DESIGN OF FUELLING MACHINE BRIDGE AND CARRIAGE TO MEET SEISMIC QUALIFICATION REQUIREMENTS

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by

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ABSTRACT

During each refuelling operation, the boundary of primary heat transport system is extended up to Fuelling Machines. A breach in the pressure boundary of Fuelling Machine in this condition would cause a loss of coolant accident. Fuelling Machines are also used for transit storage of spent fuel bundles till discharged to fuel transfer system. Therefore fuelling machine including its support structures is required to be seismically qualified for both on-reactor (coupled) mode and off-reactor (uncoupled) mode.

The fuelling machine carriage used in the first generation of Indian PHWRs is a mobile equipment on wheels moving over fixed rails. As this configuration was found unsuitable for withstanding strong seismic disturbances, bridge type design with fixed columns was evolved for the next generation of reactors.

Initially, the seismic analysis of the fuelling machine bridge and carriage was done using static structural analysis and values of natural frequencies for various structures were computed. The structures were suitably modified based on the results of this analysis. Subsequently, a detailed dynamic seismic analysis using finite element model has been completed for both coupled and uncoupled conditions. The qualification of the structure has been carried out as per ASME section III Division 1, sub section NF.
Details of the significant design features, static and dynamic analysis, results and conclusions are given in the presentation.

1.0 INTRODUCTION

Fuelling machines of Indian PHWRs are designed to facilitate on power loading and unloading of fuel into/from the reactor core. Two identical fuelling machines are clamped on to a coolant channel and the sealing and shielding plugs are removed prior to movement of the fuel. The boundary of the primary heat transport system is thus extended to include the fuelling machines during every refuelling operation. A breach in the pressure boundary of the fuelling machines in this condition would cause a loss of cooling accident. Therefore, fuelling machine including the support structures are required to be seismically qualified, for on-reactor (or coupled) mode. The fuelling machines, after receiving the spent fuel are moved to fuel transfer port, to discharge the spent fuel to the fuel transfer system. Fuelling machines thus act as a transit storage for spent fuel and provide cooling to the bundles during this period. The fuelling machines including the support structures, thus are also required to be seismically qualified for off- reactor (or uncoupled) mode.

The fuelling machines used in the first generation of Indian PHWR's (RAPS and MAPS) consisted of two columns mounted a small carriage base structure fitted with wheels and it moves horizontally on rails embedded in the floor (see fig.1). As this configuration was found to be unsuitable for withstanding strong seismic disturbances anticipated at the being considered sites for nuclear reactors, the fuelling machine carriage was redesigned as bridge type with fixed columns for future generation of standardised design of 220 MWe PHWRs, beginning with Narora (see fig.2). The same bridge concept has been adopted for the 500 MWe PHWR reactors.

In this presentation, first the significant design features, considerations for design and methodology for static seismic analysis of fuelling machine bridge and carriage are discussed. In the latter part of the presentation the dynamic seismic analysis of fuelling machines and its support structures in coupled and uncoupled modes is discussed.

2.0 DESCRIPTION

The fuelling machine (FM) (See Fig.2 and 3) consists of FM head which contains complicated mechanisms for manipulating the fuel, plugs and other accessories and FM bridge and carriage which supports and positions the FM head to any desired reactor channel or FT port.

The head consists of front snout, pressure housing which houses magazine and ram housing at the rear. The head is supported on the support frame. The support frame, in turn is supported in the lower gimbals through horizontal trunnion pins and is free to tilt in a vertical plane. A spring loaded levelling mechanism keeps FM head horizontal and also limits the tilt. The lower gimbals is bolted with upper gimbals, to facilitate the removal of FM head for servicing. The upper gimbals is supported on 4 linear ball bearings fitted on the top beam. The relative motion between upper gimbals with respect to top beam provide Z-motion for FM head. The top beam is suspended from the drive plate by a vertical spindle. The vertical spindle through a set of gears permits 90 deg. rotation of FM head to facilitate its passage through hatchway into the service area for connection to FT port or for maintenance of fuelling machine. A small amount of tilt about the vertical spindle in horizontal plane is allowed at the extreme positions of 90 deg. rotation. A spring loaded centralising mechanism keeps the head in centralised position and also limits the tilt in the horizontal plane.

