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SDC
SOLENOIDAL DETECTOR NOTES

SDC ENDPLUG CALORIMETER-WBS 2.2.10 FEA BASIS FOR CALCULATING TIE-ROD WELD STRESSES

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FEA Basis for Calculating Tie-rod Weld Stresses

This note is OBSOLETE--MCR now uses plastic analyses techniques applied to tie-rod/plate weld regions--See SDC-92-330, W.L. Pope, 7/25/92.

This note provides brief documentation for the method used by MCR engineers to calculate the maximum *significant stresses* in the weld region of the tie rods in the MCR developed FEA models of the SDC Endplug.

MCR has found that although it is possible to provide accurate characterizations of stresses in all the tie rod welds and absorber plates of the SDC Endplug; because of the high degree of repetitive detail and resulting required number of nodes (degrees of freedom), the computing requirements would be astronomical. Consequently, MCR has developed a Plug FEA Model, based on the ANSYS Code (Ref. 1) consisting of two smaller models:

a) a System FEA Model, and
b) a detailed Tie Rod FEA Model.

In MCR's System Model (a quarter model of the plug with symmetric and anti-symmetric boundaries), some of the plug's absorber and wedge plates (using ANSYS "shell" elements) are connected to tie rods (using ANSYS "pipe" elements) and a relatively coarse mesh. This treatment is used only in 3 small plug regions:

1) at the back of hac 2 (3 layers of plates and wedges),
2) at the hac 1/hac 2 interface (3 layers of plates and wedges),
3) the front plate of hac 1.

Elsewhere in the plug, absorber assembly "cells" are treated as "brick solids", and in the plug-to-endcap support region, suitable ANSYS "solid" elements are used.

No attempt is made in the System Model to calculate the detailed FEA stress distribution in tie rod/plate weld regions (the mesh is simply too coarse).

The stresses in the weld region at one end of MCR's detailed Tie Rod Model, **Figure 1**, are obtained by applying unit loads to the opposite end, assuming the tie rod behaves as a fixed-guided beam with axial load (which ignores *relative rotation* between the attached end plates). Each of these models have been described in greater detail by Rodamaker (Ref. 2).

Current Calculation Basis

The maximum von Mises stresses in the weld region of the tie rods in the MCR Plug Model are calculated (in post-processing routines of the *System Model*) from:

$$(\sigma E)_{wsm} = \{ FXJ*((\sigma E)_{tr}/1\#)_{Fa} + sqrt[(FYJ)^2 + (FZJ)^2]*((\sigma E)_{tr}/1\#)_{Fl} \}_{max} \qquad (1)$$

where the various terms in Eq. (1) are defined as:

$(\sigma E)_{wsm} = (SIGE)_{wsm}$ = von Mises stress in the "weld region" of the System Model (e.g. approximately what *would have been calculated* in a highly detailed complete FEA model of the plug),

$((\sigma E)_{tr}/1\#)_{Fa} = ((SIGE)_{tr}/1\#)_{Fa}$ = the *maximum* von Mises stress in the weld region of the Tie Rod Model due to a unit axial load (one lb) applied at the other end,

$((\sigma E)_{tr}/1\#)_{Fl} = ((SIGE)_{tr}/1\#)_{Fl}$ = the *maximum* von Mises stress in the weld region of the Tie Rod Model due to a one lb lateral load applied at the other end,

FXJ = X load (axial) at the other end of the tie rod (pipe element) computed in the System Model,

FYJ = Y load (lateral) at the other end of the tie rod (pipe element) computed in the System Model,

FZJ = Z load (lateral) at the other end of the tie rod (pipe element) computed in the System Model.

The forgoing *maximum* von Mises stresses in the weld region of the Tie Rod Model are very localized stresses due to a sharp geometric discontinuity at the "bottom" of the weld, **Figure 1**. These peak discontinuity stresses (which are analogous to form stresses) will be redistributed due to local yielding during static loading. The form stresses can be related to significant stresses for static loading through the use of the material's Index of Sensitivity (Ref. 3,4) or "Notch Sensitivity Index", q, $(0 \le q \le 1)$, where $q = q(K_S, K_F)$.

