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Kinematic and Finite Element Analysis of a Master Slave Manipulator Gripper

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***Abstract*— Nuclear industry employs many remote handling tools for handling objects in radioactive environments. In Mechanical Master-Slave Manipulators (MSM) when the operator grasps the hand grip and manipulates the master arm, the motion of the master arm is reproduced by the slave arm, performing the desired manipulation task remotely. MSM is powered and controlled by human operator. Therefore the power that can be delivered by MSM is limited by the power of an operator. It demands efficient mechanisms and optimized design of the manipulator and its components. The paper aims at improving the design of gripping mechanism.**

Stress analysis is carried out for MSM gripper using FEM for finding the stresses in various components of mechanism when the gripper is holding the known weight.

***Keywords*— Master-slave Manipulator, hot cells, gripper.**

I. INTRODUCTION

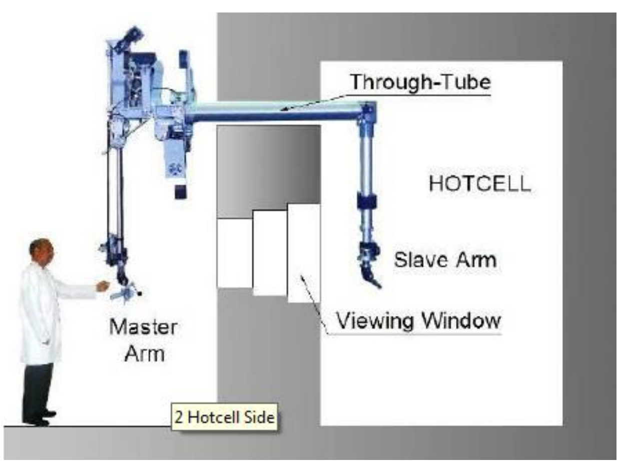

Fig.1 Mechanical Master-slave Manipulator

Figure shows mechanical MSM. It consists of three parts – the slave arm located inside the hot cell, the master arm located in the control station, and a through-tube connecting the master arm to the slave arm. When the operator grasps and manipulates the master arm, the motion of his hand is reproduced at the slave arm performing the necessary task.

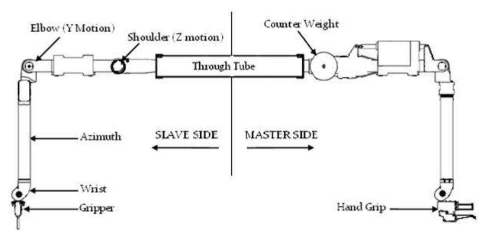

Fig. 2 Articulated MSM Details

The articulated master slave manipulator has six independently controlled joints for arbitrary positioning and orienting an object. The manipulator can perform seven manual motions namely X, Y, Z, Azimuth Rotation, and two wrist rotations- twist and elevation along with squeeze i.e. gripping action of the gripper. The wrists on both master and slave sides are identical and detachable.

II. MASTER HAND GRIP

The wrist is very flexible and allows a great variety of hand positions. The most important and fundamental way to reduce hand pressure and stress is to increase the mechanical advantage of the tool. There is an optimum grip diameter for every individual at which point their hand can apply the most force to the tool with the least stress on the hand tissues.