The drive plate is bolted to the trolley by 4 support studs. The trolley moves horizontally over the guides fixed to the underside of the bridge structure. The trolley is moved by a rack and pinion drive.

The bridge structure is a long welded beam, which is supported on the bridge supports. Bridge supports are guided vertically on guides fitted to two columns. One end of the bridge is bolted to the bridge support, the other end is freely supported on linear bearings to facilitate thermal expansion of the long bridge structure. The bridge supports are supported on 4 ball screws which are suspended from the top of two columns. Each column is a built up I-section which is supported on a base plate embedded in concrete and is tied with the nearest wall with help of the tie members.

All structural members like the column, the bridge structure, the bridge supports, the trolley, the drive plate, the gimbals and the support frame are designed to be fabricated as welded structures from ASME A 515 gr. 70 material.

3.0 CONSIDERATIONS FOR DESIGN AND METHODOLOGY FOR STATIC ANALYSIS

Fuelling machine bridge and carriage has been designed as per ASME section III subsection NF as applicable to class I components. However, the primary considerations of rigidity of structures has been incorporated to limit the deflections due to normal operating loads. For example, the cross-section of bridge structure has been so sized that the deflection of bridge for the worst combination of operating loads should not exceed 1.5 mm.

Initially, the effect of seismic loads due to postulated seismic event was considered in the design on the basis of static structural analysis. The analysis was done using the moment distribution method by calculating relative stiffness of various members. The end fixity conditions for various fixed bolted joints were conservatively fixed between 0.5 and 0.75. The calculations for bridge and column were done to determine the worst position of bridge on the column and FM head on the bridge, and to determine maximum deflections at such a position. The values of natural frequencies of vibration in different directions were computed. Similar calculations were done for all other structures including gimbals and vertical spindle. These calculations resulted in the following modifications in the design:

a) Originally an integral radiation shield on top of the bridge was contemplated for shielding of FM service area from FM vault. The concept was changed and a separate Roll-on shield was provided on Fm Vault floor.

b) The columns were tied at a number of points to the wall by tie members to provide more rigidity by reducing lengths of unsupported spans.

c) Additional bracings were provided in the column, bridge and gimbals to strengthen the structures.

d) The rating of X and Y drive brakes were augmented considering the forces generated by seismic disturbance.

4.0 DETAILED DYNAMIC SEISMIC ANALYSIS

Detailed dynamic seismic analysis using finite element technique for both coupled mode and uncoupled mode has been carried out for the new design of fuelling machine bridge and carriage by using SAP-IV computer code (Ref.1)

4.1 FINITE ELEMENT MODELLING

The finite element model using 3-D beam and 3-D stiffness element of SAP-IV computer code has been developed for both coupled and uncoupled mode of fuelling machines. Fig.4 shows the model for the coupled mode. Fig.5 shows closer details of model for FM head and carriage. The model has been evolved so as to depict the structures and the joints as realistic as feasible.

The fuelling machine bridge and carriage has a number of connecting node points where the connecting members are having multiple 'FREE' degrees of freedom. Suitable 'end release code' facility of SAP IV computer code is used at such nodes to simulate the exact end conditions and relative motions of various elements in the above models. The connection between ball screws and columns, ball screws and bridge support, bridge support and bridge, drive plate and vertical spindle, top beam and upper gimbals etc. are some of the points where end conditions and relative element motions have been simulated in detail.

