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A NEW PROCUREMENT STRATEGY TO CHALLENGE THE SUPPLIER CONSTRAINTS CREATED WHEN USING A FULLY DEVELOPED REFERENCE DESIGN

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Abstract

A common procurement strategy is to produce a fully optimised reference design that makes assumptions about the manufacturing process and supplier capability. This approach can restrict the opportunities for some companies to include their own specialist manufacturing capability to provide a more effective and cost efficient solution. A new approach is suggested following the recent experience at Diamond Light Source. The manufacture of high stiffness welded fabrications up to 13 m in length for the I21 RIXS[2] [1] Spectrometer is used as an example. The I21 RIXS Spectrometer design was optimised for stiffness and control of vibration. The use of Finite Element Analysis[3] enabled different design options and compromises to be explored utilising the supplier's capabilities. The final design was tested during manufacture to verify the FEA model. With the I21 RIXS Spectrometer commissioned the data collected shows the final stability performance of the system including detector stability over full experiment durations has met the scientific goals of the design.

REFERENCE DESIGN DEVELOPMENT

The RIXS Beamline at Diamond followed the normal development process with Concept and Technical Design Review phases of Science Case and Technical Feasibility sign off. The beamline optical layout is typical for a soft X-ray beamline having a PGM[4] and Exit Slits with focusing optics either side. However to achieve the necessary photon throughput, energy resolution and stability enhancements have been necessary.

Construction of I21 RIXS Beamline at Diamond was a complex programme of Beamline, Spectrometer, External Building and Sample Vessel projects. The Spectrometer is a 16 m long assembly that supports a detector and optics. The complete assembly is able to rotate on a vertical axis 150 degrees around the sample vessel with the sample at the centre. The optics are a series of cylindrical gratings to focus scattered X-rays from the sample on the detector with energy distributed vertically. The gratings have 4 motions and in addition the whole assembly can travel 1.5 m in beam direction. The detector is able to rotate to align with the focus of the vertical energy distribution of the X-rays by moving radially and vertically.

Project Phases

The Spectrometer project had several stages starting with a concept stage that concluded with a review by the Technical Working Group, Science Director and Head of Engineering. The first phase of work on the Spectrometer involved developing concepts for the key aspects of the design. During this phase visits were carried out to the Address Beamline at the Swiss Light Source [2] and ID32 at the ESRF [3] to discuss the approach used for similar beamlines.

At this stage, the design intention followed recognised best practice to minimise risk through the utilisation of standard parts, using developed technology and where possible solutions previously used at Diamond. With this low risk strategy in place the design of individual assemblies could then be developed including the Spectrometer Frame.

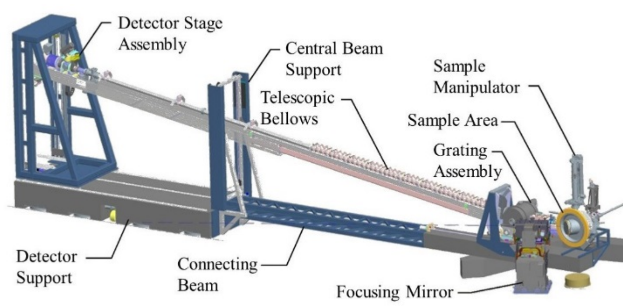

Figure 1: Concept Report Design January 2014.

In the design shown in Fig. 1 the Vertical Frame Assembly supporting the Detector Stage Assembly is able to move in the radial direction to control sample to detector distance. The range of this motion was extended in the final design to move detector from 10.3 m to 15.5 m. The completed Vertical Frame Assembly is able to move the detector 1.4 m vertically with a minimum height of 900 mm above the sample. At the concept stage it was expected the detector would need to be the same height as the sample for alignment. This requirement was later

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removed allowing more space for stiffening members once the optical alignment process had been defined.

Tender Stage

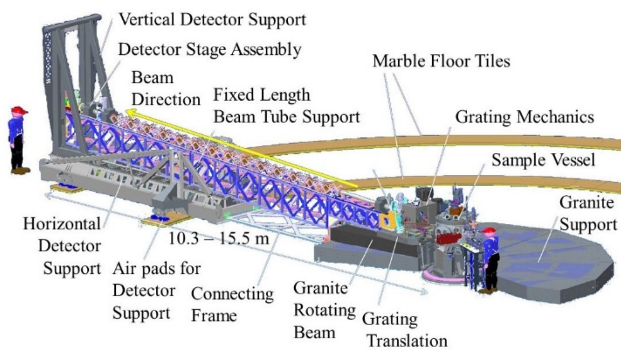

Figure 2: Tender Reference Design April 2016.

