Fusion Engineering and Design 88 (2013) 3014–3020

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Improving concept design of divertor support system for FAST tokamak using TRIZ theory and AHP approach

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HIGHLIGHTS

- Optimization of the RH system for the FAST divertor using TRIZ.
- Participative design approach using virtual reality.
- Comparison of product alternatives in an immersive virtual reality environment.
- Prioritization of concept alternatives based on AHP.

ARTICLE INFO

Article history:
Received 14 May 2013
Received in revised form 10 July 2013
Accepted 11 July 2013
Available online 6 August 2013

Keywords:
FAST tokamak
Remote handling
Concept design
Interactive design
TRIZ
AHP

ABSTRACT

The paper focuses on the application of the Theory of Inventive Problem Solving (TRIZ) to divertor Remote Handling (RH) issues in Fusion Advanced Studies Torus (FAST), a satellite tokamak acting as a test bed for the study and the development of innovative technologies oriented to ITER and DEMO programs. The objective of this study consists in generating concepts or solutions able to overcome design and technical weak points in the current maintenance procedure. Two different concepts are designed with the help of a parametric CAD software, CATIA V5, using a top-down modeling approach; kinematic simulations of the remote handling system are performed using Digital Mock-Up (DMU) capabilities of the software. The evaluation of the concepts is carried out involving a group of experts in a participative design approach using virtual reality, classifying the concepts with the help of the Analytical Hierarchy Process (AHP).

1. Introduction

The ITER project [1] needs parallel R&D activities to reach its objectives in the scheduled time. It is widely accepted that a key role for the preparation and a rapid exploitation of ITER is the design of one or more satellite tokamak experiments [2,3]. Such satellite experiments will also give an important contribution in testing new technologies. Currently, one of the most promising projects is the Fusion Advanced Studies Torus (FAST) [4]. FAST is intended to be the test bed to support ITER physical experiments, exploring new methodologies and innovative solutions, and to support the design of DEMO.

Remote handling (RH) is a fundamental aspect related to the tokamak. For the whole lifetime of the reactor, many components are supposed to be subjected to maintenance or substitution. According to the extreme working conditions of the tokamak, these operations could not be accomplished by human operators but must be performed by dedicated robotic systems. In such a perspective, FAST is playing an important role in order to provide RH solutions for future tokamak machines. A RH arm for ITER was already proposed and designed and the first operations of maintenance were already simulated [5]. FAST RH system, illustrated in Fig. 1, is mainly composed of two subassemblies, the Cassette Multifunctional-Mover (CMM) and the Second Cassette End-Effector (SCEE), the latter equipped with a further arm whose function consists in performing the critical operations of locking and unlocking the Cassette in its relative support system. Analysing the ITER-like solution, critical aspects were observed and put under discussion, concerning the use of the system known as "knuckle". This system is a mechanism that locks and unlocks the divertor in the outer side of the tokamak, and thus requires very accurate geometrical and dimensional tolerances. Moreover, it was observed that the knuckle might cause unwanted vibrations during the

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0920-3796/$ – see front matter
http://dx.doi.org/10.1016/j.fusengdes.2013.07.005

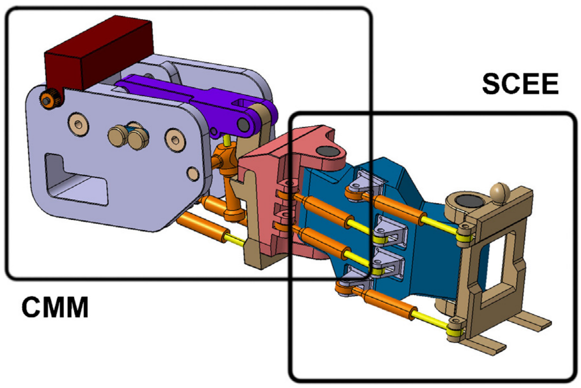

Fig. 1. RH system for FAST tokamak.

working period of the tokamak and that its maintenance might be difficult. In order to avoid these drawbacks a new solution was proposed in a previous study, aimed to propose a first concept design of the RH system, and a compatible divertor support system of FAST [6]. Nevertheless, the analysis of an alternative solution introduced new conflicts with the remote handling system. In particular, the cantilever arm of the SCEE resulted partially obstructed in its movements by the presence of the divertor's outer hook, this requiring a re-design of the entire system. In Fig. 2 the original design of the outer hook is showed together with the RH system [6].

In this study the components were re-designed in a smart way, solving technical conflicts observed during the simulation phases using the Theory of Inventive Problem Solving (TRIZ). The use of this engineering methodology suggested two different concept solutions, which have been compared with an analytic method known as Analytic Hierarchy Process (AHP). The comparison was based on the opinion of a panel of experts of the IDEAinVR Lab [7] and of the Divertor Test Platform 2 (DTP2) team [8], which finally selected the "best" concept.

