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OBJECTIVE

The Cask and Plug Remote Handling System (CPRHS) shall provide the means to handle and transport the ITER in-vessel components from/to the Vacuum Vessel (VV) ports to/from the Hot Cell (HC) docking stations during the ITER maintenance shutdown, along the scenario of the Tokamak Building (TB) and the Hot Cell Building (HCB). The CPRHS is divided in three sub-systems: the cask envelope, the pallet and the Cask Transfer System (CTS). The overall dimensions of the biggest cask are 2.62m x 3.68m x 8.50m (w x h x l), with a maximum weight (unloaded/loaded) of approximately 50/100 tonnes. The transportation can be accomplished moving the entire CPRHS or only moving the CTS, leaving the cask (cask envelope and pallet) parked somewhere.

For the work in this grant, seven different cask typologies will be considered. Results will be presented according to their dimensions and functionality, which implies slightly different requirements for each of them. The cask typologies correspond to casks for:

(1) the Cryopump;

(2) the Divertor;

(3) the ln-Vessel Viewing System (lVVS);

(4) and (5),two casks for the In-Vessel Transporter (IVT);

(6) Equatorial cask for the Equatorial Heating, Diagnostics plugs and the components coming from the Neutral Beam (NB) cell, and

(7) Upper cask for the Upper Heating and Diagnostics plugs.

All of them will transport components between the VV ports in the TB and the ports within the HCB.

The TB is divided in three levels, B1 (divertor level), L1 (equatorial level) and L2 (upper level) with 18, 14 and 14 VV ports respectively. The HCB has five levels, B2, B1, L1, L2 and L3. The CPRHS has access to:

- the levels B1 (all the ports), L1(all the ports except 4 to 7), L2 (all the ports except 4 to 7) in TB;
- the levels B2, B1, L1 and L3 in HCB with 2, 1, 6 and 2 docking ports respectively.

A lift located in the TB provides the interface between the TB and the HCB through dedicated galleries at each floor.

The CPRHS must be capable of moving between the two buildings, under remote control, with sufficient precision to allow docking and sealing and avoiding collisions with walls and boundary components. Each journey must be accomplished without needing to recharge the on-board batteries, and therefore the time required for each journey must be minimized. The best journey corresponds to an optimal trajectory that minimizes the path length (thus minimizing the time required for the journey), maximizes clearances with the building structure and other environment obstacles, and minimizes forces on the CPRHS due to change in motion direction. For the sake of an efficient implementation (in case of line guidance with the path defined at floor level), all the trajectories must maximize the common paths wherever possible.

The activities of this grant are focused in the definition of the 2D optimal trajectories, or simply, optimized trajectories, for the CPRHS and CTS in the TB and the HCB. This study of trajectories will provide important information for the cask design and for the validation of the interfaces with the building.

The above referred global objective is divided in the following sub-objectives, all of them related with the evaluation of:

1.Optimized trajectories for the CPRHS in TB and HCB

2.Optimized trajectories for the CTS in TB and HCB

3.Optimized trajectories for the rescue vehicles in TB

4.Optimized trajectories for docking and parking in HCB

The studies and results related with each optimized trajectory will include:

- Set of points and information that define each trajectory,
- 3D models swept by the CPRHS and CTS (when moving alone) along each trajectory provided in CATIA,
- Minimum distance to the closest obstacle along the entire trajectory,
- Estimation of time execution for the mission associated with the trajectory,
- Identification of potential clashes along the trajectory,
- Identification of critical zones with potential conflicts between the CPRHS or the CTS and the buildings and surrounding environment elements inside the areas of remote handling operation,
- Configuration Management Models (CMM) / CATIA models of the buildings modified according to changes' proposals (if applicable), and
- The optimized 2D trajectories above referred, obtained in the software tool developed in MATLAB, will be validated by an alternative tool/process based on 3D Virtual Models in order to ensure the quality of the so obtained 2D trajectories.

