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Applying remote handling attributes to the ITER neutral beam cell monorail crane

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ABSTRACT

The maintenance requirements for the equipment in the ITER neutral beam cell require components to be lifted and transported within the cell by remote means. To meet this requirement, the provision of an overhead crane with remote handling capabilities has been initiated. The layout of the cell has driven the design to consist of a monorail crane that travels on a branched monorail track attached to the cell ceiling.

This paper describes the principle design constraints and how the remote handling attributes were applied to the concept design of the monorail crane, concentrating on areas where novel design solutions have been required and on the remote recovery requirements and solutions.

1. Introduction

The monorail crane forms part of the ITER neutral beam cell remote handling system, for which the conceptual design review has just been completed. The status of the system design by CCFE is the subject of a paper presented at the SOFT 2012 conference (Sykes et al. [1]).

The monorail crane is the principal transporter for all plant and equipment within the neutral beam cell and is used during installation and maintenance. The cell contains up to 3 heating neutral beams, a diagnostic neutral beam and 4 upper ports.

The neutral beam cell contains a series of pillars to support the upper floors of the Tokamak building. These pillars preclude the use of an X-Y bridge crane. An overhead monorail crane is therefore proposed in the concept design, based on the IBERTEF reference design [2] and is described in detail in the ITER concept Design Description Document [3].

A summary of the remote handling attributes applied to the concept design is presented in this paper.

1.1. Principal design constraints

The safe working load of the crane is 50 t.

Virtual reality simulations of the crane operations show that the highest hook heights are required when the tall beam line components, such as the calorimeter and residual ion dump, are lifted over the balcony plates.

The height of the components and the distance between the balcony plates and the cell ceiling imposes a tight constraint on the maximum height of the crane. It is a maximum of 1400 mm when adhering to the minimum clearance of 100 mm applied to all remote crane operations.

The crane requires a four rope lift to accommodate small off-centre loads and to allow accurate position control of components during lifting and lowering. This ensures correct engagement with remote alignment and location features such as dowels.

When shielding or containment barriers have been removed during maintenance, personnel access to the neutral beam cell will not be possible. The crane must therefore be operable and recoverable entirely remotely.

The safety case requires the crane to retain its load during a seismic level 2 (SL-2) event.

The ITER system requirements for the concept design of the neutral beam cell remote handling equipment requires that all remote handling equipment be recoverable by credible means and for all components to have a minimum radiation tolerance of 20 kGy.

1.2. Design overview

The monorail crane is shown in Fig. 1 transporting the calorimeter. The crane system comprises; the monorail, upon which run two bogies that are mounted to the crane frame. The crane frame supports four hoist assemblies that raise and lower the lifting frame. Each of these assemblies is described in more detail in the following sections.

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Fig. 1. Monorail crane system.

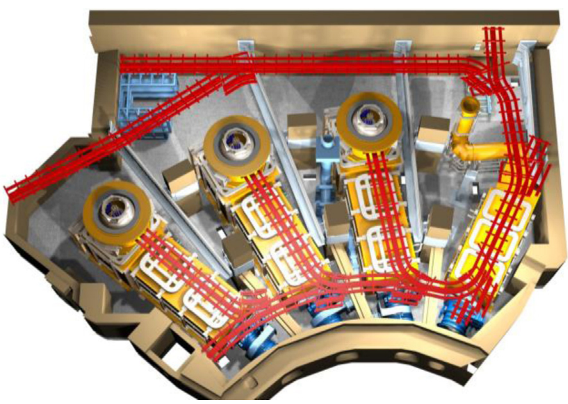

Fig. 2. Plan view on the neutral beam cell.

2. Monorail

The neutral beam cell monorail is shown in red (Fig. 2). At the top of the figure, the monorail track passes behind the three heating neutral beam lines and at the bottom it passes above the front end components and has branches to pass over each of the three heating beam lines. (For interpretation of the references to color in this text, the reader is referred to the web version of the article.)

Seven sets of switches allow the crane to move between the different branches of the monorail. The switches run on linear slides driven from the level 3 high voltage deck above.

The monorail design is shown in Fig. 3. It comprises a main central I beam with stabilizer rails to each side to react eccentric loads. These are attached to cross-beams, mounted to plates embedded in the cell ceiling.

The two stabilizer rails contain bus bar electrical lines that connect to the crane via multiple pick-ups on the crane bogies to ensure pick-up when crossing switches and to provide redundancy. The bus bars can carry power and signal communication.

