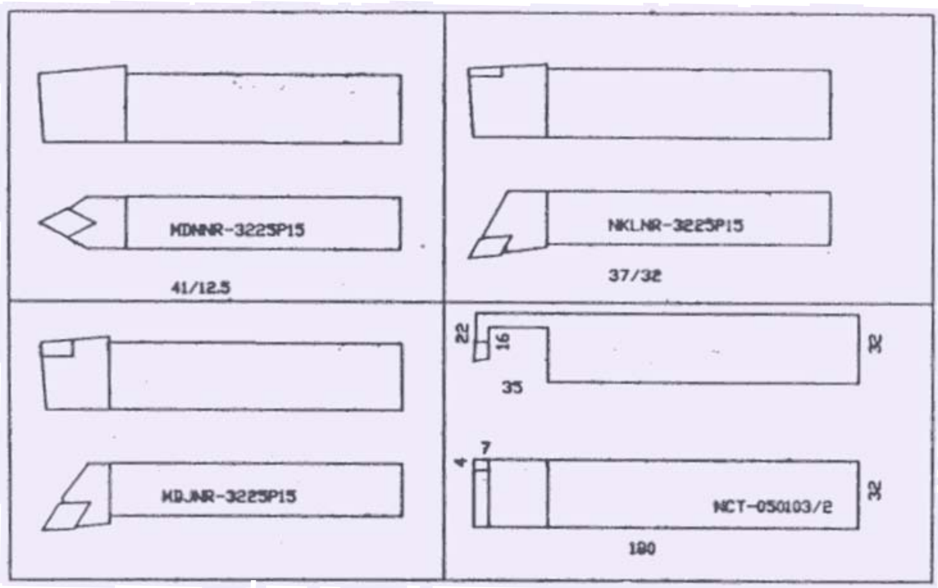
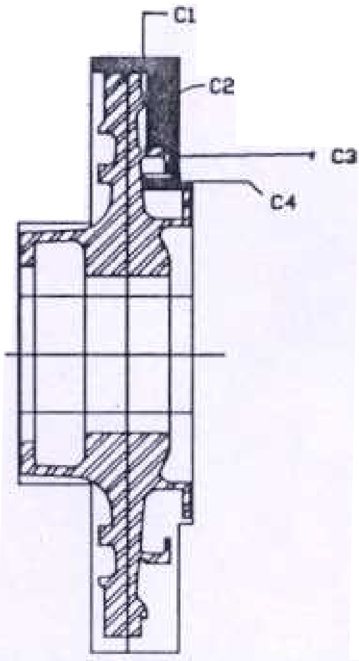


Figure 4. A sample view of tool library



CUT	TOOL	LENGTH mm	FEED mm/r	SPEED m/min	RPM	DEPTH mm	CUTTING TIME	VOLUME cu.m
C1	PCLNL	72	.18	80	104	2	11	8.13898E-06
C2	PCLNL	61	.18	80	122	2	42	1.781801E-04
C3	PCLNL	35	.18	80	159	2	10	3.36568E-05
C4	NCT1058	39	.18	80	175	1	8	6.00054E-06

Figure 5. Process sheet for turbine disc.

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%
N 10 G 71
N 20 G 90
N 30 G 95
N 40 G 00X 9  Z 8
N 50 S08T0100M03
N 60 G 92X 100 Z 100
N 70 T0101M 08
N 80 G 01X 6 Z 5 F 9999
N 90 G 01X 2 Z 5 F 20
N 100 G 01X 2 Z 4.647 F 20
N 110 G 01X 6.023 Z 4.647 F 9999
N 120 G 01X 6.023 Z 4.388 F 20
N 130 G 01X 2.009 Z 4.388 F 20
N 140 G 01X 2.009 Z 4.128 F 20
N 150 G 01X 6.024 Z 4.128 F 20
N 160 G 00X 100 Z 100 T0100M 09
N 170 S07T0200M03
N 180 G 92X 2 Z 2
N 190 T0202M 08
N 200 G 01X 9 Z 8 F 9999
N 210 G 01X 1.544 Z 5.17 F 20
N 220 G 01X 1.544 Z 2.572 F 20
N 230 G 01X 1.361 Z 2.572 F 20
N 240 G 01X 1.361 Z 5.166 F 20
N 250 G 01X 1.049 Z 5.166 F 20
N 260 G 01X 1.049 Z 2.572 F 20
N 270 G 01X .713 Z 2.572 F 20
N 280 G 01X .713 Z 5.166 F 20
N 290 M 30
%
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Figure 6. CNC Part program output for one set up.

9. CONCLUSION

Group theory has been successfully implemented in various fields of industry. In gas turbine industry, this theory can not be applied as is, like in other industries for classifying the components. This is due to the intricate and diverse nature of components. Nevertheless it is possible and it has been done for the disc components.

This methodology also makes it possible to really solve the contradictions between design and manufacturing by adopting an integrated design to manufacturing approach.

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