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Study of high temperature coupling in the Context of Strength

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***Abstract*—Couplings can be considered as the backbone of the mechanical conveyance industry. The study focuses on the need to predict the surface temperature of a heavy duty machined coupling for aerospace application so as to optimize the weight of the component for the required load bearing capacity. Weight is one of the crucial factors for the aerospace industry. A machined V-band coupling secures peripheral flanges at mating ends of first and second coupling members together. The coupling includes two V-retainers disposed in end-to-end relation for circumferential receipt over considerably 360 degrees of the peripheral flanges. A transfer function has been developed with the help of statistical and theoretical equations to note the practical thermal behaviour throughout the coupling when subjected to high temperature and pressure due to internal fluid flow. The study takes concern of the structural integrity at all failure modes of the coupling. A Monte Carlo Simulation has been carried out to analyze the structural integrity of the coupling at high temperature. The objective is to frame a design methodology to optimize the design parameters so as to save on weight of the coupling.**

***Index Terms*— high temperature coupling, weight optimization, coupling design methodology.**

I. INTRODUCTION

V-Retainer Couplings provide an economical and proven method for joining ducting, tubing, filters and other closures used in high-temperature and/or high-pressure pneumatic or mechanical applications. They provide substantial savings in assembly and maintenance costs—especially when the connection requires frequent disassembly and re-assembly. Compared to bolted flanges and welded joints, which are costly to manufacture and difficult to assemble, the V-Retainer Coupling, with only one or two bolts to fasten, can be easily assembled even when very limited access is an issue, or when a small envelope is specified.

The strength of material follows an inverse proportion with temperature hence it drops down with increase in temperature. Thus structural integrity and proper material selection is very important from application perspective [1]. Inconel 718 material is eminent with its high strength properties for the high temperature couplings application in aerospace industry. Hence the design of the couplings should be with adequate margin of safety. However, if the product is overdesigned for its application, it will put in additional weight to the aircraft which is not at all desirable. Hence, all components of the coupling must have satisfactory design which provides enough strength at high temperatures and contributes less weight as compared to sheet metals.

II. PRODUCT DESIGN DETAILS

2.1 COUPLING ASSEMBLY

Circumferentially contractible clamps are widely used to clamp conduits and similar. The clamps are generally used to mount a hose on an end fitting, position and clamp a patch upon a channel, clamp the ends of aligned tubes in a sealed relationship, or used in similar applications. Such contractible clamps usually consist of a strap or band adapted to encircle the object or objects to be clamped, or the band may consist of a plurality of interconnected elements.

The function of a coupling in a rigid joint is to draw a pair of flanged ducts together. This is achieved by a wedging effect of the v-channel of the

coupling on the face of the flanges. As the Eyebolt is tightened it results in a tangential (hoop) load on the coupling retainers to create an inward radial force. This inward radial force acting on the ramp angle of the flanges results in an axial clamping force. The coupling assembled on one side by the Eyebolt and on the other side by either another an Eyebolt or a stack of connecting links. The safety link is a redundant load path that is intended to keep the retainer on the flanges in the event of Eyebolt failure.
The different profiles take into consideration weight limitations, need for Strength and size envelope constraints.
Applications: Engine Bleed air systems, Auxiliary power units, Accessory mount and check valve.

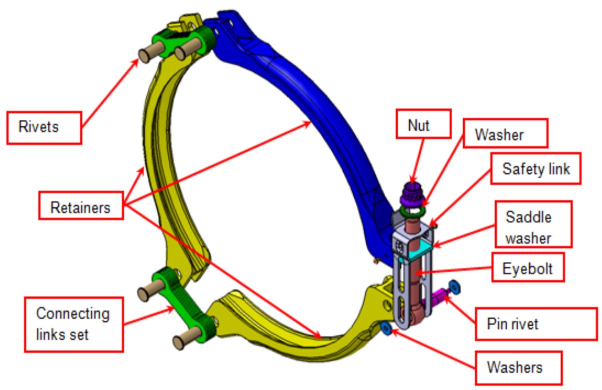

Figure 1: Components of a coupling

2.2. RETAINER

Retainers consist of a channel section with lugs at either end. The channel section draws the flanges together. The lugs serve to both draw the flanges together and provide a means of attaching the Dog bone links and the Eyebolts to the retainers. The retainer lugs are designed to receive rivets to join the retainer to the Dog bone links and Eyebolt.

