DESIGN OF THE EGT TYPHOON 2-SHAFT POWER TURBINE USING CONCURRENT ENGINEERING TECHNIQUES

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1.0 ABSTRACT

The Typhoon is a high thermal efficiency, low component count gas turbine originally launched into service in 1990. The single shaft version, used for power generation (C.H.P.), is rated at 4.1 MW ISO zero loss with a thermal efficiency of 32 per cent. At the date of writing, the Typhoon single shaft machines have accumulated 60,000 hours and 2,500 starts in service with very high levels of reliability.

This paper describes the design of the two shaft version of the Typhoon, intended for operation primarily in the Oil and Gas Industry. The paper will concentrate on the "Concurrent Engineering" techniques used during the design process. The two shaft Typhoon will enter into service in 1994.

1.1 Why Concurrent (Simultaneous) Engineering?

Why "Concurrent Engineering? The traditional approach to product design was a series approach with the need for the new product being identified by Marketing. Design/development testing carried out by Engineering and full production all occurring in series (see Fig. 1a). By carrying out many of these activities in parallel i.e. Concurrent (or Simultaneous) Engineering, significant improvements in Product Quality and reduction in lead times and manufacturing cost can be achieved (Fig. 1b). In addition, the number of design changes necessary once the product is in service is reduced (see Fig. 2).

2.0 DESIGN SPECIFICATION

At initial discussions on the market requirements held between Commercial and Engineering areas within E.G.T., it was agreed that a detailed specification would be produced and then officially "signed off" by all major functional areas of the Company.

This really initiated Concurrent Engineering activities as representatives from all areas of the company got involved at that point in providing their views on requirements for the new product.

The full design specification was drafted and circulated for comment. A final version was then circulated for approval by heads of the Company's major functional departments. The main features required by the specification were as follows:

2.1 Marketing

- Two shaft turbine will be targetted at the Oil and Gas Industry only (not for generator duty).
- A manufacturing cost target for unit was set (proprietary).

2.2 Rating

- Power turbine speed range is 10,000 - 14,200 RPM.
- Power turbine to be designed to Typhoon full Mature Rating - 4.85 MW ISO (6500 bhp).

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2.3 Design Requirements

- Detailed planning, manufacturing coordination.
- Projects

The intention is for these "core" team members to remain with the project through to production (and after). Other team members are joining as the project moves from preliminary to detail design and different disciplines and specialisations will be added into the Development and Production phases.

3.1 Ground Rules:

3.1.1 Design Reviews

A structure of design reviews was agreed and this reflects the new Concurrent Engineering approach. This has been formalised in the Design Procedures.

Reviews fall into 5 levels:

- level 1 - Informal "round the board" design reviews.
- level 2 - Informal team meetings for communication purposes.
- level 3 - Specific problem/decision reviews: using formal decision and/or problem analysis techniques (e.g. Kepner-Tregoe).
- level 4 - Internal Design Reviews - regular, minuted reviews (focusing on specific areas).
- level 5 - Formal Design Reviews - regular, minuted reviews including Senior Management and Independent Authorities. Review includes the whole project and experience from other projects is input at this stage.

3.1.2 Approach at meetings/reviews

It is essential that meetings are open and honest and that all views are considered. Every effort is made to achieve consensus on difficult issues. On the Typhoon 2-shaft project, this approach has worked very effectively and many very difficult compromises have been agreed by the whole team. It is essential that team members work well in the team and, to a certain extent, personalities need be selected on this basis. The experience of the Typhoon 2-shaft project has been very good in this respect.

3.1.3 Location

Early on in the Concept Design phase it was agreed that, wherever possible, co-location of the team would be the best option.

2.4 Maintenance/Installation

- Detailed maintenance and installation requirements are identified.

It is important to note that the above represents "Issue 1" of the specification. It was agreed that the project team would use this as their initial target but changes may be negotiated during the design/development process as required. Any change to the specification will require a full company review and re-approval of subsequent issues. Thus, the specification itself forms part of the "Concurrent Engineering" process. (See 5.1.3).