Several changes were made as the design developed for the Tender Reference Design Fig. 2. Air Pads were chosen for the Horizontal Detector Support. The telescopic bellows support was rejected in favour of a 13 m fixed length support enabling the central beam support to be removed. The rails supporting the Detector Stage Assembly could also be used to support the bellows capable of extending 7 m to link the Grating Mechanics Vessel to the Detector Stage Assembly. The chosen structure for the fixed length bellows support was a welded lattice based on a Bailey bridge [4]. The lattice design of diamonds between vertical members was found to have a significantly higher stiffness to mass ratio than a design with crossed members between verticals. In the Spectrometer application, this gives better vibration performance and reduced deflection for the same load.

Deflection of the lattice varies with radial movement of the Vertical Frame Assembly. This deflection creates a variable energy offset seen at the detector. Energy is measured by the detector through spatial separation in the vertical plane. Vibration limits the energy resolution achievable through vertical motion of the detector. Both of these effects are detrimental to the quality of data collected.

The Horizontal Detector Support material was selected as steel in preference to granite to facilitate the use of Air Pads in the support as the mass of the assembly was radically reduced. To increase the stiffness of the steel structure, towers and rigid stays were added. The overall length was increased to accommodate changes in the performance of X-Ray optics that may be available for future upgrades.

Tender Stage FEA

At this stage of the detailed design; deflection of the horizontal frame and specifically the variation of this deflection was minimised. The maximum deflection case shown in Fig. 3 is with the load from the Vertical Frame Assembly midway between supports. The maximum deflection modelled is 0.25 mm. The aim for the variation in deflection between different load cases was +/-0.1 mm with +/-0.14 mm being achieved. This models the parasitic change in vertical position of the detector for different sample to detector distances. Modal analysis was also carried out to quantify the stiffening effect of improvements. The result Fig. 3 at tender was a first mode of vibration of 18 Hz.

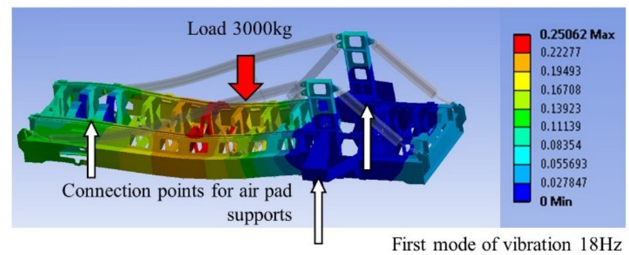

Figure 3: Horizontal detector welded frame deformation at tender stage.

PROCUREMENT

Our first challenge came right at the end of the tendering process. One of the regular suppliers to Diamond who had been contacted in the concept phase to give budget advice informed us that they would not be tendering. This was due to the scope of work being substantially outside their normal range. We had to decide whether it would be better to accept the outcome of the tender process or restart our specification and accept the delays that would follow. Since our project timescale was already under pressure we chose to accept the tender process outcome.

The second challenge was presented by the company OCSAM s.r.l.[5] who were successful in the tender process. We agreed a rapid progression to a kick off meeting at the OCSAM manufacturing plant. The main outcome of the discussion was that they liked our project but not our reference design. In the company's opinion it was not optimised, they also advised it would be possible to offer a much better solution in a reduced delivery time. We took the opportunity, and although under time pressure, we decided to revise the design. Using the potential time saved from manufacture it was possible to investigate the performance benefits of optimising the design for the OCSAM capabilities. These capabilities included custom beam manufacture, folding steel plate (6 mm thick and 13 m in length) and machining assemblies in sections up to 18 m in length. This was far in excess of what we had expected to be easily accessible in our budget and time scale when developing our reference design.

Our initial concept based on the low risk and standard part approach had led to a design based on standard section beams for the main strength of the assembly. OCSAM suggested a custom beam based on a plate with 'C' section folded around it. This 'D' shaped profile was able to fill all the vertical space available offering signifi-

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cantly improved stiffness with the increased moment of inertia from the equation (1).

$$I = \frac{b \, . \, d^3}{12} \qquad (1)[5]$$

Other changes included the width of frame, optimised at a wider span and removing the towers and stays without reducing the performance of the structure.