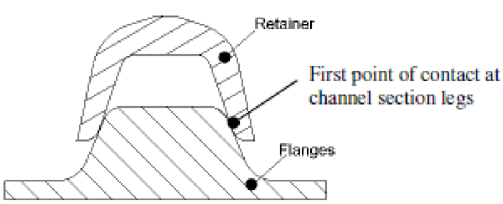

Figure 2 : Retainer face mating interface

The channel section inside profile is known as simply the channel. The channel is "V" shaped with an angle that is slightly smaller than the flange angle to insure that the first point of contact of the channel on the flanges is at the ends of the channel section legs. As the coupling is torqued down onto the flanges the retainer legs deflect outward to the point where, ideally, the flanges contact on wide surfaces inside the coupling leg.

2.3 LOAD TRANSFER DIAGRAM

Figure 3 : A typical Rigid Joint

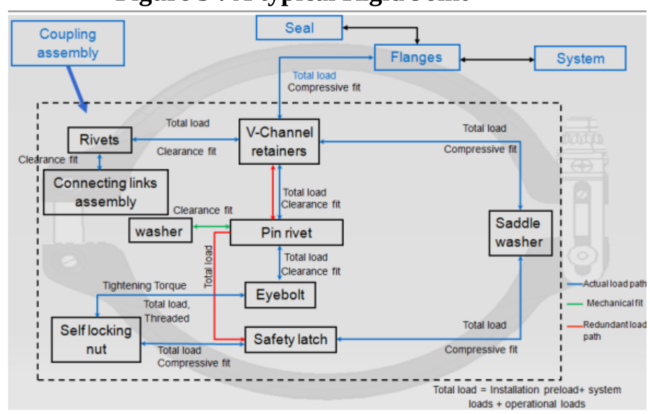

Figure 4 : Load transfer diagram in a coupling [1]

The load transfer path can be represented by the above diagram. The flanges (coupling contact surface or conical feature) convert the radial forces resulting from the coupling hoop load into axial forces, which draw the flanged ducts together.

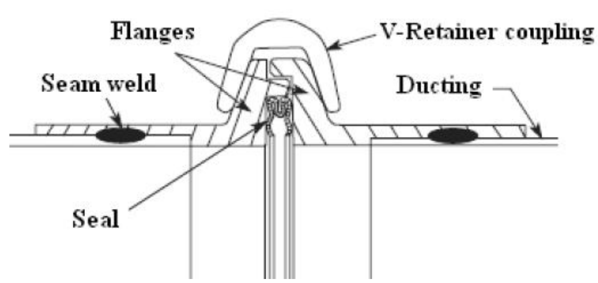

Figure 5 : Cross section of a Rigid Joint assembly

The 20º angle of the flange V-face is an industry accepted standard and aims to maximize the axial preload on the duct within the range of economical machining tolerances. All the system loads will be transferred by the connecting ducts through the flanges on to the coupling. The coupling generally consists majorly of a pair of the V-channel grooved retainers, connecting links, a rivet pin, an eyebolt, a safety link and a saddle washer. The load transfer path can be described as the circumferential load from the flanges is transferred to the coupling retainers which inturn exert radial force. The load is transfer via the rivet to connecting links and then back to the rivet and then coupling on the connecting link end. On the other side the load moves via the pin rivet to the eyebolt and is counter balanced by the threaded nut torqued on the eyebolt.

III. STRUCTURAL AND THERMAL ANALYSIS OF COUPLING

A study was done using ANSYS to understand the effect of thermal and mechanical loads on a coupling.

