Shock Resistance of a Marine Pump

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***Abstract*—Numerical method is used to build the entity model and finite element model of a marine pump, modal analysis shows that modal frequency is not equal to the operating frequency and the resonance is not produced in the pump. The finite element method is used to calculate the shock load which is the request of GJB. The allowable strength at vertical, longitudinal and horizontal direction of the pump is analyzed, and the anti-shock behavior of the pump is checked too. The results show this type pumps are not destroyed wholly and can be working normally in the shock environment, which satisfy the requirements of GJB. But the bracket position of the pump is suffered great compressive stress which leads to the designed and strengthened again.**

Keywords- modal analysis, pump，numerical method，finite element model

I. INTRODUCTION

Marine pump, whose reliability affects the dynamic system and the fire fighting system, is an important element of a ship and determines the vitality and combat effectiveness indirectly. The shock resistance performance of the ship is pay attention in recent years. At present, the shock response spectrum test method has been used widely in calculation. This method is based on a more realistic simulation of the actual shock effect on ideological foundation. The effect of shock wave and the response of the structure are taken into consideration; synthesize shock excitation, structural dynamic characteristics and their response relation are synthesized. The history and current situation of shock isolation technology are studied by G.H. Jiang [4] et al, and the initial study of the technology was focus on increasing the strength of the hull and a series of explosion and shock test and the corresponding theoretical research. According to the research and combining with the actual situation, computer simulation is used to check the pump shock design.

II. SHOCK TYPE

According to the GJB, the shock resistance grades are divided into grade A, B and C [5], which is based on the significance of safety to the ship and continuous fighting ability of the equipment. The pedestal and the equipment supported have the same shock grade. The drainage pump is mainly used in the drainage system to remove or transfer the water which due to a break, and the shock grade of the pump is A which can be determined by its' function. Equipments are divided into three types in terms of the location in the ship, the equipments located in the hull part (Class I equipments), and the equipments located on the deck (Class II equipments), and the equipments located in the outer plate (Class III equipments). The type of the base is the same as the supported devices [5]. The drainage pump is mounted in the hull, and the pump can be identified as class I by the location. And thus the grade of the pump shock resistance is grade A and class I.

III. FINITE ELEMENT MODEL OF THE MARINE PUMP

First of all, the SolidWorks software is used to build the model, and then the ANSYS software is used to establish the finite element model after the model being imported.

A．Establishment of pump geometric model

The pump includes a submersible motor, casing, pump shaft, impeller, a mechanical seal, a water lubricated bearing, base, a coupling and other multiple parts, different parts are made of different materials and the structure is complex. Because of the computing requirements the structure of the pump should be simplified and the geometric features which effected the calculation less, such as screw, thread, and chamfer and so on should be ignored in the geometrical model. In order to ensure the conversion data can be imported into ANSYS and after that the pump still has the same body and surface characteristics, parasolid format is used, such as a casing (Fig.1), the impeller (Fig.2), which makes the ANSYS finite element model be established conveniently.

Fig. 1 Casing

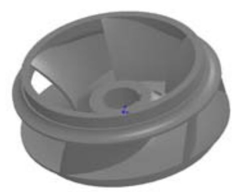

Fig. 2 Impeller

B．Establishment of finite element model of pump

The pump model is imported into ANSYS software and the finite element modeling is established based on the 3D entities SolidWorks modeling, and the unit type, nature and meshing is defined. Generally, the attributes of the solid elements are determined based on the materials, thickness and a real constant, section size and size numbers of the shell and beam elements determined based on the structure. The pedestal, casing, inlet connecting pipe, inlet conical pipe and filter head part are shell parts, which are defined with SHELL93shell unit; motor coupling, pump shaft, impeller, pump cover, mechanical seal and water lubrication bearing are solid parts, which are defined with SOLID95 entity unit; motor and the cover which can be simplified as a quality module have small volume and large stiffness which are the important quality components of the pump group shock analysis, and MASS21 quality unit is used, by the calculation, we get mx = my = mz =0.545t, the moment of inertia is: Jx = Jy =3670t / mm2, Jz =3146t / mm2 , and the distance between the motor mass center and the upper end surface of the bracket is 364mm. In the four isolators, three COMBIN14 compound spring elements which has directions and different stiffness are used to connected with the pedestal instead of the isolator. Stiffness of each direction is: Kx =5500N / mm, Ky =7600N / mm, Kz =20000N / mm, the damping coefficient is η=0.2; each flange connection is simulated with BEAM189 beam element model. The finite element model of pump group contains 23154 SOLID95 entity units, 4936 SHELL93 units, 140 beam elements, 1 MASS21 quality unit and 12 COMBIN14 spring elements, which has 28243 units and 123945 nodes in all.