Moreover, as trajectories will be provided for different navigation technologies, i.e., having both drivable/ steerable wheels of the CTS following the same path or having a different path for each wheel, comparison on CPRHS/CTS manoeuvrability depending on the navigation technology will be provided.

BRIEF DESCRIPTION OF HOW THE APPLICANT PROPOSES TO EXECUTE THE TASK(S)(Details under III.)

The entire work will be carried out by experts of IST (Applicant 1) and of ASTRIUM ST (Applicant 2) under the coordination of IST. The work is organized in four tasks with a total duration of 6 working months, starting March 2011 and ending September 2011, with an interruption during August 2011 due to holiday period. The project management plan is detailed in the Quality Plan document issued, at this proposal stage, as a draft according to the guidelines. The organization management chart includes a technical project leader, a project manager and a responsible for the quality assurance. For each task, a responsible officer is designated.

The key elements in the organization management are:

·Technical project leader: Isabel Ribeiro (IST/ISR),

·Project manager: Bruno Gonçalves (IST/IPFN),

·Quality assurance: Elsa Silva (IST/IPFN),

·Responsible officer for the four tasks: Alberto Vale (IST/IPFN),

·Other professional staff of IST: Rodrigo Ventura (IST/ISR), Daniel Fonte (IST/IPFN)and Filipe Valente (IST/IPFN)

For ASTRIUM ST the key elementsare:

·Project manager: Pierre Ruibanys,

·Technical officer: Christophe Reig,

·Other professional staff of <street w:st="on">
ASTRIUM ST
</street>:Etienne Gazeau, Nicolas Etchegoin

More details of the project management are described in the Quality Plan.

Background

The grant F4E-2008-GRT-016 (MS-RH) provided a total of 63 optimized trajectories for 3 CPRHS typologies operating in TB and HCB. A generic CPRHS typology was assumed (with the dimensions of the biggest CPRHS, i.e., 2.62m x 3.68m x 8.50m (w x h x l)),with the exception of the journeys to/from VV ports 4 and 5 in level B1 of TB where shorter and narrower CPRHS were considered.

Open issues from the grant F4E-2008-GRT-016 (MS-RH) include:

- Evaluation of optimal trajectories for the seven CPRHS typologies in all scenarios with updated models of TB and HCB in nominal operations.
- The optimized trajectories were constrained to be the same for both wheels of the CTS along the entire journey. Providing independent trajectories for each wheel, not considered in F4E-2008-GRT-016, may improve some remote handling missions, in particular in very narrow parts of the scenario.
- Evaluation of optimal trajectories for the CTS when travelling alone, in particular when moving from beneath a pallet in a VV port.
- Evaluation of optimal trajectories for rescue casks in all possible scenarios.

- Evaluation of parking operations focused on the sequence of manoeuvres each cask shall perform in the parking area of the HCB in order to guarantee the access (parking and removal) of the cask fleet.

The work to be carried out in this grant, F4E-GRT-276, will address these issues, considering also the maximization of common paths of different trajectories, useful specially in case of line guidance implementation, i.e., when a buried wire system is the navigation technology support.

Technical definitions

Before discussing the trajectory optimization using the same or different trajectories for the two CTS wheels, it is necessary to clarify relevant technical terms for this study.

By the consensual terminology in the scientific literature on mobile robotics, a *path* is as a sequence of points in a given referential. A trajectory is a *path as a function of time*, i.e., the *velocity* of the CPRHS/CTS *at each point of the path* is thus defined. In simple terms “trajectory = path + velocity”. The results of the grant F4E-2008-GRT-016 and the required results for the present grant are specified in terms of trajectories, or equivalently, in terms of paths + velocity profiles. Along all documentation, the term path is used only if the velocity is not relevant. Otherwise, the term trajectory is used.

The position and orientation of the CPRHS/CTS, or simply, the *pose* of the CPRHS/CTS, corresponds to a geometrical position (in 2D) and an angular orientation in relation to the global referential of the ITER buildings.