Consequently, Equation (1) can be modified to provide the maximum *significant stress*, σ_S, in the weld region by:

$$(\sigma_S)_{wsm} =$$

$$\{ FXJ*((\sigma E)_{tr}/1\#)_{Fa}*((\sigma_S)_{tr}/(\sigma E)_{tr})_{Fa}$$

$$+ \mathrm{sqrt}[(FYJ)^2 + (FZJ)^2]*((\sigma E)_{tr}/1\#)_{Fl}*((\sigma_S)_{tr}/(\sigma E)_{tr})_{Fl} \}_{max} \qquad (2)$$

where we define:

$$((\sigma_S)_{tr}/(\sigma E)_{tr})_{Fa} \equiv ((K_S)_{tr}/(K_F)_{tr})_{Fa} \qquad (3)$$

$$((\sigma_s)_{tr}/(\sigma E)_{tr})_{Fl} \equiv ((K_s)_{tr}/(K_F)_{tr})_{Fl} \quad (3')$$

in which K_s is the stress concentration factor, and K_F is the form stress factor (in the weld region). Rodamaker (Ref. 2) has shown that the form stress intensity factor, K_F, computed from von Mises stresses (for given applied loading direction) is constant, independent of L/D of the rods (see **Table 1**).

K_s and K_F are related to q through, $K_s \equiv \sigma_s/(\sigma)_{nom} = 1 + q\,(K_F - 1)$, so:

$$K_s/K_F = q + (1 - q)/K_F \quad (4)$$

Finally, the form stress factor, K_F, is calculated from:

$$K_F = (\sigma)_{mx}/(\sigma)_{nom} \approx (\sigma E)_{mx}/(\sigma)_{nom} \quad (5)$$

The nominal axial stress (direct shear) in the weld region, **Figure 1**, due to an axial load, P_a, applied at the other end of the tie rod of diameter, D_r, is:

$$[(\sigma)_{nom}]_{Fa} = P_a/A_s = P_a/(\pi\, D_r\, g) \quad (6)$$

where, g is the axial shear length of the weld.

Similarly, the nominal axial stress *in the weld region* (at the bottom of the "vee") due to a lateral load, P_l, applied at the other end of the (fixed-guided beam) rod is:

$$[(\sigma)_{nom}]_{Fl} = (\sigma)_b = Mc/I_r = (P_l\, L_r/2)*(D_r/2)/(\pi\, D_r^4/64) \quad (7)$$

where, M, is the *fixed end moment* and, L_r, is the effective length of the tie rod.

For tie rods welded (with a triangular fillet weld of length (and width), g, as in **Figure 1**) to the back side of 2 equal absorber plates of thickness, t_{ap}, which are separated by a plane of wedge plates of thickness, t_{wp}, the *effective length* of the tie rod, L_r, is computed from:

$$L_r = 2\, t_{ap} + t_{wp} - 2\, g \quad (8)$$

In the current MCR Tie Rod Model, we've fixed the value of the weld dimension, g, for all tie rods at:

$$g = D_r/4 \quad (9)$$

System Model & Tie Rod Model Rod lengths

Without special treatment, the effective tie rod length (of pipe elements) in the System Model, $(L_r)_{sm}$, would not be compatible with L_r given by Equation (8), because "shell" elements are used. One way to deal with this would be to use appropriately reduced input values of the elastic moduli, E_A and E_I, for the pipe elements in the System Model.

Summary

With the particular geometry of plates and tie rods we are interested in for the Baseline Plug design, K_F, is the order of 2.3-4.3 (depending upon applied load direction) when a very fine mesh treatment is used at the weld. Using a value of q of 0.1 for SAE 1010 steel (Ref. 3, Table 5-2), the ratio, K_S/K_F, becomes about 0.31-0.49.

References

1 ANSYS is a registered trademark of Swanson Analysis Systems, Inc.

2 M. C. Rodamaker, et. al. , "Finite Element Analysis of a Removable Hadronic Absorber Plug for the SDC Calorimeter", report prepared for LBL by MCR Associates, Inc. Sunnyvale, Ca, June 1992.

