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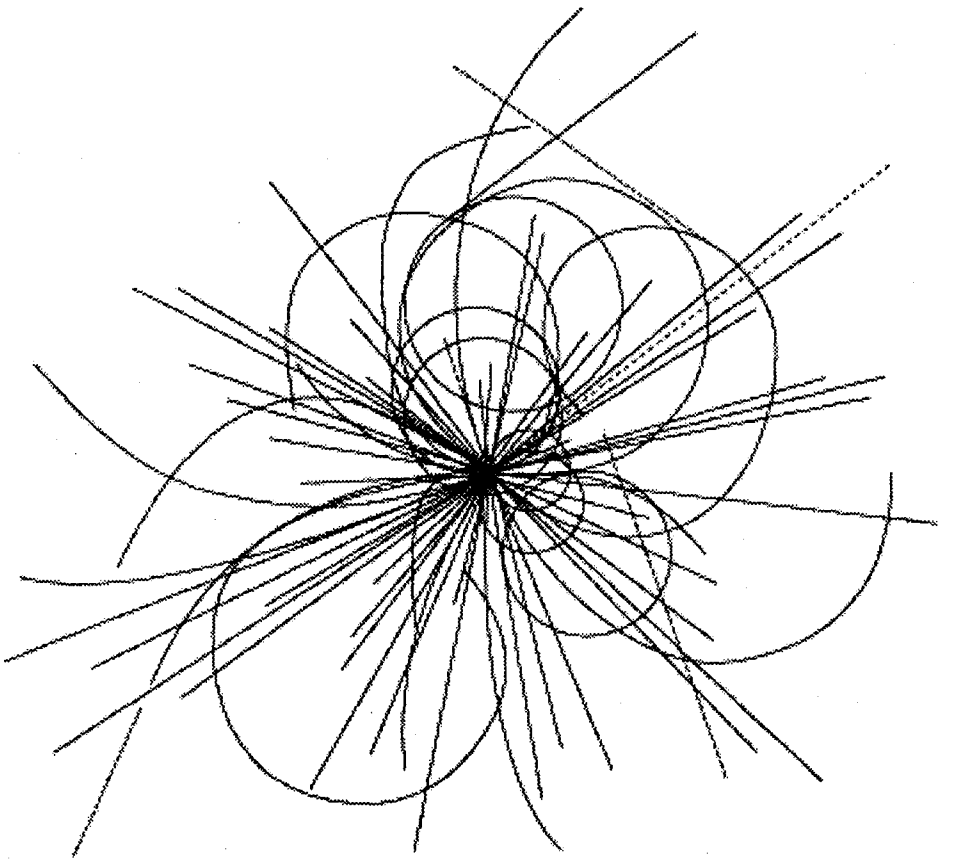

Superconducting Super Collider Laboratory

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# Stress Analysis On SSC Cryogenic Shaft Transfer Line Suspension System*

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# STRESS ANALYSIS ON SSC CRYOGENIC SHAFT TRANSFER LINE SUSPENSION SYSTEM

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## INTRODUCTION

The Superconducting Super Collider has a total of twelve refrigeration plants. Each plant requires a cryogenic transfer line to connect the above-ground refrigerator to the below-ground collider main ring. The transfer line consists of seven cryogenic circuits enclosed in a cryostat. It is to be built in a number of pieces (modules) and assembled on-site. Within each transfer line module, the internal elements including the circuit tubes, thermal shield, and multilayer insulation (MLI) blankets are supported by an internal suspension system. The suspension system for a module consists of a longitudinal support and four radial supports. The radial supports restrict any radial movement of the internal elements while allowing longitudinal thermal movement. The longitudinal support anchors all the internal elements to the vacuum jacket. Each type of support consists of three plates for supporting the circuit tubes at three designated temperature levels (4, 20, and 80 K), and two sets of stand-off rods which make joints between the 4 and 20 K plates, and between the 20 and 80 K plates. An isometric view of a radial support and a longitudinal support is shown in Figure 1.