Trajectory optimization evaluates the best trajectory (best path with the optimized velocity profile) in terms of the shortest distance between the starting and target points and the maximum distance to the closest obstacles along the journey. The CTS has two independent wheels. In what concerns path generation there are two possible situations, independent of the velocities:

- The same path for both wheels, and

·Different paths for each wheel (with a constraint between the paths, since the CTS is a rigid body).

A trajectory for the CTS corresponds to a path to be followed by the CTS using a velocity profile. The trajectory can be described in relation to the centre of the CTS or in relation to each wheel, irrespectively of having both wheels following or not following the same path.

In real operation, the paths can be represented in two ways:

- Real path – a path physically defined at floor level (e.g., painted lines on the floor, strips wrapped on the floor, buried wires, buried track, etc).
- Virtual path – a path defined at computer level, and not physically defined in any part of the environment.

In operation, the optimized paths (real or virtual) are the input for a path following control system that drives the CTS. The path following system controls the CTS engines in real time to keep the wheels as close as possible to the optimized paths and velocity profiles, given the feedback acquired by sensors. According to the path representations, different control systems can be used:

a)Line guidance control systems that, based on sensors (usually placed close to the wheels) that detect the deviation of the CTS relative to the path defined at floor level, correct the vehicle position and orientation to take the vehicle on top of the real path.

b)Free-roaming control systems that, based on the comparison between the virtual path and the real vehicle location relative to the virtual path (obtained for instance by a GPS localization like system), correct the vehicle position and orientation to take the vehicle on top of the optimal virtual path.

<u>This grant only covers the trajectory optimization </u>issue. It is assumed that a path following system and a CPRHS/CTS localization system, not covered in this grant, will be included in the CTS.

According to the technical requirements described in the Annex B with Technical Specifications, the following types of trajectory optimization must be performed:

(1)Line guidance with the two wheels of the CPRHS/CTS following the same trajectory.

(2)Line guidance with the two wheels of the CPRHS/CTS following different trajectories.

(3)Free roaming system with the two wheels of the CPRHS/CTS following different trajectories.

In terms of this grant, the required results are the optimized trajectories, which must be considered as the input of a line guidance or a free-roaming navigation systems, depending on the adopted navigation methodology.

In type (1) both wheels follow the same path in each journey and the paths for different journeys are optimized to maximize the common paths aiming at simplifying the floor installation in case a line guidance navigation methodology is used. This same type, with both wheels following the same path, can also be used in a free-roaming navigation methodology, even though this is not common.

Types (2) and (3) are similar from the point of view of trajectory generation as considered in this grant, since both have the same requirement: different trajectories for each wheel. It is worth referring that having the two wheels following different paths with a line-guidance methodology, with the path defined at floor level (using buried wires or a similar system), is harder to implement, given the complexity of the implementation at floor level.

Since types (2) and (3) are the same in terms of trajectory optimization, we consider in this grant, for simplicity, only the types (1) and (2) to identify trajectories with the two wheels along the same path or along different paths, respectively.

From this point forward, the term trajectory is addressed as a set of numerical data representing positions, orientation and velocities in relation to the geometrical referential used in the provided models from ITER, which can be used as input for line guidance and/or free-roaming navigation systems.

Trajectory optimization and validation

The four tasks of the grant are related with the evaluation of 2D trajectories and their exportation in a CATIA format. For the multiple situations where a trajectory is to be obtained, three main actions must be performed:

- ·Trajectory optimization, carried out in 2D, with the support of MATLAB platform, and the generation of the 3D volume swept by the CPRHS/CTS along the path,

- ·Trajectory information, providing a set of data (to be detailed later in this document) for each point of the trajectory, and

- ·Trajectory validation that assesses the quality of each 2D optimal trajectory using an alternative tool/process, namely a 3D Virtual Reality system, in order to ensure the quality of the output of the optimization, as described in the sequel.

Trajectory optimization

During the grant execution, the Trajectory Evaluator and Simulator (TES), a software tool developed in MATLAB platform and compiled to be used as an executable (EXE) application, will be improved to support the required studies of trajectory optimization. TES was developed by IST under the grant F4E-2008-GRT-016 (MS-RH). The improvements proposed to cover the present call requirements include:

- ·Modifications in the Graphical User Interface (GUI) to easily handle the ITER buildings and their modifications, and the different CTS and CPRHS typologies models.