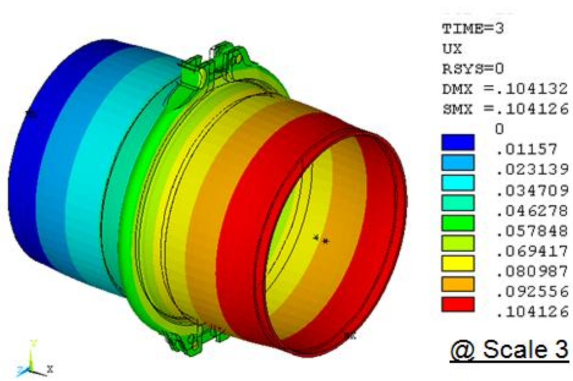

Figure 6 :Ux displacement (Duct axis)

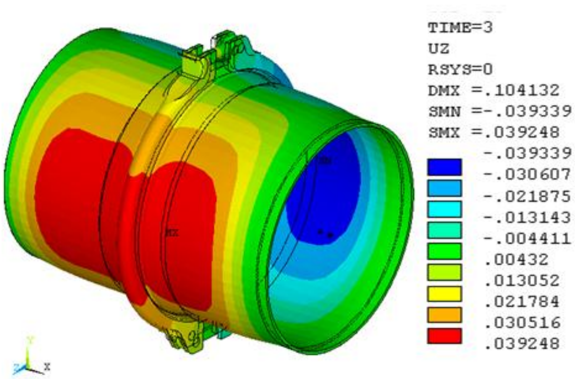

Figure 7 : Uz displacement (Duct axis)

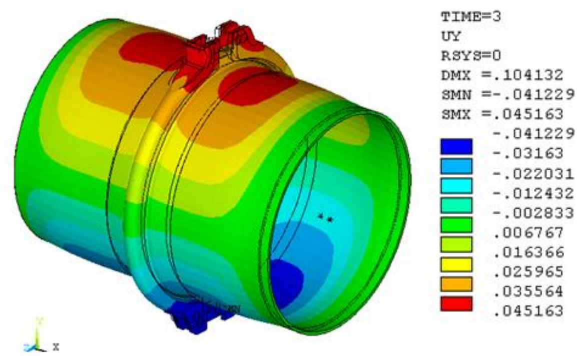

Figure 8 : Uy displacement (Duct axis)

From the results obtained by Ansys, it was observed that when completely load at high temperature, the maximum deformation was found at the retainer mid span in the Z axis direction and at the lug area location in the Y axis direction as shown in Figure 5, 6 and 7. This deformation is due to local yielding of the material at high temperature. Let us consider shear of retainer at lug hole failure for the study.

With reference of the analysed result calculating the loads analytically,

Tube outer diameter: 4 in

Torque applied on eyebolt, $\tau = 185\pm5$ lb-in

Internal air pressure, P = 2125 psig

Sealing diameter, $D_s = 4.75\pm0.005$ in

V-channel angle,$\theta = 19.4°\pm0.5°$

Friction angle,$\propto = 4.2°$

Thus,

hoop load due to torque=$(22.85*\tau)+143$
$= (22.85*185)+143$
$= 4370.25$ lb

hoop load due to axial load $=P*D_s^2*\tan(\theta-\propto)/4$
$=2125*4.75^2*\tan(19.375-4.2)/4$
$=3251.42$ lb

Total load =4370.25+3251.42=7621.67 lb

Case: Structural Integrity of the Retainer at the lug hole

This section discusses about the strength of the coupling at the most critical location per the analysis results in above section. The analyzed data points the most prone failure condition where the retainer shears at the lug hole when loaded to higher pressure and temperatures.

When there is a sudden jerk of pressure above the design limits and the retainer shears off at the lug hole taking the rivet off. The load bearing capacity of the retainer at the rivet hole can be given by below formula:

Hole bearing stress can be given by

$$\sigma_{bearing} = .591\left[\frac{H\ E\ (D_1 - D_2)}{b\ D_1\ D_2}\right]^{.5} \quad [\text{lb/in}^2]$$

From: Formulas for Stress and Strain[21], Table 33, Case 2c.