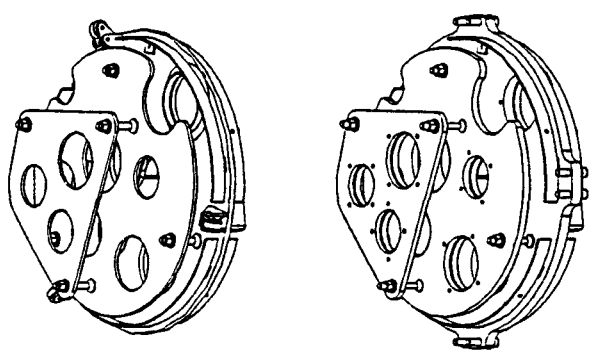

Figure 1: Isometrics of radial and longitudinal supports

The longitudinal support anchors the internal elements to the vacuum jacket through the welds between the vacuum jacket and a metal ring fastened to the 80 K plate. Each transfer line has two 90° bends where straight modules are joined by elbow pieces. There are two internal supports within each elbow piece. The elbow piece supports are similar to the longitudinal supports except they have much higher strength requirements (approximately 10 times). The three stand-off rods connecting the 4 and 20 K plates are strategically located such that an optimal weight distribution

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is achieved resulting the least strength requirement for the 20 K plate. The same design principle is applied to locating the rods between the 20 and 80 K plates in order to minimize the strength requirement for the 80 K plate. Due to the geometrical complexity of the internal suspension system design, numerical methods are required for the stress analysis of the suspension system components. The objective of finite element modelling is to investigate the behavior of the support assemblies under specified conditions.

## LOADING REQUIREMENTS AND CONSTRAINTS

The loading requirements for the support assemblies are based on the design system requirements and geometrical constraints. The system requirements are characterized by the parameters contained in Table 1. The loads on the radial supports depend on the total weight of the internal

Table 1: Transfer line system characteristics

| Cryogenic circuit | Pressure | | Temperature | Mass flow rate | |
|---|---|---|---|---|---|
| | Design (Bar) | Nominal (Bar) | (K) | Design (g/s) | Nominal (g/s) |
| 4 K helium supply | 20 | 4 | 4.5 | 400 | 400 |
| 4 K helium return | 20 | 3.5 | 4.3 | 400 | 100 |
| 4 K gas helium | 10 | 1 | 4.0 | 400 | 300 |
| 20 K helium supply | 20 | 3 | 16.5 | 200 | 200 |
| 20 K helium return | 20 | 2 | 24.0 | 200 | 200 |
| 80 K liquid nitrogen | 20 | 10 | 80.0 | 400 | 80 |
| 80 K gas nitrogen | 10 | 1 | 80.0 | 400 | 300 |

elements and the cryogen content (approximately 6,200 N) when the module is installed horizontally. They are negligible when the module is installed vertically. The load on the longitudinal support during normal operation is due to gravity when the module is installed vertically. A 2 g loading is applied to the internal elements for the stress analysis purpose. Expansion joints are provided for the interconnection of the transfer line modules. Therefore, the thermal loading on each circuit tube is neglected. The use of expansion joints (bellows) for the interconnection between an elbow piece and neighboring modules demands the tensile forces in the circuit tubes be isolated within the elbow piece. Therefore, the dominating loading for the elbow support is the hydrostatic force on the circuit tubes at the bend. In addition, loadings due to cryogen momentum change at the bend and thermal contraction are also considered. Detailed loads on the longitudinal and elbow supports are tabulated in Table 2. The loads for the elbow supports are due to hydrostatic forces based on design

Table 2: Loading requirements for longitudinal and elbow supports

| Circuit | Loading (N) | | Coordinates (mm) | |
|---|---|---|---|---|
| | Longitudinal Support | Elbow Support | Y | Z |
| 4 K supply | 864 | 8,460 | -117.62 | 2.2 |
| 4 K return | 864 | 8,460 | -117.62 | -112.83 |
| 4 K gas | 988 | 7,691 | 2.79 | -55.31 |
| 20 K supply | 864 | 8,460 | 75.64 | 60.91 |
| 20 K return | 1,196 | 15,382 | -63.87 | 139.03 |
| 80 K liquid | 3,393 | 3,716 | 16.15 | -228.09 |
| 80 K gas | 3,615 | 7,691 | 203.2 | 0 |

pressures. They will be dramatically reduced when the nominal pressures are used. The magnitudes of the actual loads on the elbow supports will vary depending on the finalization of the transfer line design and system operating modes.