3 V. L. Maleev and J. B. Hartman, Machine Design, 3rd Ed., International Textbook Co., Scranton, Pa., 1954.

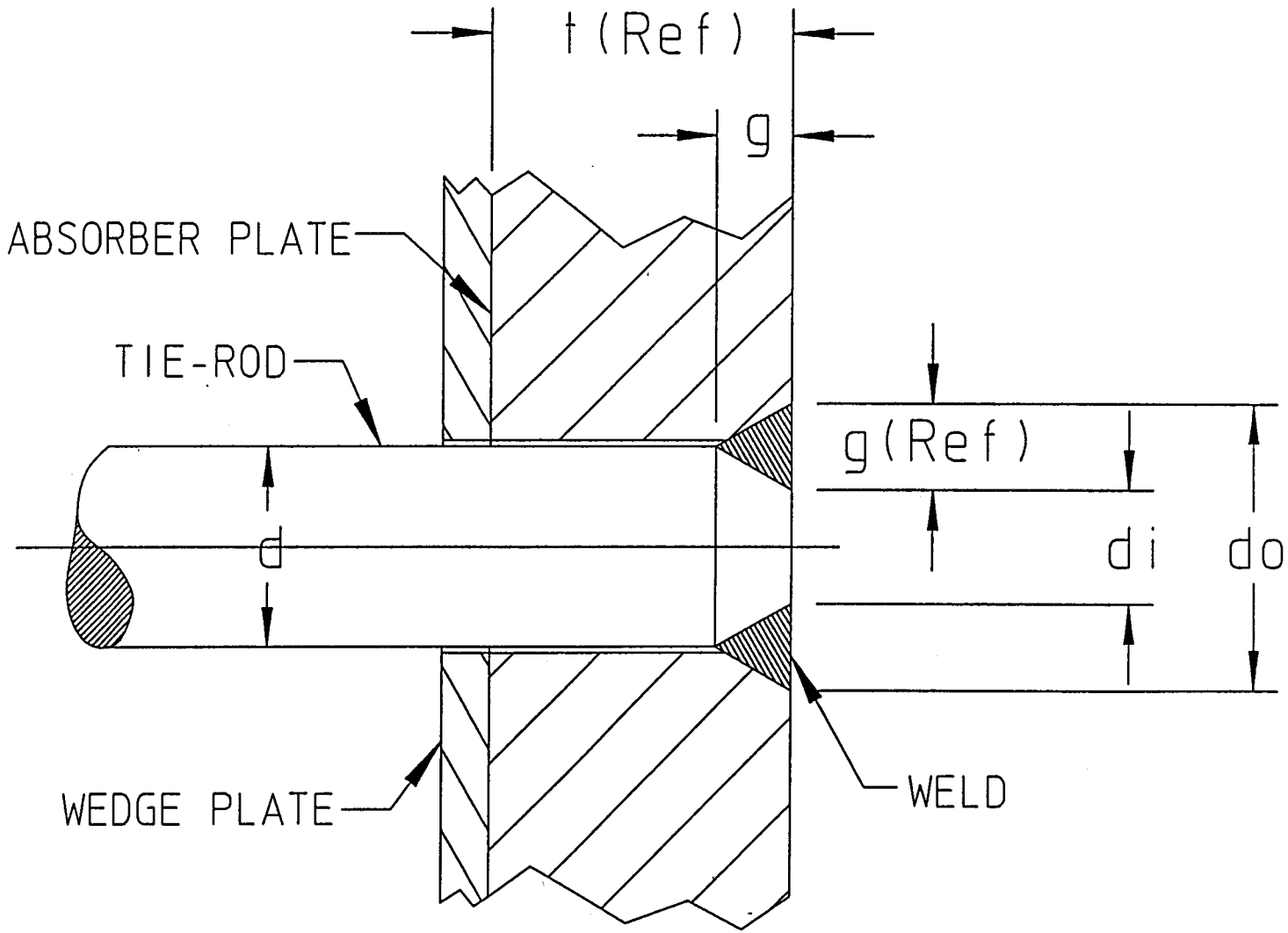

FIGURE 1 PLUG TIE-ROD WELD DETAILS (Not To Scale)