- ·A new algorithm to optimize independent trajectories for each wheel.

·A tool to optimize the possible common segments of multiple paths.

·A tool to export 2D optimized trajectories and 3D swept volumes to the software CATIA V5R19.

·TES will also provide the essential information for the trajectory analysis (e.g., evolution of the minimum distance to obstacles along a path, velocity profile, journey duration, excluding required CPRHS or CTS stops or slow down motion to account for coordinated operations with other building elements, e.g., VV port doors.) and images that will be incorporated in the technical reports provided throughout the grant.

The interface between the TES, as an executable application and the CATIA. The TES receives the buildings models and the different CPRHS/CTS typologies models and export the optimized trajectories and the corresponding 3D swept volume directly to the CATIA. The TES provides also a GUI to evaluate the trajectory optimization and to manipulate the scenarios (for instance to test modifications in the doors aperture configuration if necessary), to easily choose the CTS or CPRHS type to use in the simulation and the respective optimized trajectories. The output of the TES is the set of optimized trajectories. Additionally, TES provides trajectory information that will allow for the comparison of the different scenarios (1) and (2), i.e., both wheels following the same path or following different paths, the ability to evaluate the risk of a clash, and the time duration for a journey.

The four tasks are related with trajectory optimization for different type of vehicles (7 types of CPRHS and a non-specified number of CTS), the novelty in this grant being:

- the evaluation of trajectories when both wheels follow different paths,
- the evaluation of the 3D volume swept by the vehicles (CPRHS and CTS) in CATIA format,
- the evaluation of common paths of different trajectories.

These functionalities, required in all tasks, will be developed in Task 1, thus justifying the longer period considered in the Work Breakdown Structure (WBS) for this first task.

All these developments on trajectory generation and optimization will be carried out by IST.

Trajectory information

The TES will be able to gather the relevant information on a trajectory, in particular the estimation time for a mission execution, the volume occupied by the CPRHS provided in CATIA format, the minimum distance to the nearest obstacles along the entire trajectory, the identification of potential clashes, the identification of zones of risk in the scenario and CMM/CATIA models proposed modifications if necessary. This information will be reported for each trajectory provided in the deliverables.

Based on the information gathered from the trajectories evaluated for the same mission using different approaches, a comparative study will be accomplished to compare and discussing their performances.

Gathering on trajectory information will be provided by IST.

Trajectory validation

A 3D Virtual Reality (VR) tool developed in the grant F4E-2008-GRT-016 (MS-RH) by ASTRIUM ST will be adapted to receive the updated building models and the CPRHS/CTS different typologies models, to validate all the 2D optimized trajectories (with/without both wheels following the same path). Validation will be based on testing the CPRHS/CTS along all the trajectories, on evaluating the distances to the closest obstacles and on the identification of potential critical situations along the paths.

Videos will be provided for a sample of all the validated trajectories.

Trajectory validation will be executed by <street w:st="on">
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Tasks summary

Task 1: CPRHS trajectories

Starts on March 2011 and has duration of 4.5 months.

Task 1 aims at evaluating and validating all the 2D optimized trajectories in TB (between the lift and all VV ports) and HCB (between the lift and all docking ports and between all docking ports) for the CPRHS using all the seven cask typologies, according to the exact port allocation of each CPRHS. For each pair of initial location and final goal, two types of trajectories will be developed, with and without both wheels following the same path, their corresponding information generated, and their performance compared. Wherever possible, a common component will be identified to be shared by different paths. The study will include the 3D swept area, or simply, occupied volume, by the CPRHS with a safety margin of 300 mm.

TES will have to be upgraded to account for the evaluation of trajectories when both wheels follow different paths, for the evaluation of the 3D volume swept by the vehicle in CATIA format and for the evaluation of common parts of different trajectories. Given that most of these upgrades are independent of the vehicle type, this task will start with the activities aiming at developing these new functionalities that will be used for the CPRHS trajectories (task 1), but also to provide the results for the remaining tasks.