The boundary conditions is the X, Y, Z direction's degrees of freedom which is the constraint at the junction between the isolator and ship carina, Spring element with different stiffness in three directions is used to simulate each isolator, therefore, the finite element model should be simulated with all degrees of freedom of the 12 spring element nodes.

Automatic network is used to mesh in this paper. The total nodes are taken to connect except flange connection in which the beam unit is taken to connect. Finite element model of the pump is shown as Fig.3 and Fig.4.

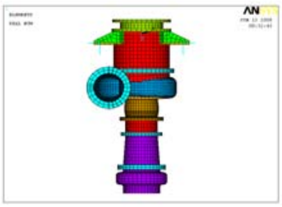

Fig.3 Finite element model of pump

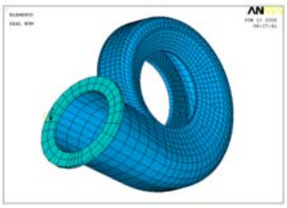

Fig.4 Finite element model of casing

IV. SHOCK RESISTANCE DYNAMICS CALCULATION

According to the national military standard requirements, the model mass is used in the shock calculation, and at the same time, it is necessary to calculate the system modal for anglicizing the vibration performance of the equipment when shock resistance being calculated.

A. Modal analyses

Modal frequency, cumulative mode quality, the vibration characteristics of evaluation system and the shock of simplified calculation type determined are the main considerations in modal analysis. The Block Lanczos method is used to calculate the first 10 order modes (non-free mode) of pump group, modal frequency is shown in Table.1 and mode shape is shown as Fig.5-8

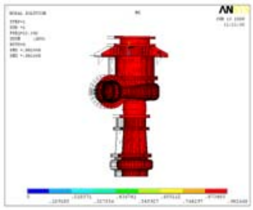

Fig.5 First step modal

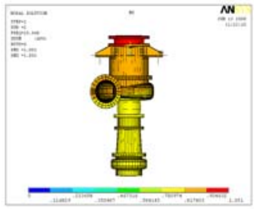

Fig. 6 Second step modal

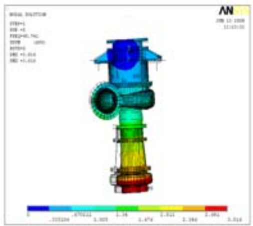

Fig. 7 Fifth step modal

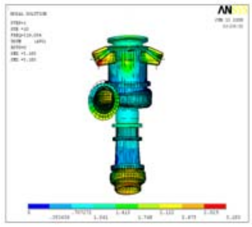

Fig. 8 Tenth step modal

After the modal analysis being calculated, the spectrum analysis with the model of the X, Y, Z direction of a single point's displacement (or velocity, acceleration) is taken, and the quality of participation of each mode inspired which in all directions can be gotten. The result is shown in Table.1. According to the national military standard requirements, the first N modal for shock resistance calculation can be chosen and the rest of the order number can be ignored when the N order cumulative modal participation mass reached more than 80%. The first order modal in the X direction, second modes in the Y direction and third modes in the Z direction cumulative modal participation quality have reached more than 98% of the total of the draining pump, which can gotten from the data in the table, and thus the order can be simplified as the mass spring system one by one when the calculation of the shock resistance of the pump is taken place.

TABEL.1 THE MODAL FREQUENCY FROM ONE TO TEN

Modal order		1	2	3	4	5	6	7	8	9	10
Frequency(Hz)		22.142	25.568	38.638	39.895	45.741	85.615	129.472	135.486	238.39	319.054
Quality of participation (%)	X	99.89	99.89	99.89	99.89	99.96	99.96	99.97	99.99	99.96	99.99
	Y	99.62	98.62	98.62	99.90	99.90	99.90	99.95	99.99	99.99	99.99
	Z	99.62	99.63	99.65	99.72	99.99	99.99	99.99	99.99	99.99	99.99

B. Math model of the shock resistance

According to the regulations, the shock test is taken with the required impulse or the shock spectrum to simulate. Shock response spectrum is used for shock resistance calculation in the United States MIL-S-072 standard and the German BV043 standard instead of the national military standards in which only the shock amplitude considered instead of the shock time when it is calculated. Although the military standard calculation method is relatively simple, which is often applied in the calculation of the shock of the preliminary design stage, and only the maximum stress force and deformation results can be gotten from the method, static G method for calculation is used in this paper.