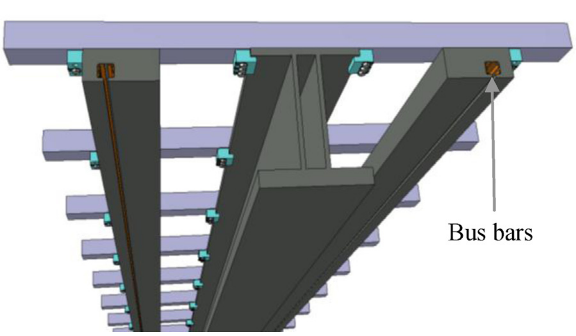

Fig. 3. Monorail arrangement.

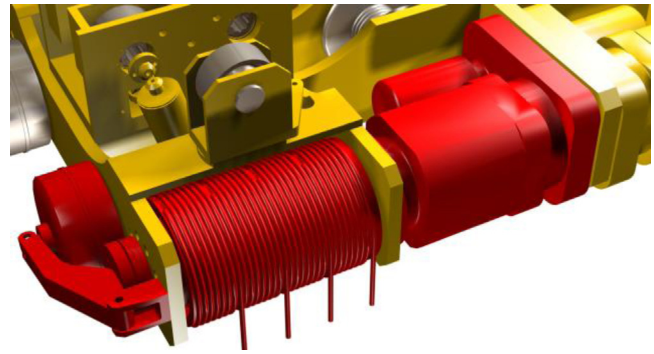

Fig. 4. Hoist assembly arrangement.

3. Bogies

Two bogies support the crane on the monorail with a total of four independent drives.

Each bogey has two stabilizer wheels with Ackermann steering and spring loading to maintain constant contact with the stabilizer rails and four conductor bus pick-up assemblies based on the Demag DCL system to supply power and signals to the crane.

4. Hoists

The crane has four independent hoist assemblies, mounted to the crane frame. The assembly comprises; rope drum, drives and brakes, shown in red in Fig. 4. (For interpretation of the references to color in this text, the reader is referred to the web version of the article.)

Due to the restricted vertical height of the crane, the rope drum diameter was limited to 450 mm. Single ropes with suitable breaking loads cannot be wound round such a small drum so four rope drops are used on each drum. The rope selected is an 18 mm diameter Diepa H50, compacted strand wire rope (Fig. 5).

The hoist drive requires a large speed range to achieve both the operational efficiency requirements and the controlled engagement of components. A Demag 20 kW conical rotor motor with integrated 2 kW creep motor and duty brake meets these

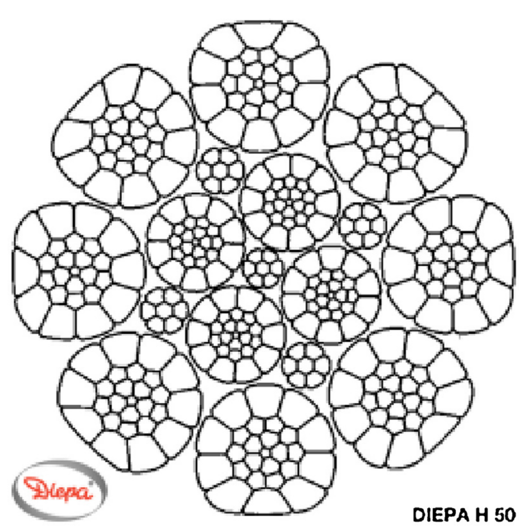

Fig. 5. Compacted strand wire rope arrangement.

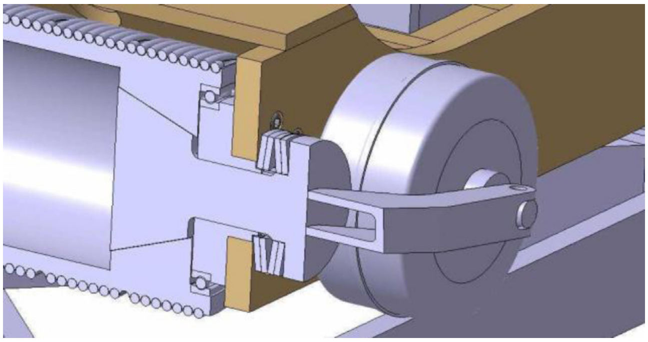

Fig. 6. Conical brake and actuator arrangement.

