Structural Strength Analysis of Lug Component for RTP Fuel Transfer Cask

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Abstract

A three decade aging PUSPATI TRIGA Reactor will soon require spent fuels to be replaced with fresh fuels. Initial procedure requires these spent fuels be cooled down due to high temperature and high radioactivity resulted from fission products activities and then transferred out of reactor tank into a spent fuel pool. Performing this task will need a fuel transfer cask (FTC) to provide sufficient radiation shielding for the workers during fuels transferring task. Currently the only economically viable route FTC to get into reactor tank is through the top of reactor tank using crane. The huge and high density lead filled FTC will be hanging throughout the task of transferring each fuel element thus FTC is subjected to tensile stress during its operation. Lug component is anticipated to be one of the main weaknesses of FTC design subjected under tensile load due to it diminutive in size but very large amount of stress to be introduced on it. Therefore lugs component requires an adequate stress analysis to prove the design reliability. This paper will discuss the structural strength using conventional engineering calculation based on best estimate approach.

Abstrak

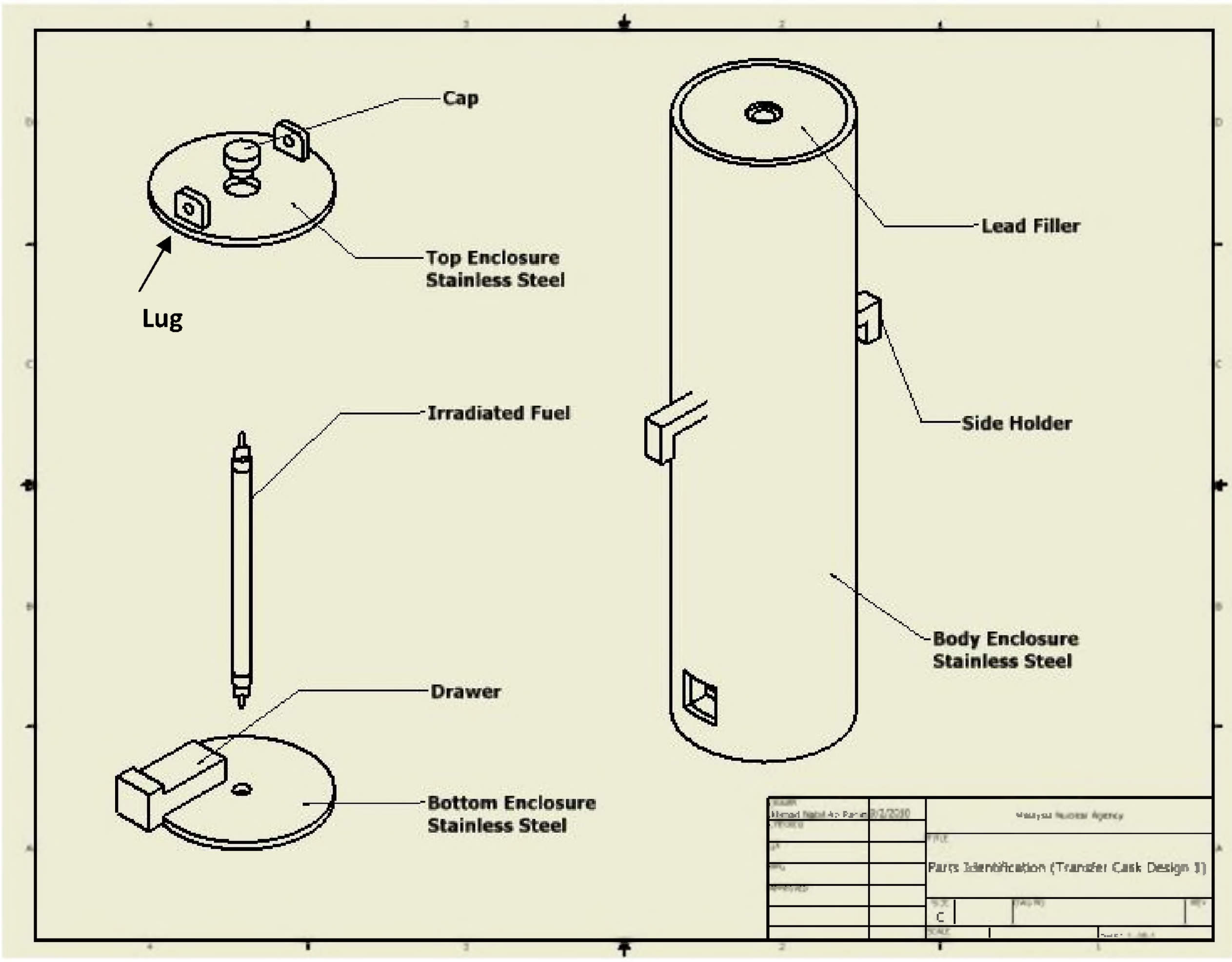
Reaktor TRIGA PUSPATI yang berusia 30 tahun berkemungkinan akan menukar bahan api terpakai dengan bahan api baru. Bahan api terpakai perlu disejukan suhu dan dibiarkan kadar kerakdoaktıfan menurun dalam satu tempoh tertentu dan kemudian di pindahkan keluar daripada tangki reaktor ke dalam kolam simpanan. Aktiviti ini memerlukan FTC sebagai perisai radiasi kepada pekerja semasa menjalankan aktiviti tersebut. Bagi jangkamasa sekerang, FTC hanya boleh dimasukkan kedalam tangki reaktor melalui bahagian atas tangki reaktor dengan menggunakan krain. FTC yang besar dan berat berisi material plumbum ini akan tergantung sepanjang proses pemindahan bahan akan menyebabkan FTC dikenakan tekanan. Komponen lug adalah salah satu komponen yang memerlukan analisis suspaya dapat memastikan keupayaan rekabentuknya. Kertas kerja ini akan membentangkan kekuatan struktur dengan menggunakan pengiraan konvensional berdasarkan anggaran terbaik.