The mathematical model can be a single or multiple degree of freedom system, and a single degree of freedom system is used as far as possible. According to the national military standard, the modal is chosen for shock resistance calculation if the N order cumulative modal participation mass reached more than 98%, and the rest modal can be ignored. So the mass spring system can be used in the shock mathematical model of the drainage pump, X, Y, Z direction respectively describe the longitudinal, lateral and vertical. The spring constant is kx=4×5500N/mm = 2.2×107N/m, ky=4×7600N/mm = 3.04×107N/m, kz=4×2000N/mm = 8×107N/m, the resonance amplitude is smaller if the damping coefficient value is greater, which is in favor of shock isolation, the dereference of η is 0.2 according to past experience. The pump group quality is m= 1.129t. The formula $\omega_{ni} = \sqrt{k_i/m}(i = x, y, z)$ is used to calculate the X, Y, Z direction of the circular frequency, and ωnx=139.6rad/s,ωny=164.1rad/s,ωnz=266.2rad/s, the inherent frequency fn=ωn/2π,fnx=22.2Hz, fny=26.1Hz, fnz=42.4Hz, which is the basis of the design shock value calculated as follows.

C. Design values of the shock

The pump is mounted on the 10000t ship hull structure. The design values of the shock according to the national military standards are listed in Table 2.

TABLE.2 DESIGN VALUES OF THE SHOCK

Location	Direction of shock	Elastic design		Elasto plastic design	
		A_a	V_a	A_a	V_a
Hull structure	Vertical	$1.0A_0$	$1.0V_0$	$1.0A_0$	$0.5V_0$
	Transverse	$0.4A_0$	$0.4V_0$	$0.4A_0$	$0.2V_0$
	Lonitudinal	$0.2A_0$	$0.2V_0$	$0.2A_0$	$0.2V_0$

A_0 and V_0 are calculated through the formula as follows:

$$A_0 = 196.2\frac{(17.01 + m_a)(5.44 + m_a)}{(2.72 + m_a)^2}$$

$$V_0 = 1.52\frac{5.44 + m_a}{2.72 + m_a} \tag{1}$$

Where A_0 is the acceleration, V0 is speed of the design value, ma is the modal quality, the equipment quality is taken as the list quality spring system.

According to the selected rules of specifications elastic design and elastic-plastic design in the national military standard, the equipment is not allowed to produce permanent deformation or a small permanent deformation after being shocked, and elastic check calculation is chosen instead of elastic-plastic check calculation.

According to the Aa, Va, the smaller between Va,ωn and Aa is taken as the design acceleration of the shock which on the direction of shock of dynamics analysis system in a given shock.

The quality of pumps group is: m=1.129t, and A0=1578m/s^2,V0=2.592m/s according to the formula (1)

The velocities and accelerations shock design value of X, Y, Z direction are shown in Table.3

TABLE.3 DESIGN VALUES OF VELOCITY AND ACCELERATION

Part	Direction of shock	Elastic design				
		A_a	V_a	ω_n	$V_a\omega_n$	D_a
Hull structure	Vertical	1578	2.594	266.2	690.5	690.5
	Transverse	631.2	1.038	164.1	170.3	170.3
	Lonitudinal	315.6	0.5188	139.6	72.42	72.42

D. Shock resistance stress and deformation calculation

The shock design acceleration Da, which determined in Tabel.3, is effected in finite element model of the pumps as the static acceleration for calculating the shock on base, shock stress and deformation on key part.The calculation results are shown in Table.4, the stress in the table is the equivalent stress of Von. Mises's.

TABLE.4 THE CALCULATION RESULTS OF THE SHOCK RESISTANCE

Direction of shock	Base force (KN)	Deformation (mm)	Bracket stress (KN)	Casing stress (KN)	Pump shaft stress (KN)	Impeller stress (KN)	Inlet pipe Stress (KN)
Vertical	691	7.626	662.662	91.839	41.164	104.894	21.806
Transverse	187.3	7.099	202.299	112.594	45.686	78.56	11.228
Lonitudinal	79.8	3.864	72.19	24.3	16.345	20.481	3.882

The pump group's Von.Mises equivalent stress clouds are shown as Fig.9-11,when the shock drive is been in directions of X, Y and Z. the dangerous area of pump is focused on the Bracket parts in Z direction. The dangerous areas and parts of the Von.Mises equivalent stress cloud are shown in Fig.6-4.

