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Cabin noise prediction for ships based on statistical energy analysis

基于统计能量分析的船舶舱室噪声预报

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3 Terms and definitions

Statistical energy analysis is defined as the analysis of energy transfer and balance between the parts of a system, using statistical averaging in time and space and taking energy as the independent variable to solve the medium and high frequency coupling problem between the solid structural vibration and the fluid sound field of a complex system.

A subsystem is a group of modes with similar resonant form. Modal density is the physical quantity describing the capacity of a subsystem to store energy. The damping loss factor is the ratio of the energy lost by a subsystem per unit time within a unit frequency, that is per vibration cycle, to the mean stored energy. The coupling loss factor is the percentage of transmission loss of vibrational energy at the connection of coupled subsystems.

The terms and definitions of GB/T 3947 also apply.

4 Symbols

Table 1 lists the symbols used in the document, each with its parameter name and its unit. The symbols cover the geometry and material properties of the beam, plate, sandwich panel and acoustic cavity subsystems, namely cross-sectional area, second moment of area, elastic modulus, density, thickness, surface density, bending stiffness, Poisson ratio, damping loss factor, panel perimeter and side lengths, rib spacing and total rib length, the thickness of the plate covering material and its properties, the equivalent fluid thickness of the plate, and the volume, surface area, perimeter, sound speed, fluid density and sound absorption coefficient of the cavity.

Table 1 also lists the quantities of the energy balance itself: the energy, input power and modal density of each subsystem, the internal loss factor and the coupling loss factor between two subsystems, the transmission efficiency between subsystems, the radiation efficiency from a plate to a cavity, the ratios of the thicknesses of pairs of plate subsystems, the mechanical impedance of a beam or plate at a common point and its real part, and the effective input mechanical impedance of the seating. The acoustic quantities listed are the sound pressure and sound pressure level of each cabin at each centre frequency, the reference sound pressure of two multiplied by ten to the power minus five pascals in air, the A-weighted cabin noise level, the A-weighting correction at each centre frequency, the sound pressure level and sound power level of the airborne noise of the equipment with a reference sound power of ten to the power minus twelve watts, the foot acceleration level of equipment vibration with a reference acceleration of ten to the power minus six metres per second squared, and its octave and one-third octave forms, together with the vibration isolation reduction from the equipment foot to the seating panel, the sound insulation of a component and of the common face between two cavities, the coincidence frequency of a plate, the frequency and the circular frequency, the surface area of the enveloping surface used for sound pressure measurement, and the distances from the excitation point to the nearest bracket and to the web.

5 General requirements

5.1 The airborne noise level is evaluated with the A-weighting curve, and since the A-weighted level is governed by the medium and high frequency noise, statistical energy analysis may be used as the calculation method for the cabin noise of a ship caused by the hull structural vibration excited by steadily running machinery. The result of the calculation is a statistical average in space and in frequency, and predicts with reasonable accuracy, in the statistical sense, the mean sound pressure level of the whole cabin when no resonance occurs between the structure and the equipment excitation. Using test data for the vibration and noise of the equipment and for the damping, sound insulation and sound absorption coefficient of the structure can raise the accuracy of the prediction.

5.2 The drawings and documents required are chiefly the arrangement drawings, the structural drawings and the electrical load calculation. The arrangement drawings include the general arrangement, the equipment arrangement, the fire insulation arrangement, the deck covering arrangement, the damping arrangement, the outfitting arrangement and the ventilation and air conditioning system arrangement. The structural drawings include every structural drawing of the region modelled, chiefly the basic structural drawing, the typical transverse section, the shell expansion, the superstructure structure, the engine room structure, the after body structure, the double bottom structure and the seating structure.