The Vertical and Fixed Length Beam Tube Support welded assemblies could then be focused on. The limitation was not the section of material or machine tool capacity, but the decision to avoid the need for an escort across Europe. This also reduced the cost of shipping the frame parts from Italy to the UK.

Achieving the Optimal Solution

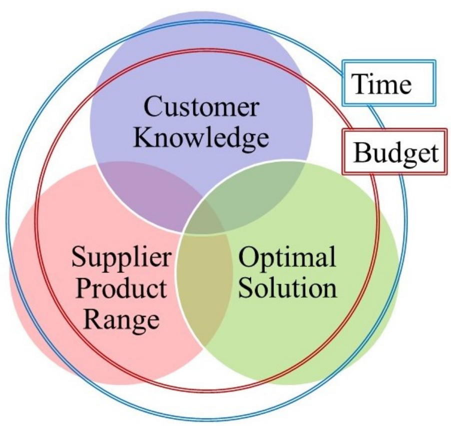

Figure 4: Venn diagram showing influences that need to converge to achieve the required outcome.

Figure 4 shows graphically how the Optimal Solution can be positioned against the Customer Knowledge and Supplier Product Range. Equally the supplier product range could be their capability or potential and Optimal Solution could also be defined as ideal specification. Also shown in Fig. 4 are the budget and time aspects, these factors provide overall constraining limitations. Recognising and responding to knowledge baseline effects is a key factor in achieving the desired outcome.

It has become clear that the convergence of Customer Knowledge and Supplier Product Range had not come together with the Optimal Solution at the Tender Stage of the Spectrometer Frame Project. The knowledge of Supplier Product Range was wrong for both companies discussed and the Optimal Solution achievable was limited by the reference design. It cannot be realistic to hope for an open ended budget to resolve these type of problems yet challenging budget contingency may be valid for projects at the fringes of customer knowledge.

Design consultancy would be a recognised route for projects where further knowledge of the optimal solution is required. The cost of doing this would need to be reflected in the overall project cost as well as potentially higher manufacturing cost of the solution. Taking a pragmatic view in a budget conscious environment leads to the option of investing time in developing customer knowledge. This is where time spent understanding technology and supplier capability at the outset of a project are the route to eliminating higher cost routes to achieving optimal design solutions. In short a more informed Engineer or Designer will have a greater opportunity to achieve the most optimum solution. The benefits from the investment in time and Engineering knowledge are returned through achieving higher quality solutions first time and also getting closer to the optimal goals of the project, whether they are low cost, efficiency, science output or data quality.

Analysis of Final Design

Finite Element Analysis (FEA) enabled the exploration of different design options and compromises. This resulted in a new optimised design based on the design parameters OCSAM had made available. The final design included changes targeting specific load cases where the position of the vertical frame caused the most deflection. Figure 5 shows a deflection of 0.16 mm for the optimised frame FEA. The variation in deflection between different load cases was improved to +/-0.06 mm. Modal analysis showed stiffness had been significantly improved with a first mode of vibration of 36 Hz.

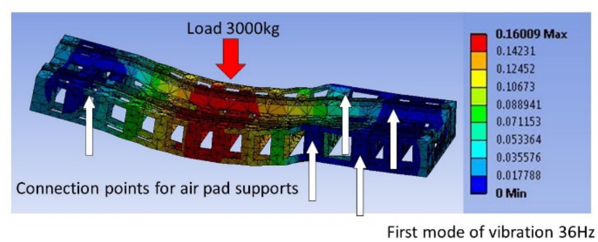

Figure 5: Horizontal detector welded frame design at FDR stage.

Changes to the vertical frame included significant additions to give lateral stiffness. The aperture for the lattice to pass through is a major weakness of the structure and stiffening this was the last priority. Following the optimisation, it was possible to hold a Final Design Review and allow manufacture to start.