3.0 Setting Up the Design Team

To achieve the specification, a "core" design team was set up as follows, (see Fig. 3):

<table>
<thead>
<tr>
<th>Responsibilities</th>
<th>Responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Leader</td>
<td>Overall project plan, team coordination, specification.</td>
</tr>
<tr>
<td>Design Engineering</td>
<td>Mechanical design.</td>
</tr>
<tr>
<td>Advanced Engineering</td>
<td>Aero-thermal design, performance.</td>
</tr>
<tr>
<td>Analytical Engineering</td>
<td>Stress and vibration analysis, Rotor Dynamics analysis.</td>
</tr>
<tr>
<td>Manufacturing (3 representatives: Group Leader, Fabrication and Machining)</td>
<td>All Manufacturing aspects.</td>
</tr>
<tr>
<td>Quality</td>
<td>Quality assurance, inspection requirements.</td>
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</tbody>
</table>
This was achieved during the early days for the Project, especially with the Manufacturing core team representatives by co-locating most of the team in one office block.

This has helped to build up a team spirit among the members which has been retained through into the Detail Design phase, even though the Manufacturing representatives now spend a greater proportion of their time in the Manufacturing areas.

4.0 PROJECT PLAN

The Project Plan consists of a Master Project Plan and from this, corresponding detailed plans for particular activities are produced. The plan showing the various phases of the projects is shown in Fig. 4.

It was again important to get early acceptance and approval for the Master Project Plan and this was achieved by detailed review meetings culminating in approval by major functional areas in the Company.

Such a plan is an essential part of any project and approval in this way is an essential part of any Concurrent Engineering project.

5.0 DESIGN

The design of a gas turbine falls into two major phases:

º Preliminary (concept) design
º Detail design

5.1 Preliminary (Concept) Design

This phase can be subdivided into the following activities:-

- aero-thermal design
- mechanical concept/layout
- Concurrent Engineering iterations

5.1.1 Aero-thermal Design

The basic aero-dynamic/thermodynamic cycle requirements are dictated by the Specification. Using well developed methods a gas path (annulus) and turbine blade and vane numbers were established (see Fig. 5) as were the basic aerofoil shapes.

5.1.2 Mechanical Concept

Approximately in parallel with this, a preliminary mechanical concept was laid out to get a feel for the main features of the new turbine. Fig. 6 shows the preliminary concept.

The main features of the preliminary mechanical concept were:-

- 2 stage, over-hung power turbine
- Fabricated rear spoked frame
- shaft support in 2 hydrodynamic bearings
- single centre bolt and dowelled spigot locating turbine discs to shaft
- segmented stator vanes
- unshrouded PT blades
- split multi-piece bearing housing and bearing
- conical diffuser

This configuration was based very much on a scale of an existing EGT engine, the Tornado, designed in the late 1970's, early 1980's.

5.1.3 Concurrent Engineering - Iterations

The design of a complex machine such as a gas turbine involves a significant amount of iteration in several areas:-

- Analytical considerations:
 º rotor dynamics
 º aero-mechanical iterations (blade stress and vibration)
 º disc stressing/sizing
- Manufacturing considerations
- Involvement of Suppliers
- Achievement of specification

a) Analytical Consideration

The following is a summary of some of the main Analytical findings:

Rotor Dynamics

The preliminary concept was analysed from a rotor dynamic viewpoint and the general specification requirements were met. However, any changes to the rotor have resulted in further rotordynamics evaluation and iteration.

Aero-mechanical iterations

Blade and vane numbers and basic aerofoil shapes were investigated from a stress and vibration aspect and several vibration interferences were identified as being unacceptable. This necessitated changes to blade numbers and aerofoil profiles and several iterations were carried out before acceptable blade and vane aerofoil shapes and numbers were fixed.
The very large involvement of manufacturing engineers in the Concept Design has also generated a feeling of "ownership" of the design by these engineers. This will benefit the Product as it is developed through to Production.

c) Involvement of Suppliers

Several suppliers were brought into the design loop at an early stage to ensure that their experience was also considered. Casting suppliers for the turbine vanes and blades had a very important input on features relating to the design of the castings. EDT have moved towards a partnership relationship with their suppliers and this helps to ensure that both customer and supplier needs are achieved to the benefit of the end user.

d) Achievement of Specification

The Technical Specification is outlined in 2. above. This was extensively discussed and debated prior to initiation of the conceptual design phase and felt to be realistic. However, in one area, Rotor Blade Dynamics, initial analysis showed that there were certain vibration interference problems. For this reason the operating speed range was reduced by 1,000 RPM. The implications of this decision were again discussed Company-wide before formal approval was given to re-issue the Technical Specification.