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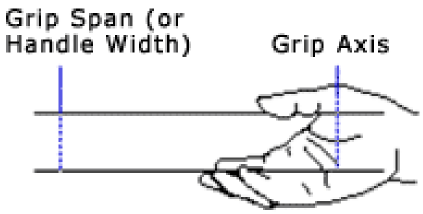
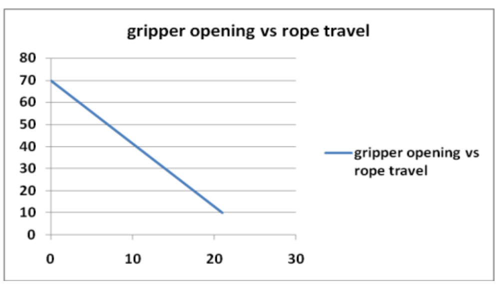
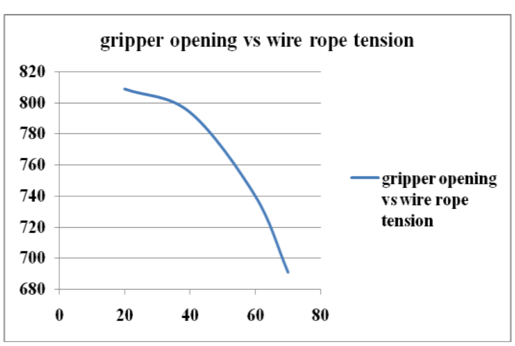


Fig.3 Grip Span for Handle

The optimal grip diameter is 2.95” (75mm) for females and 3.15” (80mm) for males. The maximum force that males can apply at their optimum grip diameter is 112 lbs. Or 500 N. Females are able to apply 58.5 lbs. or 260 N at their optimal grip diameter. It is very important to design tools so that the maximum required force is near the optimal grip diameter.



Graph shows variation of rope travel with the gripper opening as the manipulator is operated through pulley wire rope arrangement.



Graph shows variation of tension in wire rope with the gripper jaw opening distance as the manipulator is operated through pulley wire rope arrangement. The tension in wire rope increases with gripper closing. The maximum tension in wire rope is 808 N.

III. CAD MODEL OF GRIPPER ASSEMBLY

Gripper Assembly

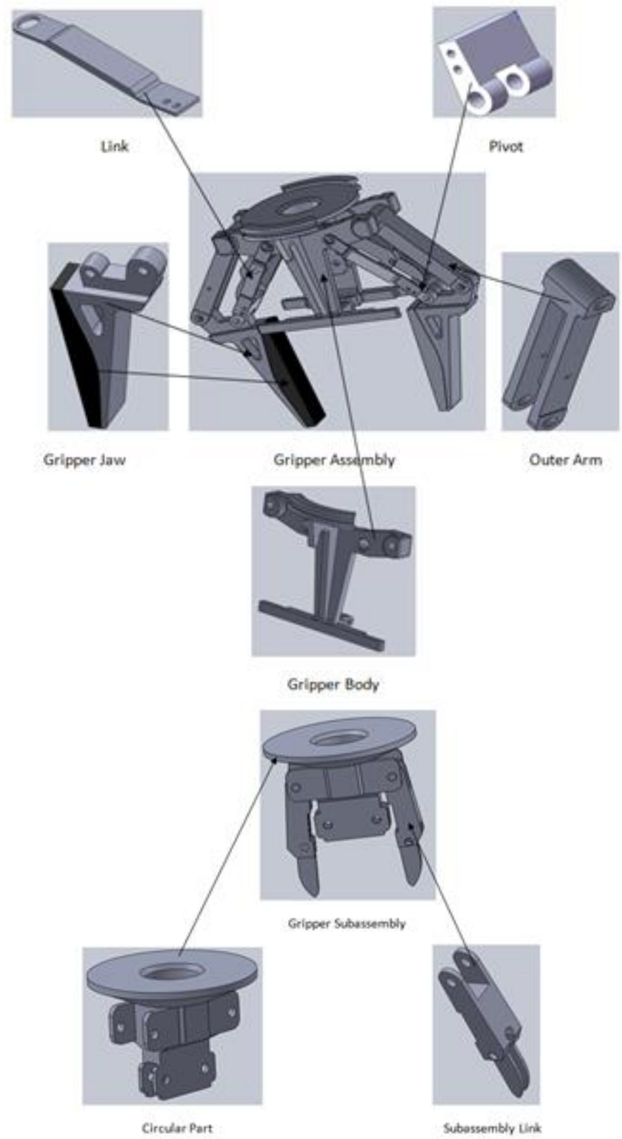


Fig. 4 Gripper Assembly CAD Model

Figure shows CAD model of gripper assembly. The assembly consists of two parts. One is the basic tong and another is removable part inserted inside the basic tong. All the gripper components are made of SS 304. The material properties are used while carrying out the analysis. The part highlighted with black is the neoprene rubber material as the jaws are used for material handling.