4.2 QUALIFICATION METHODOLOGY

Fuelling Machine Bridge and Carriage has been analysed for dead load and two levels of earthquake viz. operating basis earthquake (OBE) and safe shutdown earthquake (SSE). The dynamic analysis using response spectra method has been done using SAP- IV code. SSE analysis has been carried out using 4 % damped SSE response spectra (Fig. 6) for horizontal direction.(Ref.2) The SSE response spectra used is envelope of response spectra for different floors/wall elevations supporting the FM bridge and carriage structures. Multiplication factor of 0.67 has been used for vertical direction spectra accelerations. The value of damping was chosen as per the ASME code (Ref.3) OBE analysis has been done using 70 % of 2 % damped SSE response spectra (see fig.7) .

Qualification of the structures has been done as per requirements of ASME III division 1 sub section NF (Ref. 4) . The load combination for supports for different loading categories are taken as follows :

Design condition -- Dead wt.+OBE loads
Level C -- Dead wt.+SSE loads.

4.3 RESULTS

The dynamic analysis of fuelling machine bridge and carriage has been conducted to extract 32 modal frequencies for coupled mode and 16 modal frequencies for uncoupled mode (see table-1). The stresses and deflection experienced by various structures in different elements were calculated and checked. Table 2 and 3 show the maximum stressed structural members. The deflections for various modal frequencies were combined by SRSS method. Table 4 shows the maximum deflection for coupled and uncoupled mode.

5.0 CONCLUSION

The results of the detailed dynamic seismic analysis shows that the structures are relatively rigid for the seismic excitations. The results have also given strength to the view that initial conservative static analysis calculations remain a useful tool in the process of designing such structures.

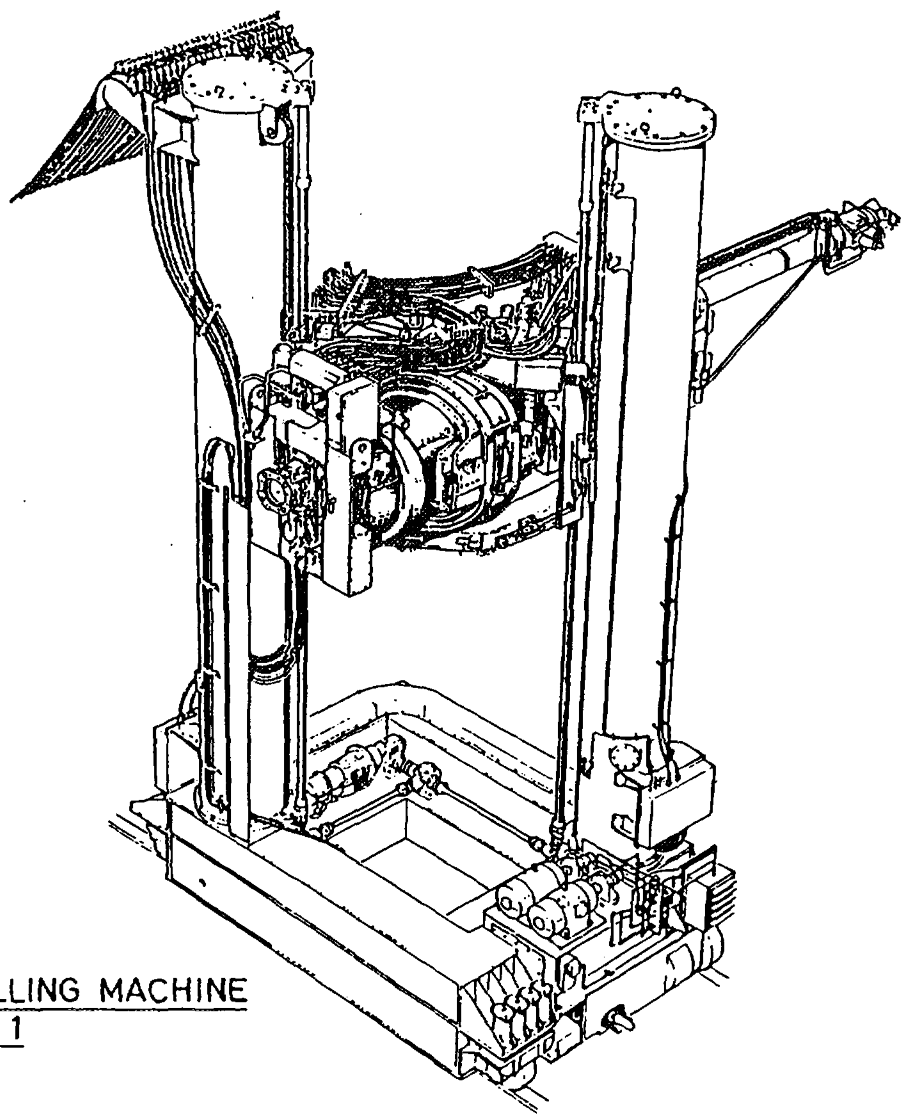
REFERENCES :