Thus the Specification is a "live" document which can be modified, but only with the agreement of all areas concerned.

5.2

Detail Design

It is interesting to note that the starting point for the Detail Design has now changed significantly from the original design described in 5.1.2 and Fig. 6.

For example, the method of attaching the 2nd stage disc to the shaft, the shrouded rather than un-shrouded rotor blades and the one piece vanes and casings (rather than segmented or split). In each case the change has been fully discussed and justified with Concurrent Engineering playing a major role. The configuration on initiation of Detail Design is shown in Fig. 7. This is likely to change during the Detail Design phase.

Some of the main features of the Detail Design phase are as follows:-

Early involvement of Analysts

As described in 5.1.2 above, there was a significant amount of analysis carried out during the Preliminary Design phase.
This identified many changes necessary to lead into the optimised Detail Design phase. The early involvement of Analytical Engineers has resulted in two advantages:-
- early identification and solution of potential problems.
- building up of team relationships.

Thus, the Detail Design of Typhoon 2-shaft Power Turbine has been initiated with a team who are already familiar with the Conceptual Design and, perhaps of equal importance, with other team members.

5.2.4 Manufacturing Team members - links to other areas

With such a careful control of cost it is now estimated that the Manufacturing Cost of the new product will be below the Target Cost by a small margin. This is regarded as being approximately on target due to potential inaccuracies in estimating but is a very encouraging position to be in at the Design stage.

5.2.2 Production Approval/Plannings

In the traditional (series) approach to design, Production were presented with a design which they were required to make in the best way they could. Production Plannings would only be initiated once the Detail Design schemes, detail drawings and Bills of Material were issued.

On the Typhoon 2-shaft Project the majority of the following have been drafted (i.e. not finalised) by the completion of the Conceptual Design:-
- Production Plannings
- Layout sketches
- Sourcing statements
- Capacity requirements
- Tooling General Arrangements and requirements
- Gauging General Arrangements and requirements

The planning of the production of the new products is therefore very advanced and concurrent with the status of the design. The approval of the final design by Manufacturing will be much faster due to their extensive involvement through the Design Process.

5.2.3 Product Cost

Very detailed target costs for each component were agreed during the Conceptual Design Phase. These targets were derived from complete package selling price and specification cost target. The cost of each component has been carefully monitored during the conceptual and now the Detail Design phases. Many decisions during the Design process have been taken very much with cost in mind, but not to the detriment of other factors such as integrity and performance.

The Value Engineering process including function/cost analysis has been used extensively during both the conceptual and now the Detail Design phase.

With such a careful control of cost it is now estimated that the Manufacturing Cost of the new product will be below the Target Cost by a small margin. This is regarded as being approximately on target due to potential inaccuracies in estimating but is a very encouraging position to be in at the Design stage.

6.0 SUPPORTING SYSTEMS/DEVELOPMENT

5.2.5 Progress to Plan

Much more effort than was anticipated has been required in the Concept phase. Many more Design/Analytical/Manufacturing iterations have been carried out than were envisaged. The additional time invested at the Concept stage will, in the view of the author, be recovered during prototype manufacture and initial production, due to the many "Design for Manufacture" features incorporated. The number of design changes necessary should also be reduced.

6.1 Supporting Systems

In order to improve data communication throughout the Company on the Typhoon 2-shaft Project, the engine has been designed on the CAD system.
This includes both 2-D design schemes using C.V. CALMA and 3-D models (using C.V. CALMA and SDRC "Ideas") of certain components.

The use of such models has made data communication between Design Engineering and the other Analytical groups very effective.

The electronic definition of components in this way has also enabled manufacturing to produce various tooling and gauging layouts and will be used to communicate geometry definitions to the blade and vane casting suppliers which improves accuracy and control and speeds the production of the wax dies used in the investment casting process.

The Company has mounted a major initiative due to experience on this Project, to fully integrate CAD and CAM activities as part of a long term strategy with Concurrent Engineering as the focal point.

6.2 Development

To properly validate the design, extensive development testing on individual components and the whole engine will be carried out. This is already being planned and some special testing of the existing gas generator is being carried out to investigate and understand in detail the gas entry conditions into the new Power Turbine.

The Development Engineer on the Core Team has been involved in discussions on areas of the design that are particularly in need of investigation. This early involvement will again reduce "learning curve" effects once the new turbine gets into the Development phase.

