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Seismic analysis and testing research of emergency diesel generator set

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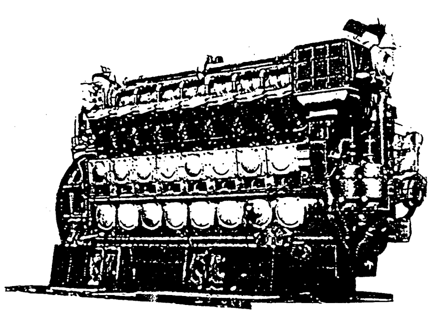
ABSTRACT: In this analysis, the dynamic decoupling conditions are applied to rotating components so that functional verification is separated from seismic verification. For main components attached to the EDG body, seismic qualification is confirmed by means of combined methods of analysis and testing, taking account of the decoupling conditions. Then, the seismic analysis for the EDG set is performed.

1. Introduction

The function of the Emergency Diesel Generator Set (acronymed as EDG set) is to supply emergency electric power for the nuclear power plant when the normal power is lost, so as to enable the reactor to be kept in a safety state. The set is classified as safety class Ⅲ and seismic category Ⅰ, and is required to start up and reach the rated rotating speed and voltage in a definite time and then take up emergency loads in a predetermined sequence. Thus, the EDG set must have favourable seismic and fast startup behaviors.

The diesel engine of the EDG set in Qinshan NPP in type 16V240ZDA, which is an inproved one of Dong Feng type 4 locamotive internal–combustion engine. In order to satisfy the special requirements of NPP, the design was improved with respect to its performances and structures, and about 300 times of reliability tests and effective fast startup were carried out. This engine has good operating records and reliability. But it is still necessary to carry out analysis and verification tests for its seismic behaviors.



Emergency Diesel Generator Set

2. The seismic analysis of the EDG set

The EDG set is a very complicated system, which can be divided into three main subsystems: the diesel engine, the generator and various kinds of auxiliary pipings. Each subsystem contains diverse components and the diesel engine is the most complicated.

In seismic analysis, any attempt to represent the set by one or several simple but complete seismic models in not only very troublesome but impractical. Thus, first of all, we must cousider whether the set can be separated into seismic system and seismic subsystem, in order to judge if the subsystem can be decoupled or nor. Secondly, the loads of the set, the boundary conditions and the structural complexity should be considered. We can select important components and weak portions to implement detail analysis for earthquake. But for other components, simplified analysis suffices.

The diesel engine body and its baseplate together with their foundation are regarded as the seismic main system, and all other components attached to the seismic main system such as the supercharger, inter cooler, various types of pumps and pipings are seismic subsystems. Owing to the characteristics of mass and stiffness, the dynamic effect between the main system and its subsystems in obviously interactive. Judging if there are coupling effects between them should observe certain rules. [2]

The decoupling analysis between the main system and each component of the diesel engine is shown in Table 1.

The fundamental frequency of the EDG set is $f_1 = 39.3Hz$ [3].

According to French experiences on seismic analysis of EDG sets [4], and our analysis of the EDG set in Qinshan NPP-1, the following components should be emphasized for seismic analysis:

(1) The main components attached to the EDG body. The seismic analysis for each component is carried out in accordance with decoupling conditions.

(2) The crank shaft—connecting rods systems [3].

(3) The baseplate of the diesel engine.

(4) The auxiliary piping systems.

For other important devices in the diesel engine such as the crank case, cylinder block, cylinder liner and piston etc., their principal causes of failure are all fatigue damage produced by mechanical and thermal stresses, which have already been taken into consideration in design of the diesel engine. For the stand and various parts attached to its interior, the stress caused by earthquake is not likely to exceed 10% of the total stress due to the large stiffness of the EDG stand. Thus, no detail research is made in this parer.

The critical damping ratios in the analysis and tests are defined as 3% for SSE and 2% for OBE in accordance with ASME—Ⅲ, Appendix N—1230.

Analysis is done by FEM. The results of seismic response analysis for the main components and weak portions of the diesel engine are listed in Table 2 to 3.

3. The seismic testing of the EDG set

The seismic testing of the EDG set is done mainly for those components with complicated configuration and internal moving parts such as the supercharger, intercooler, governor and so on, which are very difficult to verify their proper functioning by means of analysis during and after eqrthquake.