1. Computer Code SAP- IV (A structural analysis programme for static and dynamic response of linear systems by K.J. Bathe et.al.,Engineering Analysis Corporation, Berkeley, USA)

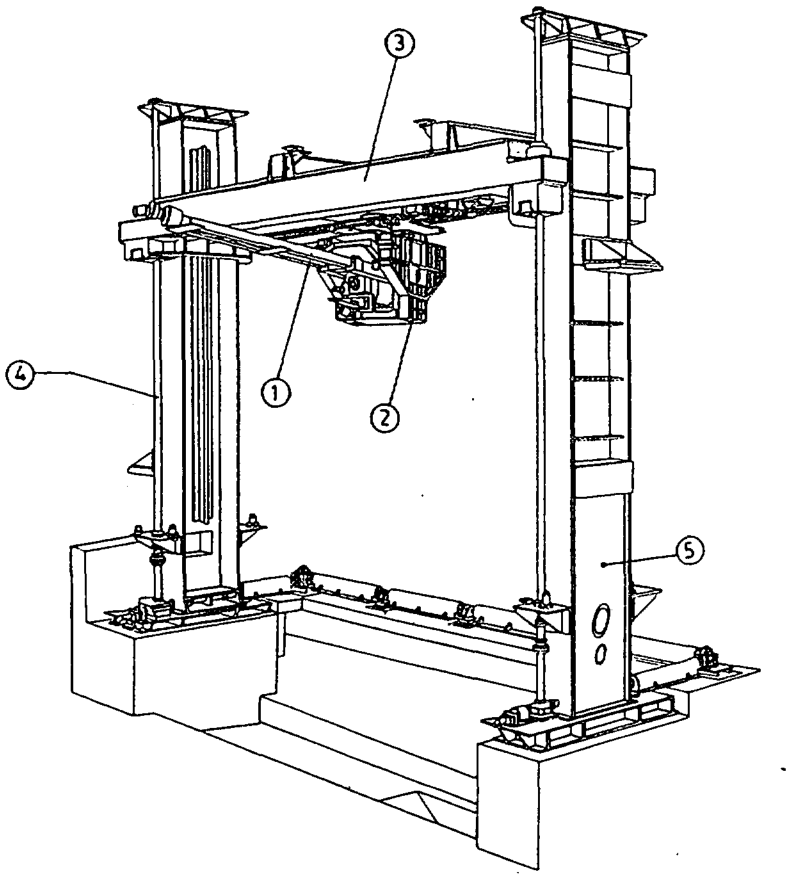
2. Earthquake Engineering studies Eq-7771, Seismic Analysis of RB of NAPP under horizontal ground motion including flexibility of internal structures, A.S.Arya et. al. University of Roorkee.