6.3 Rapid Prototyping

The Company has been working for several years with other companies and research establishments on a new process generally referred to as "Rapid Prototyping". This process uses CAD generated 3-dimensional data to produce an accurate plastic model of the component. On the Typhoon 2-shaft project, it was necessary to inspect the aerofoil shape and stacking early in the Conceptual Design phase. A preliminary computer solid model of the blade was produced (Fig. 8) and from this a plastic model (Fig. 9) was produced using the Stereo Lithography (SLA) method. This plastic model was measured using a very high accuracy 5-axis measuring machine and found to be within drawing tolerance.

It is envisaged that the above process will be used to produce prototype parts for component test (and even possibly engine testing) and hence will help to maintain the overall programme and identify any potential problems earlier than possible with conventional methods.

7.0 CONCURRENT ENGINEERING - PROBLEMS/ISSUES IDENTIFIED

The following problems/issues have been identified with regard to the Concurrent Engineering process:

- The process represents a "Cultural" change within the Organisation and the effort taken to implement C.E. against this background should not be underestimated by other companies embarking on C.E. initiatives.

- Some Core Team members have found difficulty in attending meetings due to other commitments and this has been resolved by effectively dedicating them to this Project. This has, at times, proved to be a difficult decision to make but in the author's view, is necessary for the success of the C.E. process.

- Frequent communication and technical review meetings are essential to the C.E. process, however time at meetings means time away from the technical job and a compromise between too few and too many meetings has been hard to establish. Making meetings more structured and effective reduces time wasted.

Training in meeting organisation and time management for all team members is proving beneficial in this area.

- The team need support and subtle guidance from their functional managers. At times it has proven difficult to balance between support and interference by managers in the design process. Again, there is a cultural change in which managers take on a support role to ensure that the team is provided with adequate resources, including manpower, budget and training to ensure success.

Experience and training on the C.E. process appear to help but this is likely to remain a difficult balance to achieve.
8.0 CONCLUSIONS

The use of Concurrent Engineering in the design of the Typhoon 2-shaft power turbine has produced several advantages:

- The Core Team members are taken from all areas of the Company at a very early stage and input ideas from many sources. This has resulted in a sense of "ownership" of the New Product throughout the Company.

- The incorporation of the latest Manufacturing techniques by Manufacturing Engineers at the Conceptual design stage, will result in good cost control and ease of manufacture and assembly of the new turbine in Production.

- The early involvement of Analytical Engineers and extensive use of design/analytical iterations, again early in the Conceptual Design phase, have resulted in a high performance, high integrity product at a very competitive cost.

- The Concurrent Engineering Process involves a very high level of communication which in itself has presented challenges to the Core Team and management alike.

- The incorporation of the process of Concurrent Engineering represents a very fundamental change in the culture of typical Western companies at both Core Team and management level. This should not be underestimated by others wishing to employ the technique.

- In many ways, despite some of the challenges and problems described, the C.E. process brings the whole company together to work to a common goal.

- Using C.E. Product Design/Development/Production Cycle time will be reduced on the new product, however, experience on the Typhoon 2-shaft design suggests that a considerable additional effort has been required in all areas of the company than was Originally envisaged at the Concept stage.

- The use of "Rapid Prototyping" techniques such as Stereo Lithography will further accelerate the Development phase of the project and bring the product into service more quickly.

- Overall C.E. is a very powerful method to accelerate the Design/Make process, generate "ownership" of the new product within the company and bring a competitive, high quality product to market more quickly than possible with tradition approaches.

- The overall product quality will be improved by the use of Concurrent Engineering (although difficult to measure quantitatively) and this will benefit the Company reputation and, ultimately, the profitability of the Company.
CONCURRENT ENGINEERING

TRADITIONAL APPROACH (FIG. 1A)

"CONCURRENT" OR "SIMULTANEOUS" ENGINEERING (FIG. 1B)

$T_2 < T_1 = \text{VAST REDUCTION IN DESIGN CYCLE TIMES}$
PRODUCT CHANGES
BEFORE & AFTER ENTRY INTO SERIES PRODUCTION

NUMBER OF CHANGES

TIME

START OF PRODUCTION

TRADITIONAL APPROACH

CONCURRENT ENGINEERING
FIG. 8
CAD SOLID MODEL

FIG. 9
PLASTIC MODEL PRODUCED USING STEREO LITHOGRAPHY