In general, the operating conditions for these components should also be considered in the seismic testing. However the loading conditions will become more complicated, and intricate boundary and operating condition modelling will also be encountered so that the testing cost will increase. Reference concludes both in theory and experiments that the vibrational response of an EDG set is a simple superposition of seismic forces and operating load responses based on experimental results. The results of this paper also show that for rotating equipment with stiff foundation, having high matural frequencies and short startup time, no strong coupling occurs between the rotating effects and the floor response spectrum. [2]

The main testings are as follows:

(1) verification testing of dynamic characteristics on shaking table.

(2) simulating seismic testing.

(3) functional verification testing under operating conditions.

(4) dynamic measurements on site.

The frequency characteristics of the EDG set is an important parameter for calculation. Owing to the complexity of the diesel engine structure and also its total weight about 22.5 ton, normal testing excitations are all ineffective. Thus, the natural frequency of the EDG set is measured by means of "loss of load". the diesel engine runs at 1000r / min with loading. Its speed will decrease gradually during loss of load. When the natural frequency of the diesel engine is double of certain rotating speed, its vibration will increase. Just as in the case of exciting testing, we can then find the frequency of the diesel engine. Typical spectrum array of the EDG set in the course of shutdown is shown in Fig.1. It can be seen that resonances occur at certain rotating speeds. To obtain the frequency response curve, the response spectra at different times during shutdown are completed respectively and the response at different frequencies near the resonant point is resolved. The fundamental frequencies in longitudinal and transverse directions are respectively 56.25Hz and 35.9Hz, damping ratios are respectively 2.17% and 4.7%.

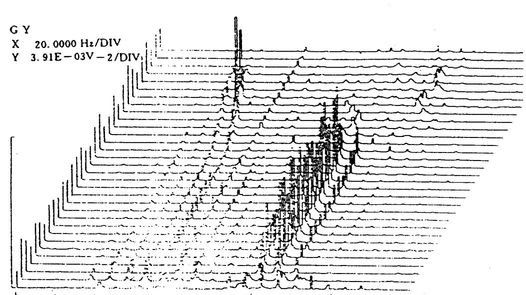


Fig.1. Spectrum array in the course of shutdown of EDG set

In the shaking table tests for the main rotating components, their resonant frequencies are determined by the frequency response functions (transfer functions) of the acceleration response history of the components. If the excitation at certain point is X(t), the response wave form is y(t), then the transfer function at the point is:

$$H(f)= G_{xy}(f) / G_{x}(f)$$

where $G_{xy}(f)$ is the cross-power spectral density function of X(t) and Y(t), and $G_x(f)$ is the self-power spectral density functioin of X(t).

The tests show that the fundamental frequencies and damping ratios of each component after the seismic tests coincide basically with those before. In these tests, we take that the test response spectrum (TRS) envelops the required response spectrum (RRS) as the governing requirement.

The re-verification tests for the supercharger, intercooler and the governor under operating conditions before and after seismic testing are carried out. For the supercharger, the methodology used is: arbitrarily select a piece of supercharger from normal products to check its appearance, if good, the gap measurement in cold state is made. Transverse movement of the rotor, radial gap of wind-guiding wheel of the compressor (measurable portion) and radial gap of worm-whed leda are measured. The supercharger is tested at 25000r / min, 22000r / min and 9000r / min. The flow rate, pressure ratios, rotating speed, temperature, and atmospheric conditions are recorded at the same time. The efficiency of the supercharger is calculated, the amplitude value of vibration of the supercharger is measured and oil-leaking, if any, at 9000r / min is checked. The hydrostatic test for the intercooler is performed in accordance with "technical requirements" TC651-88JT. The testing pressure is 0.5MPa, for 5 min, no leak is allowed. The performance measurement for the governor is implemented on a wind-tunnel testing rig. No obvious performance distinction before and after seismic testing is detected.

No abnormal phenomena during all of seismic behavior qualification is found. All components remain in good condition and no mechanical damage caused by seismic tests is discovered.