3. ASME Boiler and Pressure Vessel Code, Section III, Division 1, Appendices, Para N-1230.

4. ASME Boiler and Pressure Vessel Code Section III Division 1, subsection NF, Components Supports, para NF-3320.

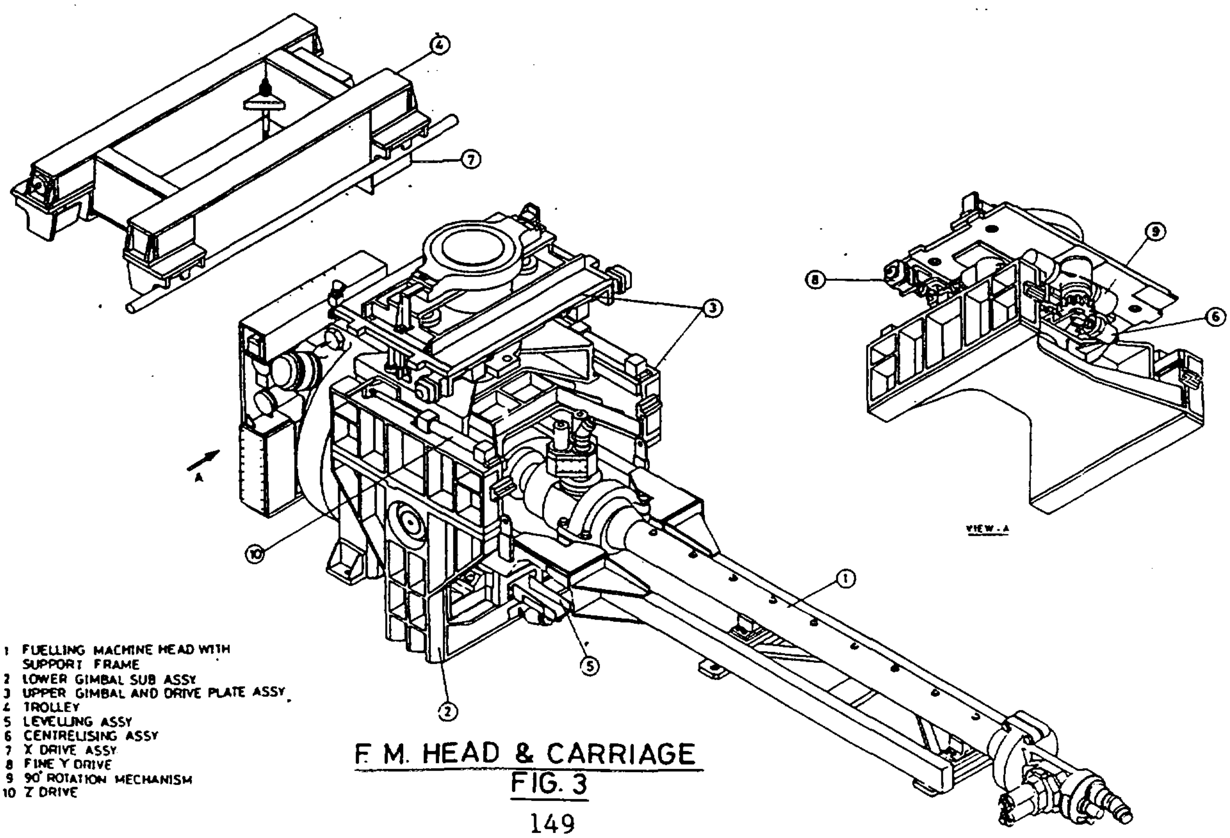


RAPS / MAPS FUELLING MACHINE
FIG. 1



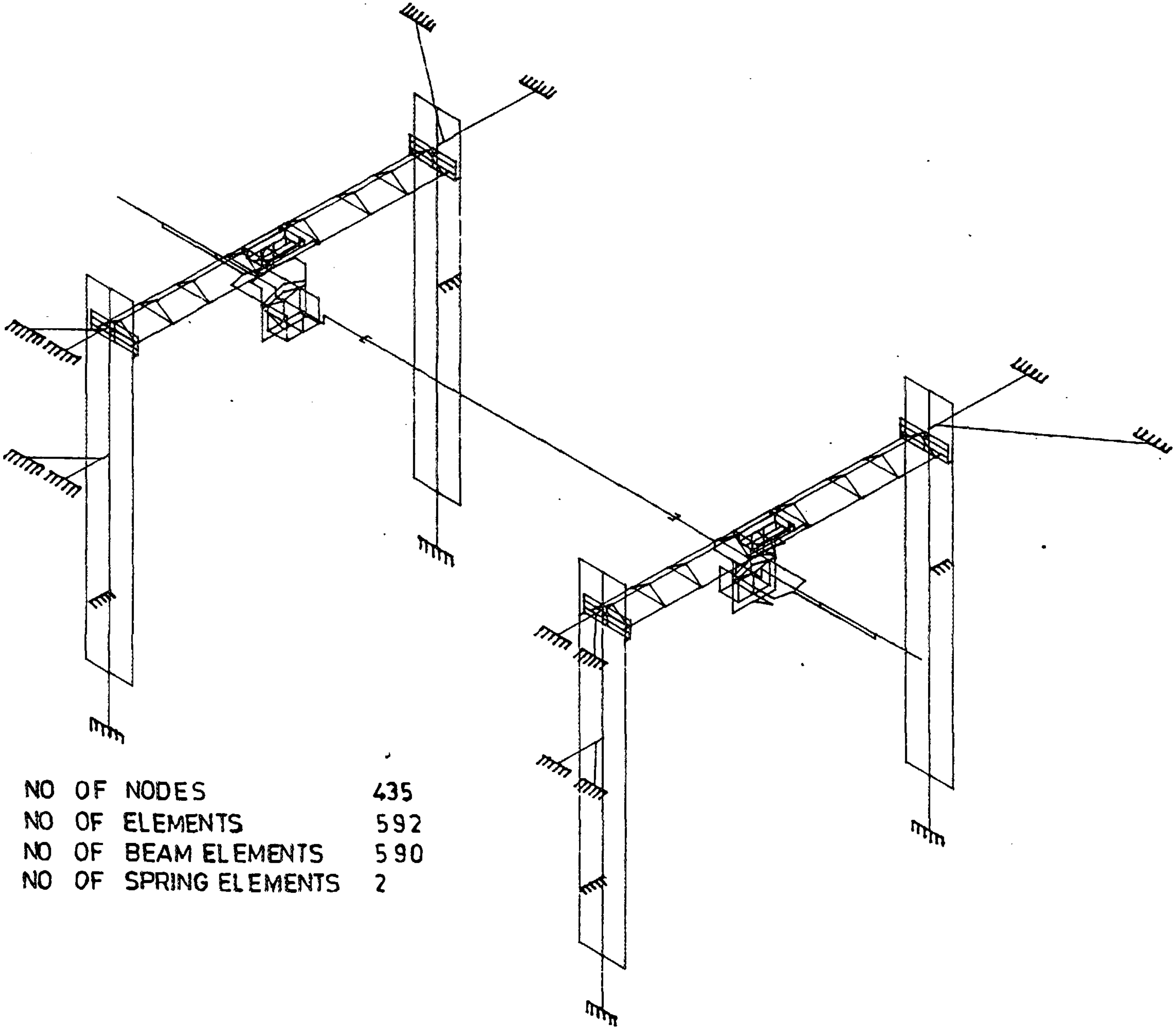
1 F M HEAD
2 GIMBALS
3 BRIDGE
4 BALL SCREW
5 COLUMN

