UCRL-JC-133045
PREPRINT

Automatic Registering Receptacle Safety Design for Bottom Loading System Used in National Ignition Facility

K. K. Leung
D. H. Tiszauer

This paper was prepared for submittal to the
8th International Topical Meeting on Robotics and Remote Systems
Pittsburgh, PA
April 25-30, 1999

January 26, 1999

Lawrence Livermore National Laboratory

AUTOMATIC REGISTERING RECEPTACLE SAFETY DESIGN FOR BOTTOM LOADING SYSTEM USED IN NATIONAL IGNITION FACILITY

Kent K. Leung and Detlev H. Tiszauer

L-447, National Ignition Facility, University of California
Lawrence Livermore National Laboratory Livermore, CA 94550/USA
Email: kkleung@llnl.gov Tel: 925 422-2445

ABSTRACT

The National Ignition facility (NIF) is a high power laser facility for fusion research. The project's design philosophy modularizes the laser' optical subsystem components into Line Replaceable Units (LRU) for ease in maintenance over its expected 30 year life. The LRUs are transported between the Optics Assembly Building (OAB) and the laser structure by a robotic material handling system. A major component of part of this handling system is a portable clean room, or canister, which protects the optics of the LRU during transport between the OAB and the laser. The canister itself contains robotic systems that move the LRU into position inside the clean laser cavity, once the canister is docked to the laser's enclosure. The bottom loading canister carries a variety of different LRUs for placement in different portions of the laser. With this canister docking is accomplished from underneath the laser enclosure. Once docked, the canister becomes the reference from which the robotic insertion mechanisms inside the canister load the LRUs into the laser.

Three concave downward conical cavities, mounted on the bottom of the laser enclosure are the receptacles which guide a set of kinematic pins on top of the canister to achieve a precise canister position. Because the canister with LRU can weigh up to 8000 pounds, each receptacle is subject to several thousand pounds of three-dimensional seismic loads during a seismic event. This paper presents an approach developed for the application of the three dimensional seismic loads with consideration of time-phasing to obtain both an upper and lower bound solution to the combined stress on each receptacle. The contacting seismic loads for a bottom loading cnaister, dock to the laser enclosure, are obtained by other NIF group. They obtained the loading on the kinematic mounting pins by a nonlinear time-domain seismic analysis using a site-specific seismic acceleration time history.

This paper focuses on the application of these loads to determine the seismic effects on the complex stress distribution in each steel receptacle. Finite element analysis is performed to predict stresses in various parts of the receptacle. The net stress state, includes the combined stress from the mounting threads, bending stress in the thin section on the cone and the surface compressive stresses.

1. Introduction

The present finite element analysis is performed for a docking receptacle subject to seismic loads from a bottom loading canister that is part of the NIF Transport/Material Handling System. We focus on one of three receptacles used to guide and register ball-end pins to a specified position for the bottom loading canister.

2. Allowable Seismic Contact Stress

Standard closed form solution for contact stress under static loading based on Hertz's method assumes elastic and isotropic material behavior. Contact stress associated with dynamic loading, such as a ball and roller bearing, gears, cams and rolling wheels, are associated with surface fatigue failure. These failure modes called pitting, (removal of small particles of metal from the surface layer as a result of fatigue action) and spalling, (surface cracks on hardened faces causes the separation of larger flake like particles).

The seismic loads on the docking receptacle over a 30 year life can be related to loads seen by the contact surfaces of spur-gear design without consideration of the fatigue factor. A good correlation has been observed between the Hertz stress and surface fatigue failure of spur-gear teeth. The most widely accepted procedure for analyzing spur gear contact stress is the Buckingham method [1]. Using the finite element method, the contact stress zone and the pressure angle are determined by modeling the load contact points. The present finite element model uses 17336 elements and 3972 nodes to represent the assumed loading locations for a V=7.7 kips, Hx=4.9 kips, Hz=5.5 kips load. The significance of the timing of the applied loads along the different axes shall be detailed in the next section. Material static bearing strength is used for the allowable seismic load. For example, the allowable bearing strength for AISI 4130 steel is Fbry=146 ksi minimum and for 17-4PH stainless steel, Fbry=152 ksi.

3. Method of Seismic Dynamic Loading Analysis

The present method of seismic analysis follows the memo of the NIF program, NIF-214-OB [2]. Three orthogonal directions of seismic input are specified for conducting a response spectrum analysis using a finite element code. Seismic analysis using ANSYS has been performed on nuclear power plant equipment in the early 1970s [2]. Using the same procedure as [2] and take advantage of a cost reduction in computing hardware, seismic analyses was conducted on equipment for scientific research facilities in the late 1980s [3, 4]. Equipment for the NIF project is analyzed in the same procedure as [2, 3, 4] with an emphasis on the detailed state of stress in order to obtain high accuracy for precision automation requirements as well as for seismic safety [5]. The response spectral approach requires that the individual axis results are combined by one of the following methods:

(a) The square root of the sum of squares method.

