Challenges, Analysis and Design Solutions for a Bolted Target Support Frame within a Remote Handling Area

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Abstract. The ISIS Neutron Source TS1 Project will include the replacement of a significant amount of equipment, including the existing support frame for the Target, Reflector and Moderator components. This paper discusses the challenges affecting the design, and a summary of the analyses carried out to verify the safety case. Having established a baseline model, verified using hand calculations, a number of investigations were carried out to inform design decisions. The results were that the new design could support the applied loads for all load cases, with a greater factor of safety than the current installed frame. In addition, it was found that the number of bolts could be significantly reduced, potentially representing a significant time saving for end-of-life disassembly.

1. Background
The ISIS Neutron Source TS1 project (discussed thoroughly in the work of S. Gallimore, D. Coates, D. Wilcox and L. Jones at ICANS XXII) will incorporate a new Target, Reflector and Moderators (TRAM) assembly, along with a full new set of services. All of this will be supported by a new frame, made of bolted stainless steel plates. Due to the high radiation environment around the Neutron Target, the assembly is enclosed in a shielded cell, and only accessible with remote handling equipment. The frame is cantilevered from the door to the remote handling cell to allow for sealing around it during operation. The resulting complex loading situation on the frame and bolt patterns required further analysis to evaluate the safety case, and to inform further design decisions.

1.1. Reasoning for moving to a bolted design
As discussed by D. Coates, one of the significant engineering improvements being implemented in the TS1 project is to move from the current layered reflector (shown in Figure 1) to a design that can be split horizontally, allowing fast access to the moderators (see Figure 2). It was found that this could not be implemented on the existing frame, and the decision was therefore made to replace it with a new design that better suits the new TRAM layout. However, removing the existing welded frame (shown in Figure 3) poses its own problems: the frame is too large to be put in a radiation shielded flask and extracted; instead, it must be cut up into smaller pieces for extraction (tests of this have already been carried out, shown in Figure 5). It has therefore been decided that the new design should be made of bolted sections (see Figure 4), removing this difficulty (and the radioactive material handling considerations that go along with it) for the future end-of-life disposal.
2. Design Challenges

Whilst moving to a bolted design facilitates easier end-of-life disposal, the challenging environment and loading state prevent this from being a straightforward transition. To begin with, the combined cantilevered moment and torque on the frame from the TRAM and services loads gives a sufficiently complicated stress state that Finite Element Analysis (FEA) modelling is required in order to accurately assess the safety case for the frame and bolt patterns.
From a logistical point of view, the extremely high radiation environment around the Neutron Target (> 1 Sievert per hour at a distance of 1m) also represents a significant challenge for the installation, maintenance and end-of-life disassembly and disposal of the frame, and must be considered carefully at the design stage. For example, stainless steel is required for both the bolts, and the plates, requiring specially coated bolts to prevent galling of the screw threads. All interactions with the frame must be done with remote handling “Manipulator Arms” (see Figure 6); these are limited in maneuverability, strength, and, crucially, the torque load that can be applied to bolts.

3. Structural Analysis

Ansys Workbench FEA software [1] was used to assess the stress state and maximum deflection in the frame. In order to model the stress state in the frame, the loads for each of the components in the TRAM assembly needed to be extracted and modelled (as shown in Figure 7). A baseline model was then developed, with verification using hand calculations approximating the loading state of the frame. From this, a variety of different load cases were evaluated, and the effect of different design features, or material choices could be evaluated for designers. The deformation and Von-Mises Equivalent Stress results are shown in Figure 9 and Figure 10 respectively.

![Figure 7: Extracted TRAM and services loads applied to the frame model](image)

![Figure 8: 1-D Beam models of bolts with "Spider" connections to holes](image)

![Figure 9: Deformation results, assuming bonded contact](image)

![Figure 10: Equivalent Stress results, assuming bonded contact](image)
Further information can be extracted from this model, such as the expected discontinuities in the rails along which the reflector wheels roll at the transitions between the plates (shown in Figure 11).

4. Bolt Pattern Analysis
A significant challenge was to quantify the loads and stresses on the bolts and plates due to the combined moment, shear and torsion load on each of the bolt patterns. Hand calculations gave initial estimates for the bolt loads, but only for a simplification of the loading on the frame. Using Finite Element Analysis of the full frame, with realistic load locations, yielded the additional shear and axial bolt-loads associated with torsion due to unequal loads on each side of the frame. This was done using 1-Dimensional Beam Elements, a method of bolt modelling requiring comparatively low computation time; this was crucial to be able to model all 68 bolts on a single workstation. This simplified methodology gives quite poor local stress results due to the unrealistic rigid bonds at the head and the nut of the bolt [2][3], but generates accurate bolt loads; these loads could then be extracted and compared with the recommendations from standards for Stainless Steel bolts and frames [4][5].

5. Conclusions and Further Testing
The first (and crucial) requirement of the analysis was to verify that the frame is capable of supporting the applied loads for all load cases; this was shown to be the case, with a significantly higher factor of safety than the current installed frame. Additional investigations were also conducted, exploring design concepts such as alternative materials, different bolt load-transfer methods, and the impact of additional shielding. The results showed that alternative materials (such as Aluminum) could feasibly be used for the frame (although would represent other challenges in manufacture and installation). Another useful conclusion was that the size and number of bolts in each bolt pattern could be reduced, thereby reducing the amount of work required for end-of-life disassembly of the frame.

References
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