NAPS FUELLING MACHINE
FIG. 2

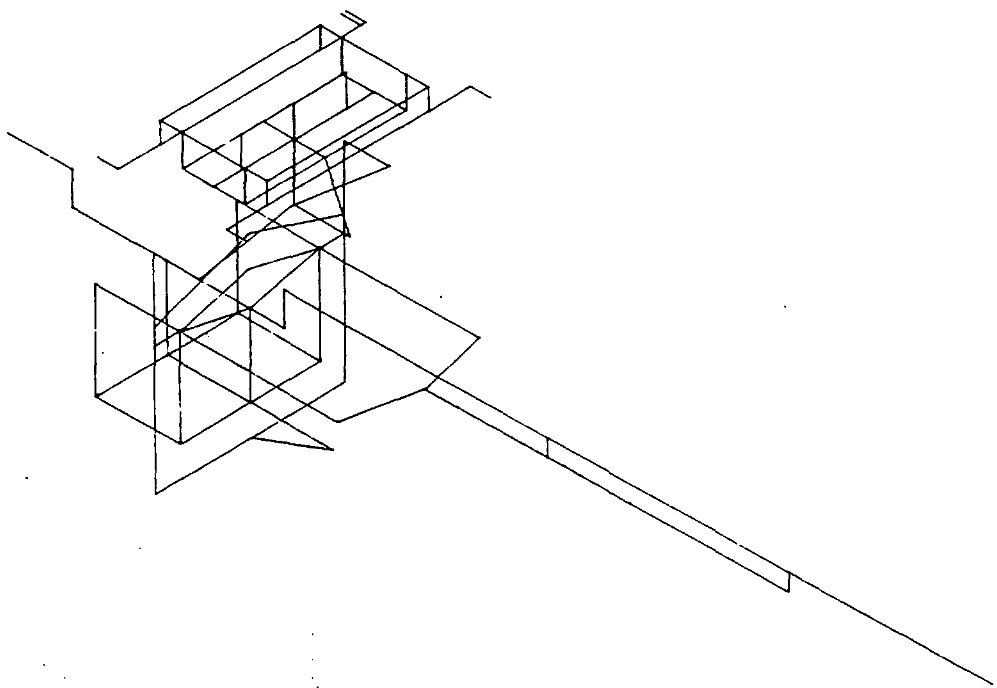


1 FUELLING MACHINE HEAD WITH SUPPORT FRAME
2 LOWER GIMBAL SUB ASSY
3 UPPER GIMBAL AND DRIVE PLATE ASSY
4 TROLLEY
5 LEVELLING ASSY
6 CENTRELISING ASSY
7 X DRIVE ASSY
8 FINE Y DRIVE
9 90° ROTATION MECHANISM
10 Z DRIVE