4. Conclusion

Owing to the structural complexities and large stiffness and heavy mass of the EDG set, decoupling conditions are obtained by theoretical analysis subsystems for the seismic analysis and testing of the set. The set is divided into various piping systems and main assembly components, and combined analysis and testing is then used. This approach is reasonable and feasible. The results meet the decoupling criteria in NRC SRP 3.7.1.

For complicated rotating components of which the seismic qualification can not be performed by analysis, it can be proved that under certain circumstances the method of separating the seismic test from the functional verification test is feasible and satisfies the requirements in NRC SRP 3.10.

The EDG set installed in Qinshan NPP is the first one designed and manufactured by China. Analysis and testing results indicate that the EDG set satisfies the seismic requirements of relevant codes and regulations such as NRC SRP 3.7, 3.10, 9.5, and IEEE344–1987 after the design is improved and 300 times of reliability tests carried out. Therefore it is believed that the diesel generator of type 16V240ZDA is suitable for use in nuclear power plants in China.

References

1. IEEE Standard, Criteria for Diesel–Generator Units Applied as stand–by power supplies for Nuclear Power Generating Stations.
2. Yao Weida et al, (1992), Demonstrations of Several Problems on Seismic Analysis and Test (Report No.19), SNERDI, China.
3. Chen Renchang, (1992), Seismic Response Analysis on EDG set in Qinshan NPP (Report No.3), SNERDI, China.
4. Y.Rtyrand et al, Stand–by electricity generator sets: Special Adaptations to Meet the Requirements of Nuclear Plants, 15th International Congress on Combustion Engines (CIMAC), P1683 ~ 1729, 1983.

Table 1 Decoupling conditions for components of the diesel engine

names of subs.	mass m_2 (Kg)	frequency f_2 (Hz)	R_m	R_f	coupling or deconpling
supercharger	260.0	221.7	0.01	5.64	dec.
intercooler and its attachments	220.0	57.6	0.008	1.47	dec.
pump	95.0	216.2	0.004	5.50	dec.
oil pump and its attachments	328.486	631.9	0.013	16.08	dec.
governor	50.0	69.3	0.002	1.76	dec.
coolant piping system	486.15	65.4	0.019	1.66	dec.
oil piping system	694.276	90.8	0.026	2.31	dec.
burning oil piping system	138.866	50.8	0.005	1.29	dec.

Table 2 Maximal Stresses for Machine Oil Piping System

Loading	Allowable Stress MPa ①	Max.Stress MPa ②	Stress ratio ②/①	Location nodel No.
design weight+internal pressure	1.0SH 105.46	75.42	0.715	8
operating weight+OBE	1.25SH 126.55	94.30	0.754	8
operating weight+SSE	1.85SH 189.83	107.41	0.566	8
operating weight+SSE	2.45SH 253.11	107.41	0.424	8
testing internal pressure+dead weight	0.9Sy 221.47	75.42	0.341	8
normal operating temperature	SA 158.19	228.69	1.446*	113
operating temperature+operating weight	SH+SA 263.65	233.42	0.885	113

Note: * Stress exceeds the limit value in equation but it still satisfies requirements in regulation in terms of section 4.2 of 9th report.

Table 3 Maximal Synthetic Stresses for Main Components of Diesel Engine and Supports

Component name	OBE		SSE	
	σ_{max}(MPa)	τ_{max}(MPa)	σ_{max}(MPa)	τ_{max}(MPa)
Diesel engine:				
Body	0.473	0.008	0.96	0.017
Base	1.491	0.382	2.981	0.764
Crank	1.57	0.204	2.51	0.344
Con–rods	0.130	0.001	0.260	0.002
Connecting Screw of Con–rods	3.402	0.355	5.704	0.584
Supports of EDG:				
connecting screw	106.91	59.82	173.21	81.09
installing screw	33.19	11.19	68.9	18.11
Lubricant Pump:				
Pump Body			4.10	1.03
Pump Shaft			< 1.0	< 1.0
Support Screw			7.47	9.13
Cooling Water Pump:				
Pump Body			3.44	0.21
Pump Shaft			1.0	
Support Screw			38.8	11.0
Support Screw of Supercharger	13.04	4.03	21.29	6.55
Support Screw of intercooler	35.03	9.67	57.29	15.78
Support Screw of governor	2.11	0.98	2.87	1.23