Task 2: CTS trajectories

Starts on mid of June 2011 and has duration of 1.5 months.

Task 2 aims at evaluating and validating all the optimal trajectories for the CTS between the lift and all VV ports in TB, and between the lift and all docking ports and parking areas in the HCB, taking into consideration the different CTS typologies, to be provided at grant starting date. Required information to be provided by F4E is the correspondence between each CPRHS and the CTS used for its transportation. For each journey, two types of trajectories will be developed, with and without both wheels following the same path, and its performance compared. Wherever possible, the CTS trajectories should coincide with the corresponding CPRHS trajectories. The study will include the 3D occupied area, or simply, occupied volume, by the CTS with a safety margin of 100 mm.

Task 3: Rescue Cask Trajectories

Starts on July 2011 and has a working duration of 1.5 months (with an interruption in August).

Task 3 aims at evaluating and validating all the optimal trajectories for the rescue cask between the lift and all VV ports in TB, considering that the nominal cask is docked in the VV port. For each pair of initial location and final goal, two types of trajectories will be developed, with and without both wheels following the same path, their corresponding information generated and their performances compared. Wherever possible, the rescue cask trajectory should coincide with the corresponding CPRHS trajectories.The study will include the 3D occupied area, or simply, occupied volume, by the CPRHS with a safety margin of 300 mm. These rescue vehicles will be considered with the same dimension as their nominal casks, with the exception of the IVT rescue cask, that is shorter than the IVT main cask.

Task 4: Parking and docking in the HCB

Starts on mid of July 2011 and has duration of 1.5 months (with an interruption in August).

Task 4 aims at evaluating and validating all the parking operations focused on the sequence of maneuvers each cask should perform in the parking area of the HCB in order to guarantee the access (parking and removal) of the cask fleet. These activities will be performed based on pre-defined cask distributions in the parking area provided by F4E at grant starting date. This task includes the demonstration of accessibility to all casks or the proof of unfeasibility given the allocated space within the HCB, i.e., the accessibility to all parking places, when the other places are occupied (worst case) will be studied. This task will not include an optimization of the cask parking locations, i.e., no study will be provided for the choice of the best parking location for each type of CPRHS based on the estimated operation frequency. ■

In summary, each task will provide for each mission three types of trajectories according to what is described in Table 1.

	Type of	
	The two wheels in the same path	
Task 1: CPRHS	Individual optimization	Joint approach with maximization of the commons pa
Task 2: CTS	Individual optimization	Individual optimization, maximizing the common pat
Task 3: Rescue	Individual optimization	Individual optimization, maximizing the common pat
Task 4: Parking	Individual optimization	Joint approach with maximization of the commons pa

Table 1– Trajectory evaluation approach.

Data requirements at grant starting date

At the start of the activities, F4E should provide all material required for the development of the activities described in this proposal, in particular (but not exhaustive):

- CATIA V5R19 most updated models of TB and HCB, with indication of all door's position, opening direction and maximum aperture angle.
- Cable tray location and dimensions in the building models and the allowed areas where the CTS can move under the cable tray.

- CATIA V5R19 most updated models of all types of CPRHS and the respective palette and CTS including the dimensions of the IVT rescue cask. This includes the definition of which CTS runs with which CPRHS.

- Exact allocation table between each VV port in TB and docking port in HCB and the type of CPRHS that docks in that place, in case this is not included in ITER_D_2DTP9H v2.0.

- Location of the two pairs of drive/steering wheels and distance between the wheels in each pair for each CTS type.

- Indication of the exact stopping location/coordinates of the CPRHS in each VV port and docking place in HCB.

- Cask distribution in the parking area in HCB (exact stopping location/coordinates of) and exact free-area where parking could be done.

- Free zones in the HCB which can be used as buffer for parking operations.

- Maximum velocities and accelerations of the CTS and the CPRHS.

- Number of CPRHS of each of the seven types.

- Number of CTS of each type.