5.3 A cabin noise calculation model of the whole ship is to be built, covering the region from the noise source to the cabin analysed together with the region to which energy is transferred around it. The model is built chiefly from plate, beam and acoustic cavity subsystems: shell plating, decks and bulkheads and other ship structures are modelled as plate subsystems, pillars as beam subsystems, and accommodation cabins, offices and other ship spaces as acoustic cavity subsystems. Subsystems are to be as large as possible so that the number of modes in the analysis band of a subsystem is greater than 5. Plate subsystems are divided along the real boundaries of the ship structure, effective connection between them being ensured through common points and common edges. The shell plating and the tank bulkheads are divided into two plate subsystems at the waterline, and the subsystems below the waterline are to take account of the added effect of the fluid loading on the structure as clause 6 requires. Acoustic cavity subsystems generally follow the cabin arrangement of the ship and are effectively connected to the plate subsystems that bound them through common faces; large engine rooms, casings and stairways spanning several decks may be divided into several cavities bounded by the decks, and open regions are modelled by semi-infinite cavity subsystems. Doors and windows are treated as normally closed and may be replaced in the model by the plate subsystem of the ship structure, but the sound insulation computed for a composite component as 8.2.7 requires is to be assigned to that plate subsystem. Tables, chairs, berths and equipment inside a cabin need not be modelled, but their sound absorption coefficient is to be included in that acoustic cavity as 8.2.9 requires.

6 Calculation flow for cabin noise

6.1 and 6.2 The calculation flow is shown in Figure 1. Before modelling, the sailing condition or the specified calculation condition, the equipment that is running, the cabins to be checked and the noise control limits are to be settled from the technical specification.

6.3 and 6.4 From the arrangement and structural drawings required by 5.2, the noise source equipment, the insulation material, the deck covering, the composite rock wool panels and the damping material are to be established, together with the form, material and dimensions of the ship structure. From 8.1 and 7.2, the parameters to be supplied by the makers of the noise source equipment and of the outfitting material are to be listed, namely the foot acceleration level, the radiated sound power level and the isolation of the vibration isolators, and the elastic modulus, density, internal loss factor, sound insulation and sound absorption coefficient of the outfitting material; the design company and the yard pass the request to the suppliers.

6.5 and 6.6 The geometric mesh is built from the drawings or from the model supplied by the yard. Pre-processing software may be used to clean the geometry, delete or simplify secondary structures, divide plate subsystems by separating lines so that each face represents one plate subsystem, patch openings with faces, check the free edges of the model in wireframe view, cut cabins of irregular shape or excessive volume such as the engine room with faces, and output the geometric mesh file. In the statistical energy analysis software, octave analysis from 63 Hz to 8 000 Hz is set; the geometric mesh is imported with the correct system of units; the faces of the mesh are identified automatically and plate subsystems built, meshes for which the subsystem could not be generated being checked and patched by hand; cavities are created automatically from the closed plate subsystems that form a cabin, and cavities for open regions created by hand.

6.7 to 6.9 The input power is applied from the vibration and noise parameters as 8.1 requires: vibration data are converted into input power from the foot acceleration level, the isolation and the seating impedance; airborne noise data are to be radiated sound power levels, otherwise they are converted from the sound pressure level and the area of the measurement envelope. The properties of the beam, plate and cavity subsystems are set as 8.2 requires from the drawings and the material parameters, the subsystems being first grouped by drawing and material so that properties can be set and changed conveniently; the two faces of a plate subsystem are to be strictly distinguished so that the outfitting material and the fluid loading are set as they really are. The noise source equipment is then allocated to the several calculation conditions according to which equipment runs in each.

6.10 to 6.12 The cabin noise is computed with the statistical energy analysis software. If the calculation fails, the model is to be checked again; otherwise the A-weighted level of the accommodation and working cabins is extracted and compared with the cabin noise limits, a margin being kept according to the validity of the input parameters. If the result meets the requirement the calculation ends and the analysis report is written; otherwise the cabin arrangement is changed or vibration and noise reduction measures are drawn up following JT/T 781, and the calculation is repeated. The content of the report is given in Annex A and generally includes the basic information and principal dimensions of the ship, the cabin noise limits, the information on the main noise source equipment, the vibration and noise parameters and how they were obtained, the material property parameters and how they were obtained, the calculation method, the model and the modelling method, the results and their analysis, and the noise reduction measures.