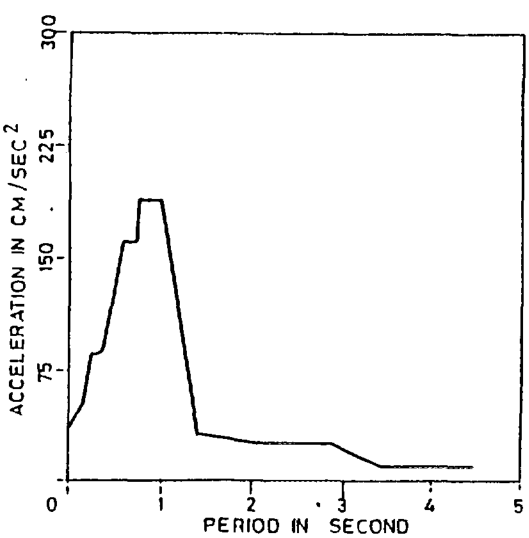
F M. HEAD & CARRIAGE
FIG. 3



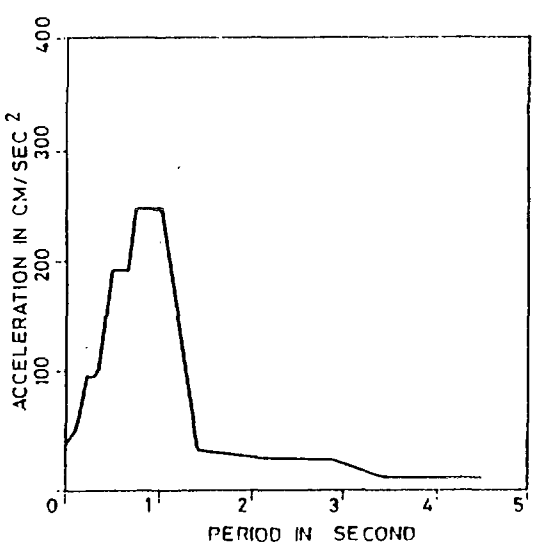
FINITE ELEMENT MODEL OF
FUELLING MACHINES IN COUPLED MODE
FIG. 4



FINITE ELEMENT MODEL OF
F. M. HEAD & CARRIAGE
FIG. 5



SSE ENVELOPE RESPONSE
SPECTRUM WITH 4% DAMPING
FIG. 6



OBE ENVELOPE RESPONSE
SPECTRUM WITH 2 % DAMPING
FIG.7

TABLE -1

MODAL FREQUENCY DATA

COUPLED MODE			UNCOUPLED MODE		
MODE NUMBER	FREQUENCY (CYC/SEC)	PERIOD (SEC)	MODE NUMBER	FREQUENCY (CYC/SEC)	PERIOD (SEC)
1,2	3.637	0.2750	1	3.261	0.3066
3,4	3.640	0.2747	2	3.637	0.2750
5-16	3.663	0.2730	3	3.640	0.2747
17	5.933	0.1686	4	3.663	0.2730
18	6.018	0.1662	5	3.663	0.2730
19	6.139	0.1629	6	3.872	0.2582
20	6.191	0.1615	7	3.873	0.2582
21	9.369	0.1067	8	3.874	0.2581
22	10.23	0.09778	9	3.874	0.2581
23	10.67	0.09370	10	6.326	0.1581
24	15.42	0.06484	11	9.042	0.1106
25	15.49	0.06458	12	10.280	0.09724
26,27	18.23	0.05484	13	17.230	0.05803
28	22.22	0.04501	14	23.940	0.04176
29	22.75	0.04395	15	31.210	0.03204
30	31.34	0.03190	16	40.920	0.02444
31	31.35	0.03190			
32	34.48	0.02900			

TABLE-2

MAXIMUM STRESS FACTORS (UNCOUPLED MODE)

STRESS TYPE	DESIGN CONDITION	LEVEL C CONDITION	STRUCTURAL MEMBER
SHEAR STRESS	0.6053	0.4484	RAM HOUSING
AXIAL COMPRESSIVE STRESS	0.1428	0.1200	SUPPORT STUD
AXIAL TENSION STRESS	0.3399	0.2974	SUPPORT STUD
COMBINED AXIAL COMPRESSION AND BENDING STRESS	0.9668	0.6953	RAM HOUSING
COMBINED AXIAL TENSION AND BENDING STRESS	0.9654	0.6941	RAM HOUSING

TABLE-3

MAXIMUM STRESS FACTORS
(COUPLED MODE)

STRESS TYPE	DESIGN CONDITION	LEVEL C CONDITION	STRUCTURAL MEMBER
SHEAR STRESS	0.0798	0.06317	UPPER GIMBAL
AXIAL COMPRESSIVE STRESS	0.7679	0.7176	COOLANT TUBE
AXIAL TENSION STRESS	0.1499	0.1102	SUPPORT STUD
COMBINED AXIAL COMPRESSION AND BENDING STRESS FACTOR	0.9300	0.8230	COOLANT TUBE
COMBINED AXIAL TENSION AND BENDING STRESS FACTOR	0.7080	0.5734	END FITTING

TABLE-4

MAXIMUM DEFLECTIONS

STRUCTURAL MEMBER	UNCOUPLED MODE (CM.)	COUPLED MODE (CM.)
1.RAM HOUSING TAIL END(Y-DIR)	3.3	0.8
2.BALL SCREW (X-DIR)	1.8	1.8