Challenges in the Realization of the In-Vessel-Components of Wendelstein 7-X

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The In-Vessel Components (IVC) for the Wendelstein 7-X stellarator at the Institute for Plasma-Physics (IPP), to be installed for the initial phase of operation, are nearing completion and a significant fraction of the components was delivered in 2011 and 2012. Due to the considerable amount of different components including many variants, the timely realization required a comprehensive management approach, not only covering the demanding technology and system requirements, but also coordination, planning and control issues. A variety of tools were set up to address the technical, financial and timescale challenges. The implementation of this comprehensive management approach is illustrated by the production of the water-cooling system of the IVC. Careful design and manufacture of these components is needed to fulfil the cooling function under high vacuum conditions within very restricted available space. The evolution of the complexity of these components together with changes of boundary conditions had to be managed, integrated into the overall project planning and adequately resourced.

Keywords: Stellarator, Wendelstein 7-X, In-Vessel Components, Management.

1. Introduction

The Wendelstein 7-X (W7-X) stellarator is presently under realization by the Max-Planck Institute for Plasma Physics (IPP) at its site in Greifswald, Germany (IPP-HGW). The In-Vessel-Components (IVC) are being designed and built at Garching site of IPP (IPP-GAR). The IVC-team is responsible for the delivery of the first wall protection and divertor components [1, 2, 3]. The 5-fold period symmetry of the machine is disrupted by the variety of different diagnostic sets, heating systems and a significant number of closed ports, which results in a high number of individual versions and sub-types, which represents more than 2500 IVC built from over 700,000 parts. Most of the IVC were delivered to IPP-HGW in 2011 and 2012. The organization and challenges of the team as well as the management aspects to deliver the IVC in time and to budget are presented and illustrated on the example of the delivery of the cooling supply system.

2. Organization and Challenges

2.1 Organization

Two departments have been formed at IPP-GAR to organize the design and procurement of the IVC-work packages: the Divertor and the First Wall Department. The divertor department is responsible for the following components: 10 Temporary Divertor Units (TDU, with 10 module-types and 2 sub variants), 10 High Heat Flux (HHF) divertor (with 12 module-types and 2 sub variants), 10 control coils, 10 cryo-pumps. The First Wall department deals with the components: 317 panels (30 types and 94 sub variants), 172 heat shields (in 36 types and 49 sub variants), 160 baffles (16 types and 9 sub variants), 122 port liners (20 types with 22 sub variants), 304 cooling circuits (22 types and 106 variants), incl. 80 plug-ins (8 types and 2 sub variants) and 10 glow discharge electrodes. In spite of the departmental work division the team structure is organized as a matrix (Fig. 1) to make best possible use of the available resources and the highly integrated set up of project, design, manufacturing and testing capabilities at IPP GAR. The matrix approach also ensures the flexibility needed in a complicated design environment with concurrent development and evolving design requirements. This approach allows for fast reaction and is failure tolerant, but requires close monitoring and management.

The team has 10 core members (6 engineers, 4 technicians). The number of designers was adapted on a periodic basis with a peak at 19 designers. Up to 15 experts were working in production of the components.

As shown in fig. 1 the activities of the Project Team cover the following topics: management and organization (resources, planning, and budget), design, manufacturing and procurement, and testing. A component team led by a responsible officer (RO) coordinates the different activities for the individual components of each department. The Design Team and the Manufacturing Team are managed by Coordinators who are members of the Project Team. A high information level with well established communication channels, including regular team meetings, is maintained for successful execution of the knowledge based work. The management tools have to support this working structure whilst also being adequate for communication with the main project W7-X.

The work is supported by the Quality Management department [4] of W7-X as well as the Project Control department, the administration of IPP-GAR and IPP-HGW, in particular the purchase department for external procurements.

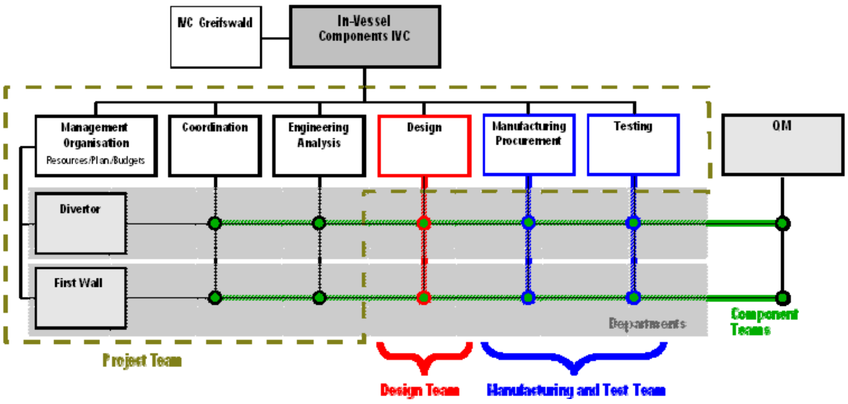

Fig.1 Process structure of the IVC work packages at IPP-GAR

2.2 Challenges

The IVC team has to handle a variety of technical and management challenges.