(b) The double sum method.

(c) The grouping method.

(d) The complete quadratic combination method.

(e) The NRL-Sum method.

(f) The absolute sum method.

Method (a), because of its simplicity and because it intends to represent the most probable system response, is recommend by LLNL ME Design Safety Standards. However, the SRSS method may substantially underestimate or overestimate the total response when the mechanical system is characterized by closely spaced modes. The results for the total response stress need to be extracted from three analyses with given input in each axis, and then, selecting the significant dynamic modes, manually combined in accordance with specific formulas. Mechanical component stress results for NIF operations are mostly in the form of von Mises stresses.

Method (f) is the most conservative method. This method is used for the present design to take into consideration of the uncertainty in the mechanical tolerances in the assembly. Equivalent stress, as computed from the three principal stresses with square root of three stress groups in a value of their differences. A cost-effective approach with a single set of 3-D dynamic input was included to obtain the von Mises stress directly on the components or structural systems without additional post processing. This paper uses an approach produces an upper bond solution that based on method (f) and a standard solution based on method (a) for comparison.

4. Loading Applied for FEA Modeling

The vertical load, given as 7700 lbs, acts simultaneously with two horizontal loads Fx = 4900 lbs and Fz = 5500 lbs. These were computed as the peak loads during a 30 second seismic event by a nonlinear dynamic time domain analysis by Tabiei and Tiszauer [7].

The response of equipment loads to seismic ground motion depends on the frequencies as well as the damping factor. The vertical load of 7700 lbs is applied to the receptacle in a ring contact between the ball end and the conical cavity of the receptacle. Nine key points (8556 lbs each) placed around a ring model the ring contact. This 9 points contacting is the result of 8-volumes used in a mesh generator of solid elements that creates 2167 solid elements per volume. The rotational generator in ANSYS, version 5.3 [8] is limited to 8 volumes in a 360 degree revolution. The 2167 elements is the maximum wavefront limit on the desktop NIF30 system. The applications of the horizontal loadings is considered in two seperate load cases [9]. (1) Assuming the two directions of horizontal frequency are closed to each others (within 10%), the two horizontal response loads can be added together. That is the base of method (f). The docking receptacle stress was determined in this load case as the upper bound solution and considered to be conservative result. (2) Assuming the two directions of horizontal frequency differ by more 10%, the two horizontal response loads can treated separately. The resulting of seismic contact stresses are significantly reduced in this load case.

5. Finite Element Model

The results of the seismic stress analysis are obtained from an FEA conducted with a 3-D 4-node tetrahedral structural solid element (called SOLID72) using the rotations generation option in ANSYS, 5.3 [8]. The details of the modeling are: 17336 ELEMENTS, 3972 NODES, 242 KEYPOINTS, 489 LINES, 256 AREAS, 8 VOLUMES.

6. Conclusion

The docking receptacle seismic stresses determined from load case (1) and the factor of safety evaluated from two candidate materials are listed in the following table.

1	2	3	4	5	6	7
A	Surface Contact Stress From FEA Analysis (ksi)	Allowable Bearing Contact Strength (ksi)	Factor of Safety on Contact Stress	Combined (VM) Stress From FEA Analysis (ksi)	Allowable Tensile Yield Strength (ksi)	Factory of Safety on Combined (VM) Stress
B	=132 (Surface)	Fbry = 146 AISI 4130 Steel	146/132= 1.1	= 99 (Internal)	Fty = 100 AISI 4130 Steel	100/99= 1.01
C	=132 (Surface)	Fbry = 211 17-4PH Steel H1025	211/132= 1.6	= 99 (Internal)	Fbry = 145 17-4PH Steel H1025	145/99= 1.46

ACKNOWLEDGMENTS

The authors acknowledge the support from the NIF Operation Group and would like to thank Erna L Grasz, and Steve Yakuma for their support in this study. Work performed for U.S. DOE by LLNL(W-7405-Eng-48).

REFERENCES

(1) E. Buckingham, "Analytical Mechanics of Gears," McGraw-Hill Co. NY.
(2) S. Sommer & M. Kamath, "Seismic Provision for NIF." Memo NIF214-OB, LLNL,1997, CA.
(3) K. K. Leung, "Seismic Stresses on Piping and Equipment for Nuclear Power Plant." Transactions of the 3rd international Conference on Structural Mechanics in Reactor Technology, Vol. 4 Part K. Section 7/6, 1975, London.
(4) K. K. Leung, "Frequency Response Study of Dipole Magnet Cold Mass for the Superconducting Super Collider." Proceeding Supercollider 3, Plenum Press, 1991, New York.
(5) K. K. Leung, "Dynamic Response Analysis of Advanced Light Source Synchrotron Radiation Storage Ring." IEEE Particle Accelerator Conference, 1993, DC.
(6) K. K. Leung, "Three-Dimensional Simulation of Rotary Latch Assembly in Seismic Response and Interactions" ASME/JSME Pressure Vessels & Piping Conference, 1998, CA.
(7) A. Tabiei & D. H. Tiszauer, "Dynamic Response of NIF Bottom Loading System During A Seismic Event." ASME/JSME Pressure Vessels & Piping Conference, 1998, CA.
(8) J. Swanson, " Engineering Analysis Finite Element Code, ANSYS 5.3." 1997, USA.
(9) " Combination of Modes and Spatial Components in Seismic response Analysis." Regulatory Guide 1.92, 1974, Directorate of Regulatory Standards, DOE.