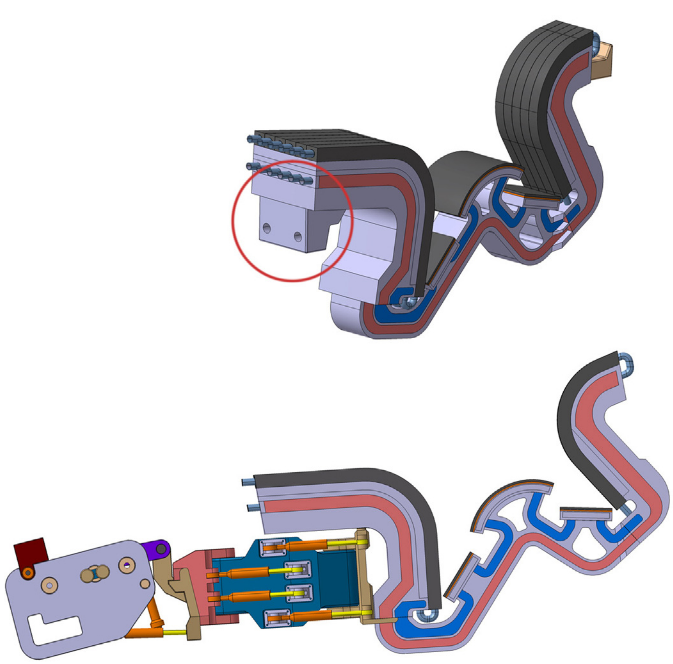

Fig. 2. The conflict between the RH system and the outer hook.

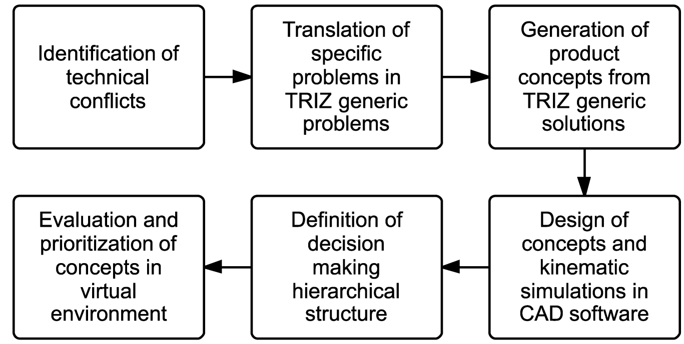

Fig. 3. Flowchart of the methodology adopted.

2. Materials and methods

The methodology adopted is illustrated in Fig. 3. The whole process starts with the identification of several design issues. Technical conflicts present in the considered system are translated in TRIZ language following the "contradiction matrix" approach, generating different concepts from specific solutions derived from TRIZ principles. The concepts are then designed in CAD software, performing kinematic simulations and analyses, where these can help comparing the alternatives. A set of criteria is thus selected, on which the comparison of concepts will be performed, following the AHP methodology. The final evaluation session is carried out in virtual environment, involving several experts in the judgment.

2.1. *TRIZ contradiction toolkit*

TRIZ is the abbreviation of "Theory of Inventive Problem Solving", in Russian "Teoriya Resheniya Izobretatelskikh Zadatch". TRIZ is an engineering problem solving toolkit which provides a methodology useful to systematically solve problems, in which the principles of good inventive practice are encapsulated in a general problem solving structure [9]. TRIZ focuses problem understanding to the particular, relevant problem model and then offers conceptual solutions to that model. With TRIZ it is possible to save time, as the instrument lets the engineer focus on valid solutions to the problem and then develop those solutions [10]. The purpose of TRIZ is to overcome the psychological barrier in problem solving through the generalization of the specific problem to an analogous generic problem, for which a generic solution can be found. At this point, a specific solution can be identified, usually with the help of brainstorming sessions and experience. The use of brainstorming and technical knowledge is very useful because TRIZ works in a high level of abstraction [11].

TRIZ is a toolkit in which each tool covers an aspect of problem understanding and solving. TRIZ theory provides several techniques and methods, one of the most important being the contradiction matrix. The strength of this tool is to remove contradictions rather than finding compromises or trade-offs. During the problem solving activity, instead of a simple brainstorming activity, TRIZ theory brings 40 principles, widely available in literature, that suggest a direction for the innovation [10]. The steps to the solution are well summarized in [12,13]:

1. define the problem and the elements that need to be improved;
2. in the contradiction matrix, map the elements of design in terms of the 39 parameters;
3. identify the solution direction to solve the problem and the elements that are in contradiction with them;
4. find inventive principles joining two characteristics in the contradiction matrix;