Technically, the main challenge was to fit the IVC design into a tight space envelope given by the physics concept of W7-X. The main difficulty was the geometry and the number of variants; the technological difficulties were limited in this highly integrated approach. Another issue was caused by the simultaneous design of the IVC (at IPP-GAR) and its adjacent components and interfaces such as media inlets and outlets at IPP-HGW requiring permanent and extremely careful communication between IPP-GAR and IPP-HGW.

In the management sector the procurement activities posed a large challenge. These were set up as a combination between external and internal activities with internal fabrication in ITZ (Integriertes Technik Zentrum in IPP-GAR) taking the majority of the workload, thanks to its well equipped workshops However, originally dedicated to support a variety of large scale IPP projects, ITZ has to deal with a number of concurrent manufacturing orders requiring careful planning and permanent optimization of priorities and resources.

External contracting required a comparable high level of communication. Clear specification requirements and quality assurance proved to be extremely difficult to achieve [5]. So far, the encountered difficulties were solved by close cooperation with the different industrial partners involved in IVC. The contractual framework was sufficiently flexible to reach the required performance and quality of the selected technological solution while remaining within acceptable cost and time schedule conditions. This flexibility was also achieved thanks to the support of the procurement departments, which had the difficult tasks to combine demanded regulations with the very particular scientific requirements.

The last challenge is the development of a project management system well-adapted to the IVC procurement to cope with the high amount of non-standard components to budget and plan with the available resources.

3. Meeting the Challenges

3.1 Meeting the Technical Challenges

When in 2006 / 2007 the number of variants of IVC components and their parts significantly increased due to detailing of the IVC design and iteration with diagnostics, a check of interdependencies between the individual IVC was performed with the method of the design structure matrix (DSM) [6]. This approach studies the influences between components of a system and assesses the coupling strength of the influences. This study clearly identified the strong interface coupling between the plug-ins and the cooling circuits. The outcome was the creation of a component team covering these activities as a set handled by a single RO.

Industry studies have shown an increased development risk for projects with simultaneous component and technology development [7]. However, in the experimental environment, it is often difficult to rely on well proven technologies. For several key components, such as the HHF-divertor, the technology required had to be established concurrent to the component development. The selected technologies were checked with the model of the Technology Readiness Level (TRL) [8] in 2006. This model offers a standardized approach to check if a technology is mature enough to be applied. The development effort for raising envisaged technologies to the required maturity level was assessed. The results were implemented into an updated work plan. For components with low TRL technologies additional development activities were introduced.

Extensive market surveys identified industrial partners and availability of required technologies. When no available solution could be identified, technology solutions were developed at ITZ.

3.2 Meeting the Management Challenges

For the control and efficient execution of the work package (see fig. 1) a set of tools was introduced and adapted to the evolving requirements. Tool packages for management and documentation were pooled (Fig. 2).

The main tools used by the W7-X project are SAP® for financial accounting, Work Breakdown Structures (WBS) for budget and planning, and the Project Lifecycle Management (PLM) system for documentation. Data from SAP® are directly linked to the WBS. The main design tool was the CAD (Computer Assisted Design) system CADDS, work is now transferred to CATIA.

Early in the IVC activities, a Product Management System (PMS) was developed for the production and procurement activities at IPP-GAR. PMS is used to structure the products, extract the procurement needs and automatically prepare the manufacturing and quality documentation.

The WBS-system was updated in 2008 into a server based version to enable integrated planning of time and cost per component. The available IVC schedules were adapted and transferred into the WBS. However, the special organization of the ITZ workshop and the share of resources with other projects required considerable on-site coordination within IPP-GAR, could not be introduced into the WBS. Therefore a set of internal control tools run in parallel. These tools provide the IVC master plan for budget and resources (MBR), the data for long-term resource control and forecast (RCF), and the data for coordination of on-site manufacturing resources (MR). Earned value monitoring (EVM) is performed now by the project control department in IPP-HGW and the IVC internal monitoring focus only on the control of the manufacturing progress of the components and the design resources. A module for the status control of the components (SCC) is executed to monitor the availability and readiness of all individual IVC, their installation in the plasma vessel (PV) and their operation.

The PLM system makes the documentation available to the W7-X project and archives. Design models and drawings of the IVC are introduced into PLM when released for manufacturing. The IVC activities at IPP-GAR were already fully running when the PLM-system was installed. The release process for the IVC components is organized outside PLM and only in the end all information is filed into PLM.