Keyword: hanging component, fuel transfer cask,

Introduction

The operational of PUSPATI TIRGA Reactor (RTP) is dependent on fissile material in the fuels. The longer RTP in operation the more burn-up will be for the fuels. More burn-up means less neutron flux can be provided by each fuel. For the past three decades of PUPSPATI TRIGA Reactor operation, many core configurations has been changed to provide better neutron flux for experimental facilities. The demand of continuous operation of RTP in long term would need the spent fuels of the RTP to be changed with fresh fuels. Performing this task will need a fuel transfer cask (FTC) to provide sufficient radiation shielding for the workers. Further discussion on preparation of required equipment is needed. Understanding the design concept and engineering limitation of the equipment is necessary for the reliability of the equipment and safety consideration. This paper will discuss about the structural strength analysis of the lug component based on the design concept proposed. Several modifications might be required to enhance the safety operational of this component. Based on the studies we can anticipate what kind of failure and what kind of approach should be taken.

Conceptual Design



Motivation

Stress analysis of lug component is one of the very critical aspects to ensure the safe operation of transferring fuels into the cask. The huge and high density lead filled FTC will be hanging throughout the task of transferring each fuel element thus FTC is subjected to tensile stress during its operation. Lug component is anticipated to be one of the main weaknesses of FTC design subjected under tensile load due to it diminutive in size but very large amount of stress to be introduced on it. Therefore lugs component requires an adequate stress analysis to prove the design reliability. Failure of these components would result dropping the cask into the core, which is extremely hazardous since the impact could fail the cladding material of the spent fuels. Besides, it could also damage the RTP tank structural integrity and thus might lead to leakage of coolant water in the reactor tank.

It is also important to analyse whether the current design has certain weakness subjected to different type of factor involved. Based on the analysis pre-failure could be detected before full failure occurs by acknowledging the yield stress limit.

Methodology

The analysis began with the confirmation of the shielding effect using the thickness proposed. According to design requirement based on Atomic Energy Act, Radiation Protection (Transport) Regulation 1989, where the external dose rate allowed is not more than 2mSv/hr at the surface of the cask and 0.1mSv/hr at 2m away from the cask. Based on the result from the Shielding Calculations For PUSPATI Triga Reactor (RTP) Fuel Transfer Cask With Microshield written by Nurhayati, 2010, it is confirmed that shielding thickness is more than the required limitation by regulatory body.

Table 1: The fuel transfer cask exposure rate without build-up

Source Input	Exposure rate at Detector #1 at the surface of the cask (μSv/hr)	Exposure rate at Detector #2 at 2m away from the cask (μSv/hr)
1 year decay	1.25 E-07	5.929 E-09
5 year	3.963 E-08	1.886 E-09
10 year	3.41 E-08	1.633 E-09

Table 2: The fuel transfer cask exposure rate with build-up

Source Input	Exposure rate at Detector #1 at the surface of the cask (μSv/hr)	Exposure rate at Detector #2 at 2m away from the cask (μSv/hr)
1 year decay	6.12 E-05	2.835 E-06
5 year	1.955E-05	9.080 E-07
10 year	1.693E-05	7.862 E-07

From the design concept, the total mass for the FTC can be measured using Autodesk Inventor Professional 2010 by selection of appropriate assigned material to each of the components. It has adequate library for the material selection with provided density, material ultimate strength and yield strength with are the important parameters for structural strength analysis.