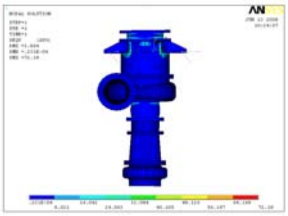

Fig.9 shock value in X

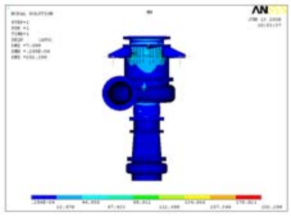

Fig.10 shock value in Y

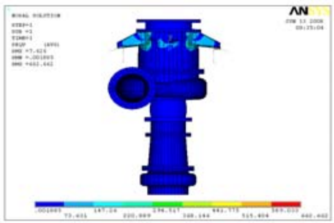

Fig.11 shock value in Z

The shock values in X, Y and Z are shown as Fig.6-1, Fig.6-2 and Fig.6-3. The Maximum shock in X direction is 72.2 MPa, in Y direction is 202.3 Mpa, in Z direction is 662.7 Mpa. The Von. Mises stress cloud is shown as follows after the pumps being shocked in three directions of X, Y and Z:

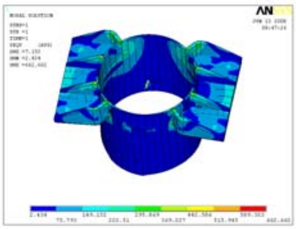

Figure 12 stress on bracket

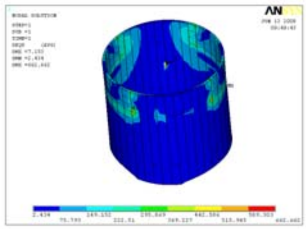

Figure 13 stress on shell

Von. Mises stress cloud of bracket (maximum in the brackets, 662.7 MPa) is shown as Fig.12 when being shocked in Z direction, and Von. Mises stress cloud of bracket shell (maximum in the brackets shell , 662.7 MPa) is shown as Fig.13 when being shocked in Z direction.

E. Allowable stress and shock resistance performance check

The stress should be less than the yield strength of the material if permanent deformation is not allowed according to the elastic design of equipment or the base. This pump is designed as elasticity according to the national military standard requirements, the yield strength of the material is taken as allowable stress, and the yield strength of pump group's material is shown in Table.5

TABLE.5 CALCULATED STRESS AND ALLOWABLE STRESS

Direction of shock	Casing stress (KN)	Pump shaft stress (KN)	Impeller stress (KN)	Inlet pipe Stress (KN)	Bracket stress (KN)
Vertical	91.839	41.164	104.894	21.806	662.662
Transverse	112.594	45.686	78.56	11.228	202.299
Lonitudinal	24.3	16.345	20.481	3.882	72.19
Allowable stress	173	432	173	173	173
Check	Congruent	Congruent	Congruent	Congruent	Disaccord

The calculation of stress and allowable stress are shown in Table5. The shock stress of the pump body, pump shaft, impeller, and inlet pipe in the direction is far less than the yield strength of the material which can be gotten from Table.4-8, which is in line with the shock resistance requirements. However the bracket cannot meet the shock resistance requirements in vertical and horizontals.

The base force and deformation of the isolator is shown in Table.6 from which the vibration isolator is in line with the standard requirements.

TABLE.6 THE BASE FORCE AND DEFORMATION OF THE ISOLATOR

Direction of shock	the base force(kN)	Rated value（kN）
Vertical	172	300
Transverse	46.8	210
Lonitudinal	20	90

V. CONCLUSIONS

Conclusions can be gotten as follows from the analysis of the shock resistance dynamics above:Partitional modeling and conode-connecting method was applied during modeling process and as a result, the stress meets the requirements of shock resistance due to the stress of pump body, shaft, impeller, casing cover and inlet pipe under the shock from all directions much smaller than the yield strength of the material. But the bracket is failure to meet the shock resistance. So it is suggested that the bracket should be produced through casting method and widen the flange on the bracket as well as increase the rib and fillet for reducing stress concentration around the bracket thus to connect the load-carrying parts on both sides of the bracket into a whole body. The load-carrying condition of vibration isolator has met the requirements of national military standard, while it is not possible to check and test its deformation performance for the lack of reference standard.

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