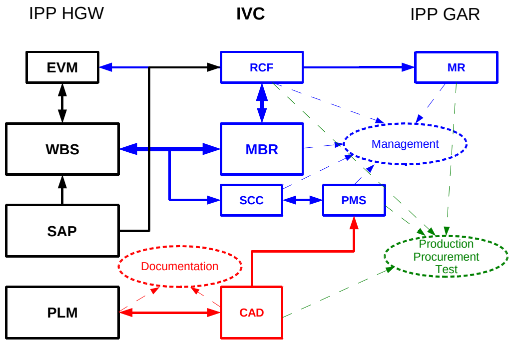

Fig.2 Management tools introduced for the IVC work package

4. Implementation of Management Methods on Example of the Cooling Supply System

4.1 Component Description

The method described above is illustrated by the work package for the cooling supply system, with its plug-ins and cooling circuits [9]. Supply to the individual water-cooled IVC in the PV is performed by a cooling circuit network of steel pipes with a total length of about 4.5 km. Water is feed from the external periphery into the PV via 80 plug-ins. The plug-ins include eight basic types with two sub-versions, two types are equipped with installation space for diagnostic lines. The in-vessel cooling network is an arrangement of 22 baseline circuit types, having 304 branches in 106 variants.

The cooling circuits are delivered in a pre-assembled state and will be connected in the PV during installation. For the production of the cooling circuits a modular welding facility had to be developed (Fig. 3). More than 2000 high-vacuum orbital welds were completed and tested to complete the circuits.

Plug-ins and cooling circuits were delivered to IPP-HGW and at present are prepared for installation in the first PV modules.

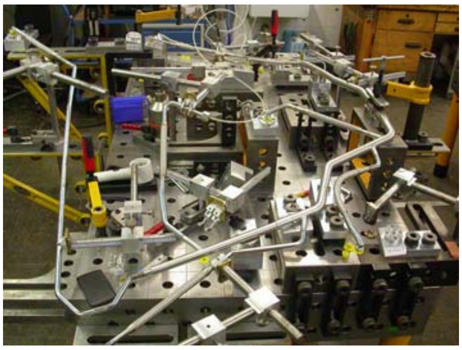

Fig.3 Cooling circuit on the welding facility during production at ITZ, IPP-GAR.

4.2 Work Package Management

DSM analysis showed a strong coupling of plug-ins and cooling circuits. As a consequence these components were grouped in one work package, coordinated by the RO closely with the Design and Workshop Coordinators. A dedicated team of designers and workmen was allocated via RCF and MR to the component for a defined time.

When the TRL analysis showed a low maturity level for the manifolds, several test items were built and a market survey was performed, which resulted in the collaring technology finally being applied. Manufacturing, test and installation processes of this technology were verified with a demonstrator circuit. As an outcome, the schedule was detailed, budget and milestone planning enhanced.

The serial activities for the cooling supply were planned in the WBS. Concept design and model work was performed by the design colleagues at IPP-HGW. Manufacturing design was then performed at IPP-GAR and iterated with the ITZ-workshops. Procurement of small parts, like flexible hoses and bellows was handled at IPP-GAR together with ITZ, using PMS. Coordination of the industrial partner for the manifolds was performed at IPP-HGW.

Manufacturing of most cooling supply system components was performed at the ITZ workshops, including leak testing. Manufacturing planning was detailed at ITZ and iterated with on-site demands, via MR and a user forum, within the given frame of the WBS. The user forum with MR proved very useful and allowed to identify bottlenecks in time and prepare alternative solutions, as outsourcing. Manufacturing generally was handled in type wise lots to allow an efficient use of tools and facilities.

Procurement of standard parts and material was pooled to minimize external, incl. handling, costs, using information derived from PMS. Long lead items had to be procured quite early in the schedule, in several cases a second procurement phase had to be added when real item numbers were available. Status control was handled via SCC.

Documentation of the components during design and manufacturing was reduced to a necessary minimum in order to release resources for physical realization of the components. In close coordination with the project management the urgent documentation was defined, and was then handled in parallel. Other documentation is now under completion and will be added to the projects main database in PLM. This task will continue for some time.

5. Conclusions

The IVC for the initial phase of W7-X operation were successfully realized in IPP-GAR and delivered to IPP-HGW. The matrix structure for the team proved to be adequate for the concurrent work package activities. A set of management tools was established and successfully adapted for resource friendly execution of the work. The installed procedures were able to cope with the increasing number of variants. Transfer of scheduling into the integrated WBS tool was handled successful and without delay for the ongoing work. The internal communication process and overview for the IVC team members, with regular short informational meetings were very important for this process. The knowledge base with highly integrated Project, Design, Manufacturing plus Test teams resulted in a smooth process while being highly flexible and failure tolerant.

The experience gained in this project showed that a sufficiently flexible contractual framework with external companies is needed to allow for possible evolution of the component specification due to non-standard aspects (one of a kind) of these elements. Only the establishment of a cooperation framework with industrial partners, which takes into account the different culture of a scientific institute and industry, allowed a successful execution of the contracts.

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