IV. Analysis of Gripper Assembly

The finite element analysis of gripper assembly is carried out for different payloads.

Gripper Analysis for 9 kg payload

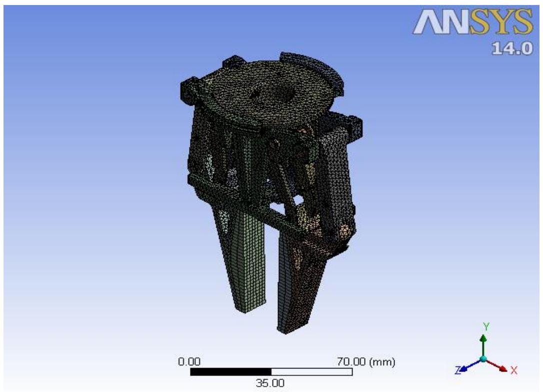


Fig. 4 Gripper Mesh Model

Figure shows mesh model of gripper with 20 mm opening of the jaws.

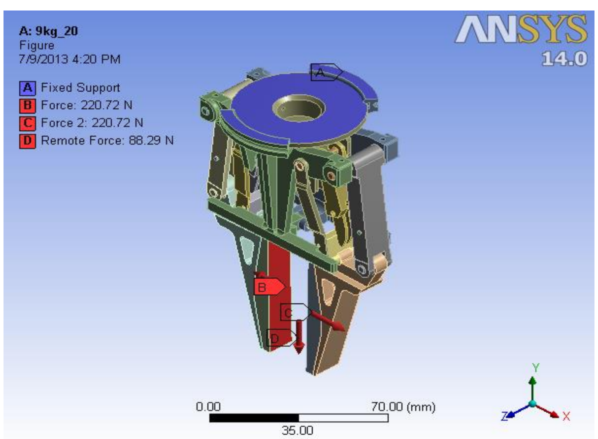


Fig. 5 Gripper Boundary Conditions (9kg payload)

Figure shows boundary condition applied gripper. It shows the weight force of the object and the gripping force applied on both the gripper jaws.

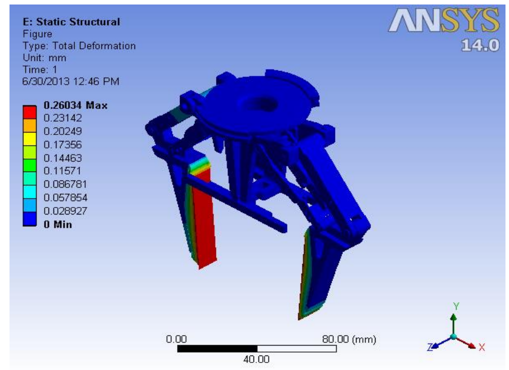


Fig. 6 Gripper Deformation Plot (9kg payload)

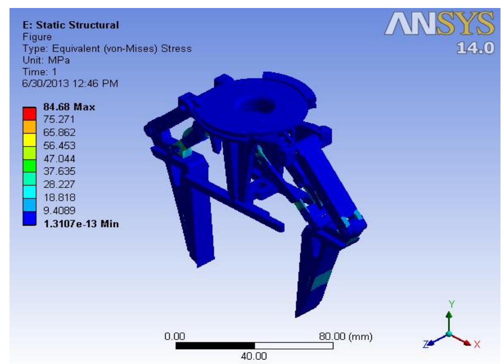


Fig. 6 Gripper Stress Plot (9kg payload)

Figure shows the total deformation and stress plot for the whole gripper assembly. Maximum deformation occurs at the gripper jaw and stress at the gripper link. The maximum deformation is 0.26 mm and stress as 84.68 Mpa.