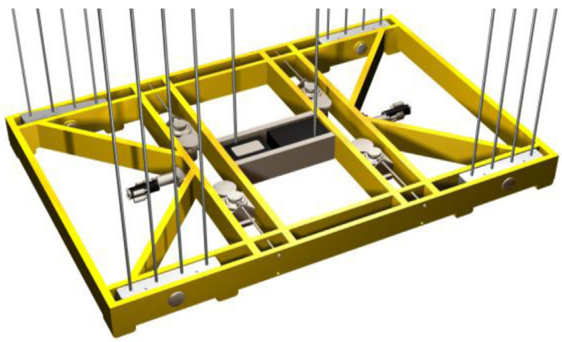

Fig. 7. Lifting frame arrangement.

requirements, coupled to a 226:1 three stage planetary gearbox packaged as one assembly inside the rope drum.

The European Standard for crane safety and general design [4] requires an emergency brake that acts directly on the drum. The diameter of a standard disc brake design is too large to fit in the restricted vertical height of the crane so a conical brake has been used at one end of each rope drum, actuated by disc springs and disengaged with a standard crane emergency brake electromagnetic actuator by Stromag (Fig. 6).

5. Lifting frame

The lifting frame provides the standard lifting interface between the crane and components and it interfaces with lifting adaptors in operations where components require additional motions or a non-standard lifting interface (Fig. 7).

5.1. Twist-locks

Mechanical engagement is provided by four twist-locks conforming to international standards [5] (Fig. 8).

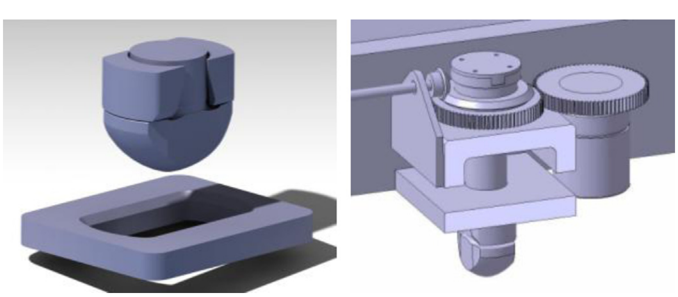

Fig. 8. Twist-lock arrangement.

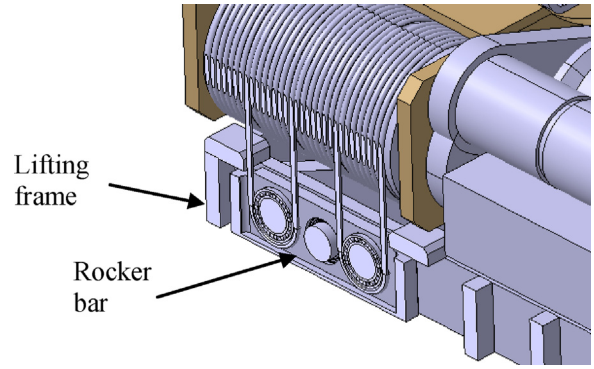

Fig. 9. Section through an equalizer block arrangement.

The twist-locks provide alignment during attachment of the lifting frame. They have external drive connections that can be driven by a tool deployed by any of the cell manipulators in case of motor failure. The entire twist-lock assembly can also be replaced remotely.

5.2. Equalizer blocks

The lifting frame is suspended from the crane ropes which pass through equalizer blocks at each corner of the frame.

Within each equalizer block the ropes pass around pulleys on each end of a rocker bar to ensure equal tension in each of the four rope drops, even if the rope creep rate or extension under load varies between drops (Fig. 9).

6. Control

Feedback available to the operator will include the position along the rail, derived from the voltage drop in a special conductor in the conductor bar and the load height derived from resolvers on the hoist motors. The hoist motors will be driven to maintain a level lifting frame derived from inclinometers mounted on the frame.

A unique umbilical control connection to the crane is not possible because the track does not have a single origin and there is no space in the cell for a reel or festoon. Three other options have been considered for the concept design and these are described below.

6.1. CAN bus

This option uses additional bars in the Demag DCL conductor bar power transmission system described above to transmit CAN bus communication signals.

The system is commonly used on production lines but is susceptible to noise and it has a relatively low bandwidth, preventing the use of video cameras on the crane or lifting frame.

The CAN bus system requires onboard processing. Radiation tolerance of the processors is a potential issue. Commercial components are available with radiation tolerance levels up to a few kGy but they are expensive.

The requirement specification states a minimum tolerance of 20 kGy. The actual dose received by the crane is likely to be much lower than this but some shielding may be required.

6.2. Wireless transmission

This option uses radio signals to send and receive control communication. It has similar issues to the CAN bus system in requiring onboard electronics and has a susceptibility to noise.