The calculation and analysis are based on strength of material and mechanics of deformable bodies. The principal objective of mechanics material is to determine the stresses, strain and deformation of the structure due to load acting on them.

It is very crucial to consider stress concentration factor in this case since there is a hole for the lug. If we consider there is a bar with rectangular cross section subjected to tensile force on both end there will be stress concentration caused by discontinuities in the shape of the bar. The intensity of the stress is called stress concentration factor, $K = \sigma_{max} / \sigma_{nom}$. For further improvement of the design, it can be considered reducing size of the hole in order to reduce stress concentration factor. Figure 1 shows the value of concentration factor, K.

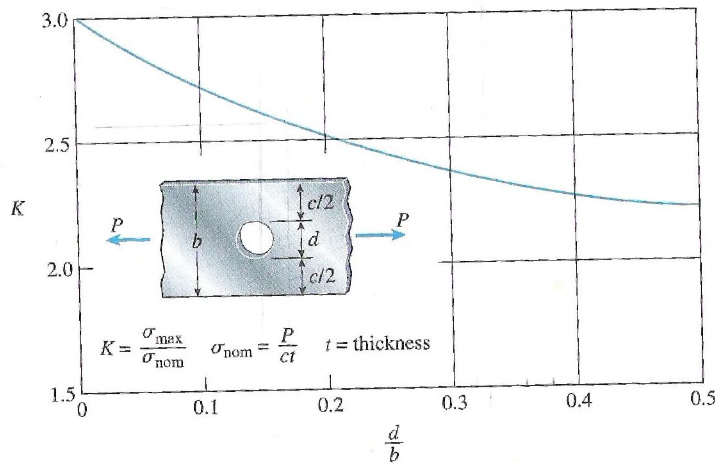


Figure 1: Stress concentration factor, K

Nominal stress is the average stress base upon net cross sectional area. According to Saint-Venant's principle, at a distance to the width "b" of the bay away from the hole in axial direction, the stress distribution is practically uniform and equal to P divided by the gross cross sectional area. ($\sigma = P/bt$).

For safety criteria of this FTC, it is better to consider yield stress as the main limitation. If the subject is put under a stress more than yield stress, the material will elongate and would not turn back into original position. This condition is not acceptable in design.

Assumptions

The mechanism of holding the lug is by grapping the upper side of the lug using two plates. These plates will have 5 bolts all together, 4 bolts function is to grab the upper side of the lug. Using this method, the axial tension on the upper side of the lug will have an equally distributed load to the cross section, P. The remaining bolt will penetrate through the hole of the lug. This bolt will act as a safety function if the other 4 bolts function fails. So the load will be distributed axially as in the figure 2.

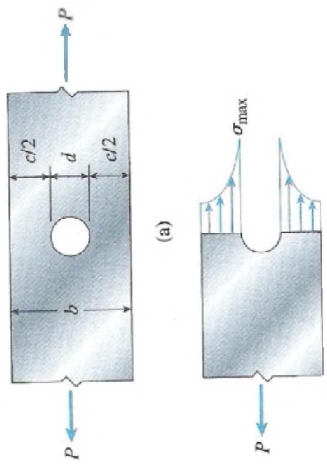


Figure 2: Stress distribution in axial direction with concentration Factor, K

Results

Dimensions are based on conceptual design considered including the shielding factor to meet the safety requirement. The mass calculations of the components and total mass are based on Inventor Software. Listed in the table 1 are the masses of each components of the FTC.

Table 3: Components and Masses

No	Component	Material	Density	Total Mass
1	Cap	Lead	11.37g/cm^3	2.384 kg
2	Top Enclosure	Stainless Steel	7.750 g/cm^3	21.771 kg
3	Bottom Enclosure	Stainless Steel	7.750 g/cm^3	20.238 kg
4	Body Enclosure	Stainless Steel	7.750 g/cm^3	307.86 kg
5	Lead Filler	Lead	11.37g/cm^3	1960.089 kg
6	Drawer	Lead	11.37g/cm^3	18.432 kg
	Total Estimated Mass, m			2330.37 kg

Total Load the will applied to the lug are as listed from each component:

W, Weight Load = (m, mass) *(gravitational acceleration, g)