Gripper Analysis for 12 kg payload

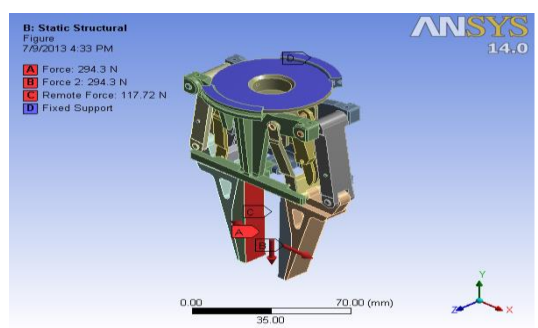


Fig. 8 Gripper Boundary Conditions (9kg payload)

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Figure shows boundary condition applied gripper. It shows gripper is fixed at the top, the weight force of the object as 117.72 N and the gripping force as 294.3 N applied on both the gripper jaws.

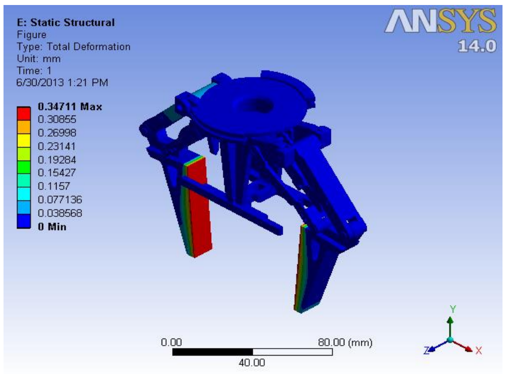

Fig. 9 Gripper Deformation Plot (12kg payload)

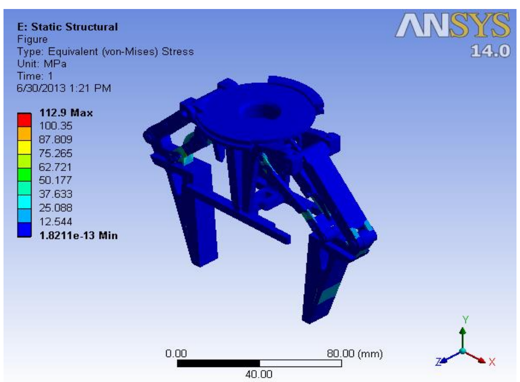

Fig. 10 Gripper Stress Plot (12kg payload)

Figure shows the total deformation and stress plot for the whole gripper assembly for 12 kg payload. The maximum deformation is 0.34 mm and stress as 112.9 Mpa.

V. Safety Factor

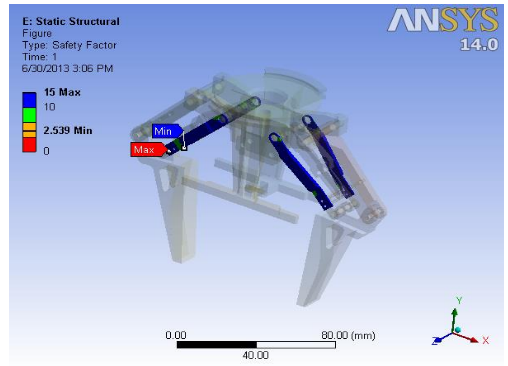

Fig. 11 Link Safety Factor(9kg payload)