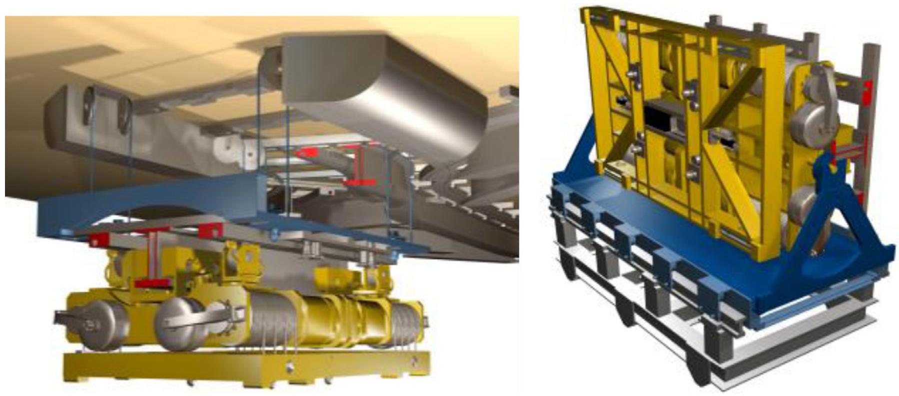

Fig. 10. The crane at the recovery hoist position and at the transfer table, rotated through 90° on the stillage to fit into a transfer cask.

The wireless transmission system is being considered for use with the ITER cask transfer system and would therefore have reduced development costs and risk and there would be commonality between the ITER control systems.

6.3. Discrete plug-in points

This option uses the DCL power bus connections to directly drive the crane to discrete points along the monorail where it can remotely connect to control plug-in points adjacent to the track. The two independent bus bars, each with four pickups on the crane provides high redundancy to ensure a continuous power connection.

Flexibility in the connection between the crane and the plug-in point could allow the crane to move a metre or so in either direction along the monorail whilst plugged in. However, a large number of plug-in points would be required and some flexibility of the design would be lost making this option only necessary if neither of the other two options can be developed into viable systems.

7. Recovery

To achieve the required availability of the ITER neutral beam systems, high reliability components, redundancy, condition monitoring and regular maintenance will be required to ensure the crane is suitably reliable.

In the event of failure when shielding or containment barriers have been removed, remote recovery must be possible. This is achieved with a number of systems, including (Fig. 10):

1. The ability to lift a load on two out of the four hoists in the event that one hoist seizes.
2. Torque limiters on the monorail drives to allow the crane to return to the transfer area with one drive seized.
3. Dexterous manipulation is available at a number of locations in cell, including at the cask transfer area to allow recovery, release or repair of failed components.
4. A recovery hoist system to lower a section of monorail and the crane onto a stillage for removal, in a cask, to the hot cell for maintenance.

The recovery hoist system will provide the preferred method of access to the crane for planned and unplanned maintenance, whether or not personnel access is possible.

8. Seismic loads

The crane is required not to drop its load during a seismic level 2 (SL-2) event. The crane is also required to provide a credible recovery scenario for other remote handling equipment in the cell following such an event. To this end, the crane has been designed to withstand the event without unrecoverable damage.

The variable natural frequency of the load suspended from the crane due to the varying length of rope during a lift means that for most heavy lifts, there is a point where the natural frequency will match that of the building response to a seismic event. Under these circumstances, during an SL-2 event, the acceleration of the mass would exceed gravity.

When the upward acceleration of the load on the rope exceeds gravity a non-linear slack rope condition arises, where higher rope tensions are seen when the rope becomes taut again, compared to the loads that would be seen if the rope acted as a spring.

Transient dynamic analysis was performed using an iterative small time step calculation on a one-dimensional system to show the maximum rope loads for a range of rope lengths and seismic input frequency. The effects of varying rope stiffness and damping was also investigated.

It was found that the maximum rope load for the non-linear system was about 1/3 higher than that for a linear system where the ropes acted as springs.

Structural analysis showed some strengthening of the crane and lifting frame was required to withstand the additional load and that the loads on the building interface were high.

Additional work was carried out to strengthen the crane and to add flexible mounts between the cross-beams and the building interface points to spread the crane load over more building interface points.

Further analysis will be required using more comprehensive input movement data and a multi-degree of freedom model to consider also the effects of a rotating and off-centre load.

9. Conclusions

A feasible concept design with all the required remote handling attributes has been achieved that meets the system requirements.

Considerable work remains for the preliminary design stage due to the novel nature of some areas of the design, most notably the hoist and control system and also in demonstrating that the requirements of the safety case have been met.

Common design principles and designs should also be implemented where ever possible between all ITER remote handling systems.

Acknowledgments

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