MANUFACTURE AND TESTING

Manufacture included load tests designed to verify the FEA model. Simple load cases were modelled that could be easily set up by OCSAM with the frames after welding. These tests were able to verify the frames achieved the predicted stiffness. The horizontal frame performed extremely close to the model with 0.36 mm and 0.39 mm vertical deformation. The FEA prediction was 0.358 mm for both sides. The fixed length bellows support and vertical frame did not follow the prediction as closely with deflections 23-33 µm greater than predicted. This was a significant proportion of the predicted deformation. These errors are not enough to create significant stresses and the

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frames were accepted. The comparable difference in reliability of FEA prediction may be due to differences in the use of welded joints to create strength. The horizontal frame is essentially two beams with stiffening sections between them, the other assemblies are welded lattice structures. This area would require further investigation and modelling to understand the differences from the FEA model.

Stability

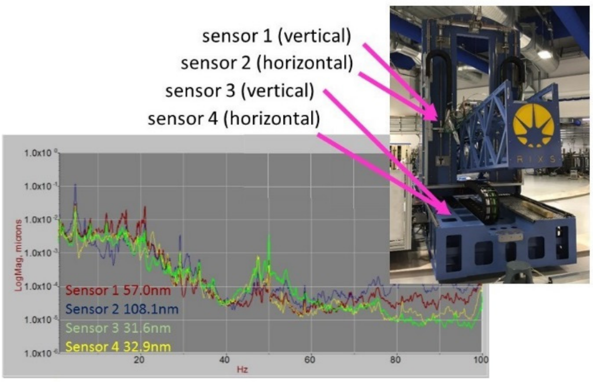

Figure 6: Spectrometer vibration measurement.

Stability measurements of the Spectrometer Frame show very good stability with a summary of results shown in Fig. 6. Vibration measurements of the frame show an RMS[6] vibration amplitude of 108nm, which is in the lateral direction. Vertical vibration, which has a more direct relation to the quality of data collected by the beamline, is 57 nm.

CONCLUSIONS

When specifying equipment and writing tenders it is necessary to draw out the suppliers knowledge to show where the equipment would fit in their circle of capability.

The risks of a reference design are to overlook the need to write specifications in a way that allows a supplier to give their best solution to meet the functional requirements of the equipment.

There is a need to recognise and be aware of the limitations of our design baseline. These limitations taken through a specification and tender process are able to influence the level of design optimisation possible.

The challenge for future projects is to apply a strategy that identifies limitations in our knowledge and enable the procurement process to meet our functional requirements within the overriding project limitations of time and budget.

Using a budget contingency allows a broad range of procurement solutions to be considered. The most appropriate solution can then be chosen to achieve the project functional specification more efficiently. Through the development of our engineering knowledge base, especially knowledge related to supplier expertise and capability it becomes possible to provide better Customer Knowledge to a project.

The best method for achieving a delivery closer to the optimal solution is for a new strategy to facilitate convergence of Customer Knowledge and Supplier Product Range. The proposed method for this is through the development and exchange of engineering knowledge to give the largest convergence of Customer Knowledge and Supplier Product Range with the Optimal Solution for a given project.

For the I21 RIXS Beamline at Diamond the Spectrometer project has been able to make the most of a second chance. Working with OCSAM provided an opportunity to learn as well as time for development of the design to take place. This lead to improvements in structural strength and vibration performance that have a direct impact on the quality of results the beamline is able to deliver.

[6] Root Mean Square

REFERENCES

[1] L. J. P. Ament, M. van Veenendaal, T. P. Devereaux, J. P. Hill, J. van den Brink, "Resonant inelastic x-ray scattering studies of elementary excitations", in *Rev. Mod. Phys.*, vol. 83, pp. 567-569, Published 24, June 2011, doi:https://doi.org/10.1103/RevModPhys.83.705

[2] V. N. Strocov *et al.*, "High-resolution soft X-ray beamline ADRESS at the Swiss Light Source for resonant inelastic X-ray scattering and angle-resolved photoelectron spectroscopies", in *J. Synchrotron Rad.*, vol. 17, pp. 631–643, doi:10.1107/S0909049510019862

[3] ESRF ID32 RIXS N. Brooks, F. Yakhou, F. Cianciosi and L. Eybert, http://www.esrf.eu/home/UsersAndScience/Experiments/EMD/ID32/RIXS.html

[4] Think Defence, https://www.thinkdefence.co.uk/2012/01/uk-military-bridging-equipment-the-bailey-bridge/

[5] W. C. Young, R. G. Budynas, "Properties of Plane Area", in *Roark's Formulas for Stress and Strain - 7th Edition: International Edition*, McGraw-Hill, 2002, p802.