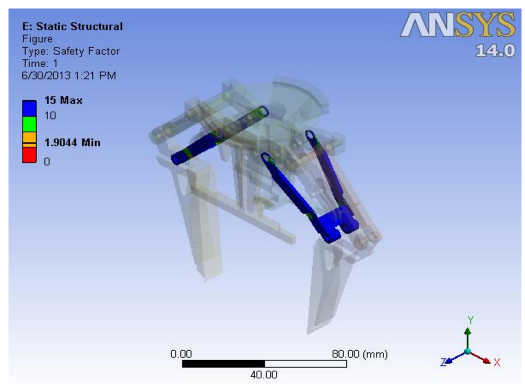

Fig. 12 Link Safety Factor(12kg payload)

Figure shows safety factor for the link as 2.5 for 9kg and 1.9 for 12kg payload capacity as the maximum stress occurs at the link. The minimum safety factor location is highlighted as Min.

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VI. MODIFIED GRIPPER ASSEMBLY

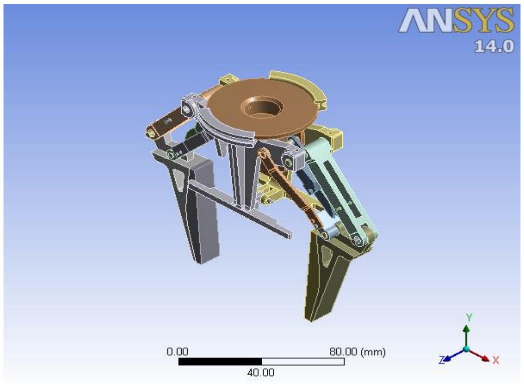

Fig. 13Modified Gripper Assembly

In new assembly the thickness of main body is reduced and the slot is created in the outer arm as shown. The modification is done to reduce the gripper weight but still it can have same payload capacity.

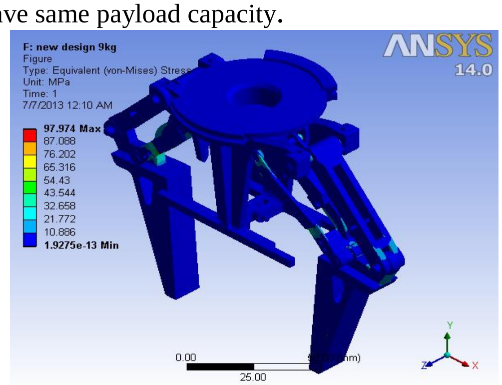

Fig. 14 Modified Gripper Deformation plot (9kg payload)

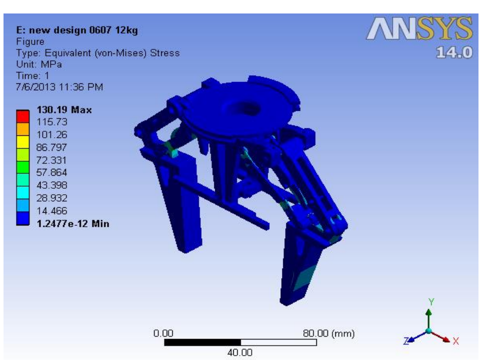

Fig. 15 Modified Gripper Deformation plot (12kg payload)

Figure shows equivalent stress for both 9kg and 12kg payload capacity at the maximum opening of the gripper with the modifications to some components and the stresses are 97.97 MPa and 130.19 MPa.

VII. RESULTS AND DISCUSSION

For 9kg payload for full 70 mm opening stress developed is 84.68 Mpa and when same structure is subjected to a 12kg payload maximum stress developed is 112.9 Mpa.

In gripper structure this maximum stress occurs at the driving link so it is component which has minimum safety factor in the whole assembly.

Components are modified to reduce gripper weight without altering much the safety factor of gripper. In this modification the safety factor for 9 kg payload capacity can be reduced to 2.2 from 2.5.and reduces the weight of gripper about 35 grams.

Wire rope is also the most important component in gripping mechanism and has to be taken into the consideration during the analysis. So as per the calculation it is found that the maximum tension developed in wire gives comparatively less safety factor. This concludes that wire rope is the weakest in the whole mechanism.

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