## MODELING

For the longitudinal support, five work sheets are created for the three plates at 4, 20 and 80 K and two sets of stand-off rods. The plates naturally fall in the plate/shell category, and the rods are considered as 3-dimensional solids. Triangle and quadrilateral elements are used for mesh generation in the plates and rods respectively. No boundary node is assigned to the stand-off rods. Each set of rods is modeled individually and linked to the plates to impose spatial constraints. The meshing statistics and geometry for the longitudinal support are presented in Table 3 and Figure 2 respectively.

Table 3: Statistics for finite element analysis

| Component | Total nodes | Nodes w/ B.C.'s | Element type |
|---|---|---|---|
| 4 K plate | 209 | 36 | triangle |
| 20 K plate | 433 | 24 | triangle |
| 80 K plate | 472 | 40 | triangle |
| Rods | 1542 | 0 | quadrilateral |

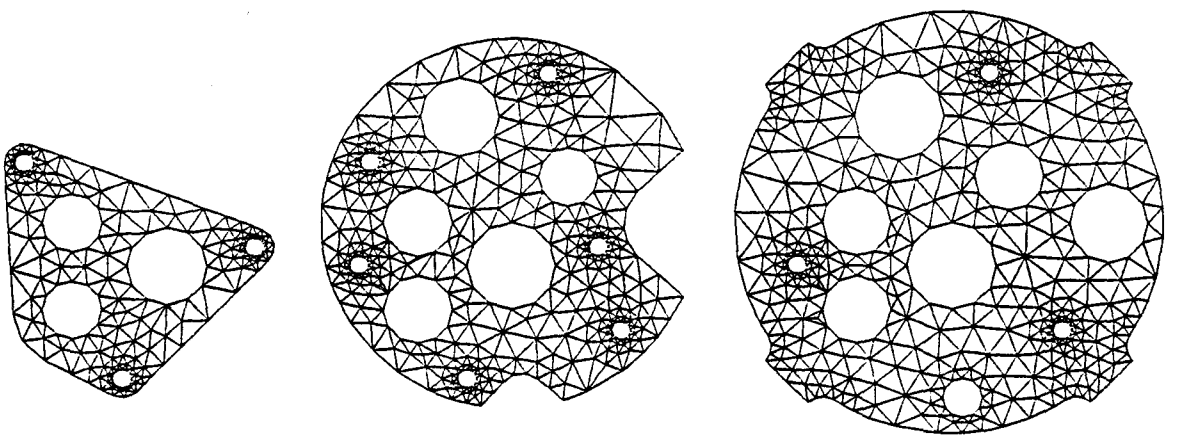

Figure 2: Geometric meshing for finite element analysis

The 4 K plate measures approximately 0.34 × 0.345 m, the 20 K and 80 K plates are circular with outer diameters of 0.482 m and 0.546 m respectively. The geometries of the elbow support plates are the same as those of the longitudinal support plates except thickness (see Table 4) and the number of anchoring locations (four for longitudinal support and eight for elbow support). Young's modulus E = 3 $\times 10^4$ MPa and Poisson's ratio $\mu = 0.2$ are used for the plates, and E=1.93 $\times 10^5$ MPa and $\mu = 0.3$ are used for the rods. The five elements (three plates and two sets of rods) are then decoded individually before they are linked together to impose mutual spatial constraints for the final stress analysis process. The stress analysis is performed using Algor's finite element analysis (FEA) processing system release 9.0.