LOAD CASE NO. 1.

Assuming maximum seismic loading in the horizontal directions and the system response frequenies are closed within 10%. The vertical responnse frequency is considered to be seperated from the horizontal frequencies by more 10%.

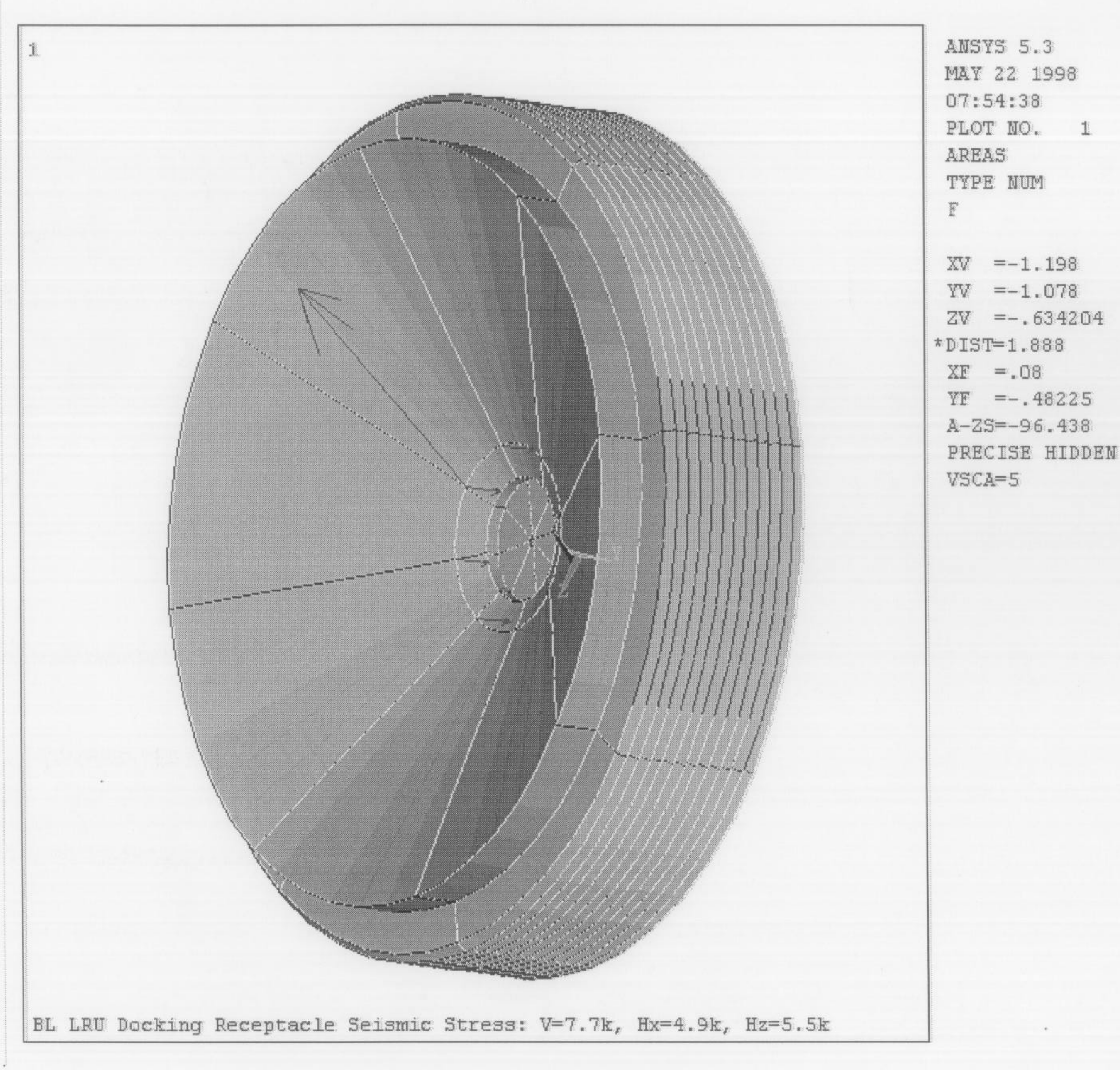

Fig. 1 Docking receiver (receptacle) load case No. 1, the govering design loading condition