= 2330.37 kg * 9.81 m/s^2

= 22, 864.89 N

= 22.9 kN

Estimated Load Apply to Each Lug

Since there are two lugs to hang the FTC, each lug is estimated to have a pull down weight load:

$$P_{1\&2} = W / 2$$
$$= 22.9 \text{ kN} / 2$$
$$= 11.45 \text{ kN}$$

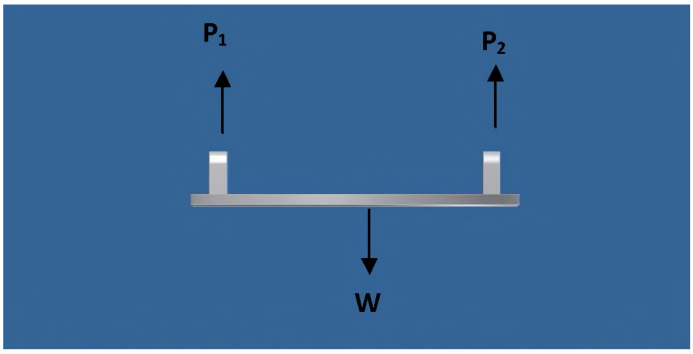


Figure 3: Free body diagram of Top Enclosure of FTC

Estimated Tensile Stress Axially "b" Further of the Hole Feature

Assuming the stress is uniformly distributed over the cross section of the lug further 2r away of the hole, stress calculation for the lug:

$$\textbf{Stress}_1 = \text{load affected/ affected cross section}$$
$$= 11.45\text{kN} / (0.08*0.02) \text{ m}^2$$
$$= 7.156 \text{ MPa}$$

Assuming the Lug is a bar, each lug will be under a tensile stress of 7.156 MPa. This load is much lesser than the allowable yield strength of the Stainless Steel Material 440C, which is 680 MPa. Based on this calculation the material has 95 Safety factor before the material goes into plastic region.

Estimation of Maximum Tensile Stress of the Lug

The maximum tensile stress at lug hole is calculated using concentration factor, K formula which is: $\sigma_{max} = K* \sigma_{nom}$

$$\sigma_{nom} = P/ct$$
$$= 11.45\text{kN}/(0.05*0.02)\text{m}^2$$
$$= 11.45 \text{ MPa}$$

To get concentration factor, the value of d/b must be calculated and then refer to the Stress-concentration factor K for flat bars with circular hole graph as figure 1.

$d/b = 3/8 = 0.375$

Therefore: $K \approx 2.35$

$\sigma_{max} = K * \sigma_{nom}$

$= 2.35 * 11.45$ MPa

$= 26.907$ MPa

The maximum value for tensile stress at the lug is also much lower than the yield strength of the material. It has 22 safety factors before reaching yield strength limit.

Estimation of Fatigue Limitation

Because of the possibility of fatigue failure, stress concentration is important the member is subjected to repeated loading. Crack begins at the point of high stress and spread gradually. The allowable stress is obtained by applying a factor of safety with respect to this ultimate stress. According to James M Gere 2001, for steel material at 10^7 cycles the fatigue limit is about 50% of the ultimate tensile stress.

Therefore the fatigue limit for this material is :

Ultimate tensile stress *50% = 860 *50% = 430MPa

Based on the fatigue limitation, the safety factor of the lug component compared with the actual loading is 60 times.

Estimation of Shear stress

If the 4 bolts mentioned earlier failed to perform its designed function, bolts number 5 which penetrate the hole will act as a safety solution. The bolt will undergoes shear stress. Average shear stress can be calculated by:

$T_{aver} = V/A$

The shear force V is equal to load P/2 since it has double shear and the area A is the cross sectional of the bolt.

$T_{aver} = V/A$

$= (P/2)/A$

$= (11.45 \text{ kN} / 2) / (\pi * 0.01^2) \text{m}^2$

$= 18.215$ MPa

The shear Stress on the bolt also is much lower than the yield strength of Stainless stress. It has a safety factor 37 times the yield strength of the material properties.

Table 4: Safety Factor due to Different Type of Stress

Type of Stress	Estimated Stress by Calculation	Safety Factor
1) Tensile stress "b" distance away from the hole	7.156 MPa	95
2) Maximum tensile stress at the lug	26.907 MPa	22
3) Stress Limitation due to Fatigue	430 MPa	60
4) Shear stress Limitation	18.215 MPa	37

Conclusion

Based on the results, the design lug component is structurally strong and robust. According to Rajendra 2012, a factor of safety of 5 is common for lifting component. For this case, all resultants stress are far lesser then the yield strength of the material. It is clearly seen that the lug hanging component would not fail due to the yield strength of the material. The estimated load applied to the lug would not caused the stress exceed the yield strength of the component material, Stainless Steel. The lug will have a very low elongation but it will return to original position when it is supported at the bottom as it rest on floor. It will be back to original length.

However further analysis is needed to confirm the structuring strength of the design due to axial loading from the weight of the cask. Such critical consideration is the welding part that might need further discussion. Impact test is also an additional consideration that required special attention before fully finalized design the FTC.

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