Where: H = Hoop load [lb]

E = Elastic modulus [lb/in^2]

b = length of contact [in]

D_1= bore diameter [in]

D_2= shaft diameter [in]

$\sigma_{bearing}$= 88.4 ksi

Ultimate strength of Inconel 718 material at room temperature = 110 ksi

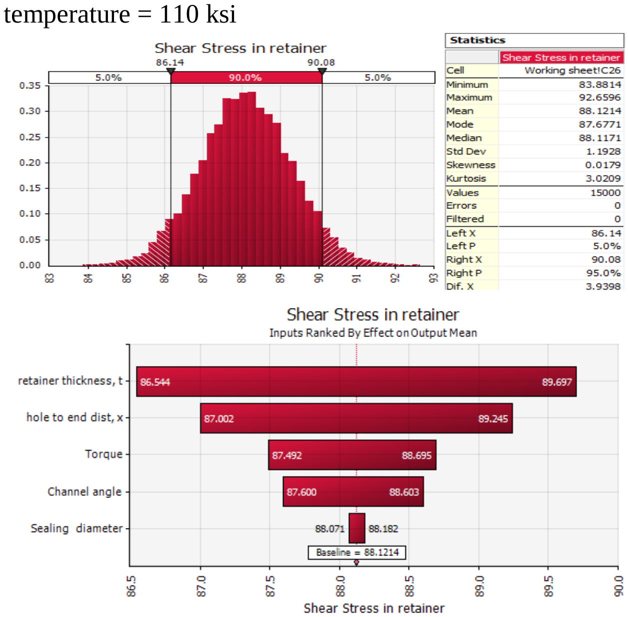

Figure 9 : Monte Carlo simulation and Sensitivity analysis of design parameters of retainer

With a Monte Carlo- Sensitivity analysis, using a 3 sigma process for all the control parameters, we find that the stress observed at room temperature is 88.1 ksi.

This stress value is well below the ultimate stress limits of the material but, when the internal air will be heated,

Strength reduction of Inconel 718 at 1350° F= 50%

Therefore, strength of material at 1350°F temp = 110*0.5=55 ksi.

Figure 8 gives us information about the sensitivity of the control parameters. A change in the retainer thickness will affect the load bearing capacity of the retainer to the maximum. The next sensitive parameter is the distance of hole from the retainer edge.

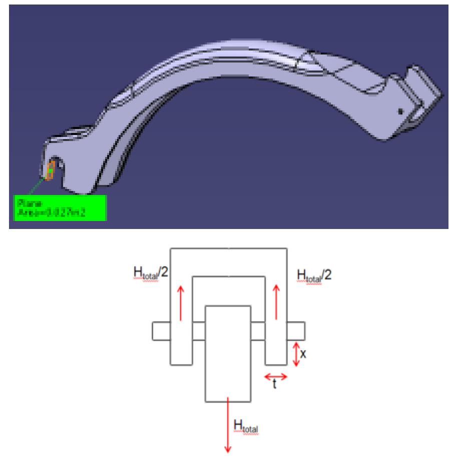

Figure 10 : Shear of retainer at the lug hole and Force diagram

Now if we consider that the temperature on the retainer surface is same as that of the inlet air i.e. 1350°F, the percentage reduction in strength of the material Inconel 718 per MMPDS -03 is 50% which gives the strength of the material as 55.5 ksi. The stress due to the resulting loads that would be observed on the retainer lug hole cross section with calculations give around 88.4 ksi. With this assessment it is evident that the temperatures observed on the retainer surface are much lower than the assumed temperatures. A thorough accurate prediction of temperatures at all the contacts and surfaces are essential in order to gauge the exact temperatures and analyse the strength of the joint. This exercise will help us to find avenues for optimization of the coupling design for weight.

IV. CONCLUSIONS

This study shows the effect of thermal and mechanical loads on components of the coupling. The most severe condition indicated as per analysis that of the retainer shear at the lug hole is discussed in the study. It concludes that there is a need to further investigate the actual temperatures that would be experienced by the machined coupling when used in high pressure and high temperature applications. An orderly DOE must be performed on all control parameters of the components of the coupling. This exercise will explore chances of optimization of weight which is very beneficial for aerospace industry.

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