Parametric study for use of stainless steel as a material for thermal shield in PIP2IT transferline at Fermilab

Tejas Rane
CEC / ICMC 2017 Madison
12\textsuperscript{th} July 2017
Introduction

Proton Improvement Plan–II (PIP-II) planned at Fermilab for providing high-intensity proton beams to the laboratory’s experiments.
Introduction

PIP-II Injector test (PIP2IT)
Front end of PIP-II consist of HWR, SSR1 cryomodules

SOURCE: CDR PIP-II FERMILAB
Introduction

PIP2IT tests will be conducted in CMTF building at Fermilab

Diagram:
- SCP REFRIGERATOR
- DISTRIBUTION BOX
- PIP2IT TRANSFERLINE
- HWR
- SSR1
- PIP2IT CAVE
Introduction

Present paper is related to the thermal shield of the PIP2IT external transferline

SCP REFRIGERATOR

DISTRIBUTION BOX

PIP2IT - EXTERNAL TRANSFERLINE

HWR

SSR1

PIP2IT CAVE
Introduction

Sectional view of part of the PIP2IT transferline

- **LINE B** – 2K SUBATM RETURN LINE
- **LINE C** – 5K 3.5 Bara SUPPLY
- **LINE D** – 8K 3.5 Bara RETURN
- **LINE E** – 40K SHIELD SUPPLY
- **LINE F** – 80K SHIELD RETURN
- **EXTERNAL SPIDERS**
- **INTERNAL SPIDERS**
- **VACUUM JACKET**
- **THERMAL SHIELD**

CAD MODEL: COURTESY – DAVE RICHARDSON, FERMILAB
Problem Description

Copper or Aluminium are preferred materials for the thermal shield because of higher thermal diffusivity.

However, stainless steel has been selected for fabrication of PIP2IT thermal shield due to following advantages—

- Easy availability of seam welded 10inch OD tube
- Reduced cost as compared to copper or Aluminium shield
- Higher strength of SS
- Welding Stainless steel (SS) shield to SS pipe is easier than brazing of Copper/Aluminium to SS
Problem Description

During cooldown, large thermal gradients occur on the surface of the thermal shield, due to low thermal diffusivity. This gives rise to thermal stresses and strains.
Problem Description

Stresses are induced because of following two reasons--

1. Hot part of the shield resists the contraction of the cold part (Thermal stresses)
Problem Description

Stresses are induced because of following two reasons--

2. The vacuum jacket and the Line F prevent bowing deflection of the shield sections (bowing stresses)
Objective and Procedure

If the length of the shield section decreases, the thermal strains decrease, thus reducing the stresses.

Geometric model of fixed diameter and thickness and variable length

Apply supports and load

Vary length to arrive at allowable value for safe stresses

For diameters 6” to 16”, thickness 3mm, 5mm
1. Support conditions:
   - Forces $F_1$, $F_2$, $V_1$, $V_2$ and moments $M_1$, $M_2$ do not allow bowing deflection
     ($F_1$, $F_2$ – forces exerted by the vacuum jacket)
     ($M_1$, $M_2$, $V_1$ and $V_2$ are the end reactions)

Support conditions: Approximated
Pure bending with symmetrical frictionless roller supports
($M_0$ is moment reaction due to supports)
Modeling of the problem-Load

2. Load (temperature distribution)
   - Temperature distribution in case of transient cooldown problem
   - φ10” shield section, 10ft long
   - 10g/s helium flow at 12bara, 80K

Load (APPROXIMATED)

Approximated as steady state distribution
Assumptions

Key Assumptions:-

- 10g/s of helium, at 12bar and 80K, through Line F is considered as the maximum possible cooling flow
- Temperature is constant along thickness
- The thermal strains incident on the thermal shield do not have nature of a cyclic load. Hence, these are considered as primary loads for evaluation of safe stresses
Results and discussions

The allowable lengths (Ls) of the thermal shield sections are plotted for different diameter values on X-axis for thickness 3mm and 5mm as shown in the figure.

Criteria for allowable stress

\[ P_l + P_b \leq S_{pl} \]  

\[ P_l = \text{Primary local membrane stress} \]
\[ P_b = \text{Primary local bending stress} \]
\[ S_{pl} = \text{Allowable stress value} \]
\[ S_{pl} = \text{Yield stress (} S_y \text{) for Stainless steel (} 2.07 \times 10^8 \text{ N/m}^2 \) \]
Results and discussions

- Flexibility decreases with increase in diameter
- Flexibility decreases with increase in thickness
- As diameter increases the hot length increases, however the angle $\theta_0$ is not modified for smaller diameters - hence conservative loads due to higher thermal gradients

Safe lengths can be selected for equal or lower thickness from the data points without rigorous analysis.
Thank you for your attention
UNRESTRICTED BOWING OF THE SYSTEM

VACUUM JACKET

RESTRICTION DUE TO VACUUM JACKET

SPIDERS

THERMAL SHIELD SECTIONS

COOLING FLOW PIPE

THERMAL SHIELD SECTION(S)
RESTRICTION DUE TO VACUUM JACKET

SPIDERS

THERMAL SHIELD SECTIONS
BOUNDARY CONDITIONS FOR SIMULATING THE RESTRICTIONS TO FREE DEFORMATION

FRICIONLESS ROLLER SUPPORT

HOT END

COLD END
THERMAL SHIELD PART(S) (SHELL+RING)

BONDED CONTACT

RINGS TO MODEL SUPPORTS

PART LENGTH ($E_1$)

GEOMETRIC MODEL OF THERMAL SHIELD FOR STRUCTURAL ANALYSIS
(UNWANTED RINGS AND PARTS SUPPRESSED)
GEOMETRIC MODEL FOR THERMAL SHIELD ANALYSIS

THERMAL SHIELD PARTS WITH RINGS MODELED FOR SUPPORTS

BONDED CONTACT
FREE BODY DIAGRAM FOR THE THERMAL SHIELD AND CONSEQUENT APPROXIMATION OF THE SUPPORT CONDITIONS

THERMAL SHIELD SECTION – SUPPORTS AND REACTION LOADS
STEADY STATE DISTRIBUTION ($\theta_0=36^\circ$)