## RESULTS AND DISCUSSIONS

The two models (longitudinal and elbow supports) are processed separately rendering stress and deformation distributions, and other pertinent informations. A screen capture of the stress distribution in the 4 K plate of the longitudinal support is shown in Figure 3 as an example.

The Von Mises stress spectrum is shown in the upper-right corner of the graph in the unit of megapascal. Higher stress is concentrated at locations where the stand-off rods join the 4 K plate as anticipated. The maximum stress in the plate ($\sigma_{max}$ = 94.5492 MPa) allows sufficient flexibility in design to provide adequate strength. The stress level in the 20 K plate is relatively low. Since all the loading from the 4 K circuits is transmitted to the 80 K plate through the 20 K plate, only the neighborhood of the stand-off rods connecting the 20 K plate to the 80 K plate needs to be examined. In the 80 K plate, higher stress is shown in the vicinity of the four tabs where the plate is anchored to the vacuum jacket. The stress at the tab areas can be significantly reduced by reducing

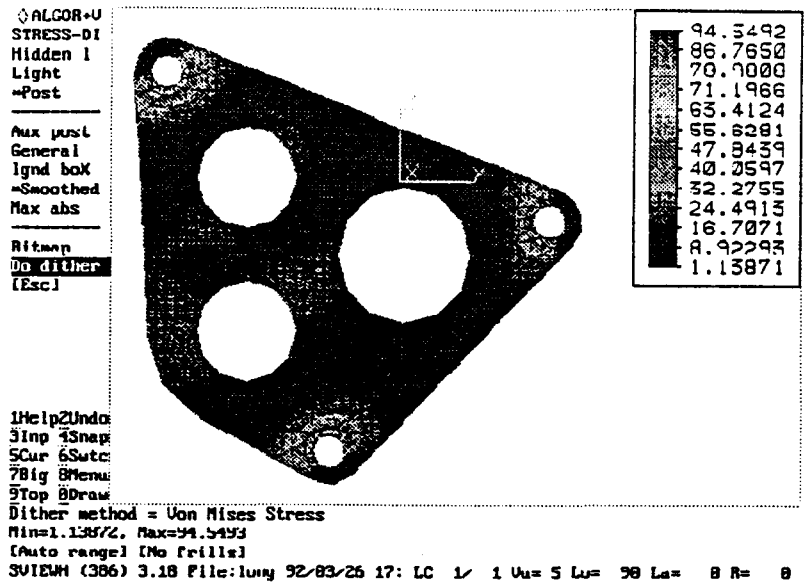


Figure 3: Stress distribution in 4 K plate

the inner diameter of the anchor ring.

Table 4: Results of analysis

| Plate Element | $\sigma_{max}$ (MPa) | $e_{max}$ (mm) | Y (mm) | Z (mm) | Thickness (mm) |
|---|---|---|---|---|---|
| 4 K longitudinal | 95 | 1.52 | -192.5 | -117.2 | 9.53 |
| 20 K longitudinal | 57 | .72 | -60 | -213 | 12.7 |
| 80 K longitudinal | 59 | .085 | 31.2 | -6.1 | 19.05 |
| 4 K elbow | 169 | 1.1 | -192 | -117 | 19.05 |
| 20 K elbow | 272 | 2.73 | -157 | 183 | 25.4 |
| 80 K elbow | 105 | .99 | -19 | 32 | 25.4 |

The maximum Von Mises stress and deformation $\sigma_{max}$ and $e_{max}$, as well as the coordinates where the maximum deformation occurs are listed in Table 4.

## CONCLUSIONS

To predict the strength requirements for the internal suspension system of the SSC cryogenic transfer lines, finite element stress analysis is performed on the longitudinal and elbow supports. The results reveal the behaviors of the construction elements. Computed maximum stress and deformation which occur under complex loading situation serve as reference for material selection and sizing in the preliminary design process. The highly localized stress in the plates may be substantially reduced by improving supporting boundary conditions. Testing apparatus has been designed and fabricated to verify the numerical results. Attention will be focused on the critical elements indicated by the numerical results to ascertain that they have sufficient strength for potential adverse situations.

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