A METHOD FOR SHIPS UNDERWATER RADIATED NOISE ASSESSMENT AND CONTROL

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INTRODUCTION

The subject of the underwater radiated noise by ships has been, in the past, studied and developed with particular attention to the silencing of warships and submarines; for military applications, in fact, quietness is one of the most important aspect to deal with in order to improve and maintain stealthness. A low underwater radiated noise can allow to remain undetected while accomplishing an operative mission, and can represent the most effective countermeasure against enemy detection with passive equipment; the military threat strongly depends on the acoustic performance and all the technical data related to the underwater noise in military application are not at disposal in the open literature. The lack of published data on the subject, as well as the few technical paper on the underwater ship noise, made difficult a previous diffusely application in merchant ships of the underwater noise control techniques, which have the added advantage of being also particularly efficiency in reducing the inside ambient noise.

Recently a growing interest has been shown in the underwater radiated noise also for civilian ships like, oceanographic and fisheries research ships as well as merchant ships sailing in special sea protected environments.

The always more demanding performance required to the acoustic equipments installed on board of oceanographic and research vessels, make necessary to guarantee a very low noise emitted in water by the ship itself; radiated noise, in fact, can affect the ship performance causing a listening degradation of the own sensors. Similar aspects are today considered also for the most advanced fisheries research ships and for ship sailing in special sea protected areas, on the basis of the research centre studies on the fish reaction to noise; for fishery ships and for the sea protected areas the reduction of the ship emitted noise has the objective to reduce, as far as possible, any fish disturbance in their natural habitat.

The studies performed and the experience acquired for the naval constructions, in the field of the underwater noise reduction and control, represent now an important aid for the underwater noise policy in merchant ships; the noise reduction procedures can, in fact, be transferred, adapted and utilised to any kind of ship having particular requirements, in general expressed in terms of maximum emitted noise versus frequency, on the underwater noise.

2. UNDERWATER RADIATED NOISE SOURCES

Usually the radiated noise contributions can be divided in three classes: propeller, hydrodynamic and machinery noise. Propeller are simple-looking devices but are extremely complex to design when a good performance also in term of noise is requested. Propeller noise is originated directly in water, making difficult every noise control measure different from a good initial design; excluding cavitation noise, only the blade frequency shows a tone that can be lowered with an optimised blade shape.

Hydrodynamic noise originates in the irregular flow around the hull; in particular the flow noise, due to the turbulent flow over a body, can give an important listening degradation on the own ship sensors. The decay of the hydrodynamic noise is very quick when the distance from the body increase, and the disturbance in far field is reduced; as for the propeller noise, the best ,most effective noise control measure is a good initial hydrodynamic optimisation.

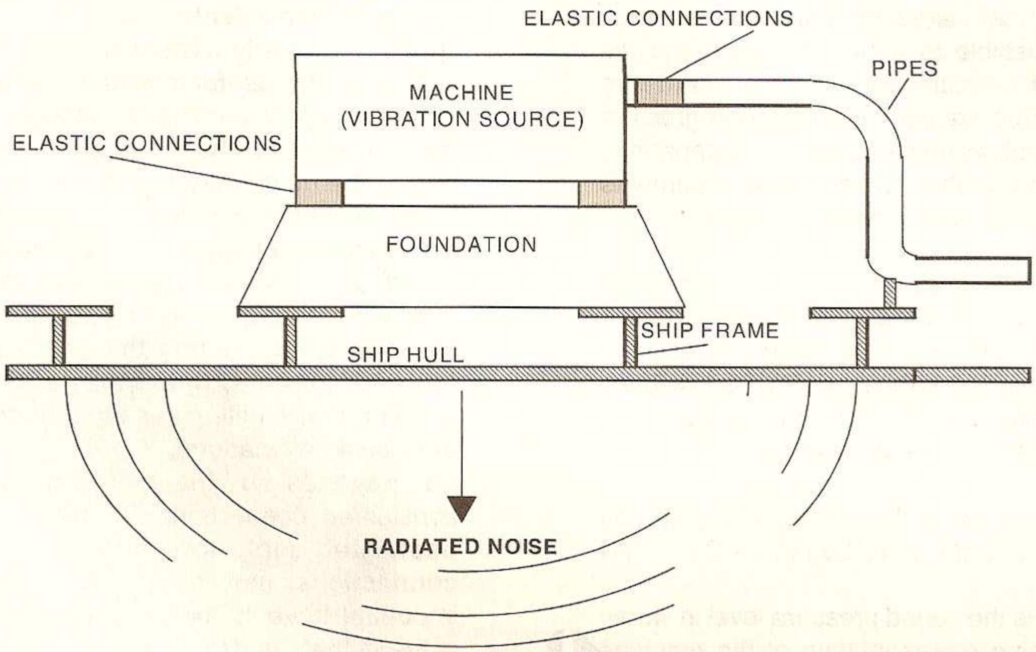

Fig. 1

Referring to machinery noise, due to the noise and vibration levels of the machines on board, besides a control on the noise source level, it is possible a proper study and application of acoustic treatments on all the internal propagation paths in order to reach the objective noise levels. Figure 1 is a schematic representation of the machinery radiated noise for a typical on board installation.

The machinery vibration represent generally the most important contribution to the underwater noise, and requires then a great attention in all the aspects that can affect the underwater noise; besides, while for the airborne noise contribution to the radiated noise only few parameters are involved and quite well theoretically manageable, for the vibration contribution the complexity of the problem make necessary a more detailed approach.

3. PREDICTION METHOD

Besides the traditional rules for a good acoustic design and construction [1], and the noise control techniques, a prediction method for the underwater radiated noise is useful to identify if the objective levels can be meet, and/or to define the necessary noise treatments on the different sources and propagation paths in order to obtain the requested noise levels.

Theoretical evaluations about the underwater radiated noise, for quite simple case study, can be found in the literature [2] [3]. However it is necessary to point out the differences between the results of the existing theoretical models, and the real applications; the complexity of the on board installations and structures can be difficulty evaluated with purely theoretical model.

The developed predictive method is then based on a theoretical model in which the parameters can be theoretically assumed and/or experimentally determined; the amount of input data at disposal for the calculations, and then the accuracy of the predictions, varies from the phase of the project definition to the construction and up to the sea acceptance tests. Being necessary to apply the prediction method already in the preliminary ship design, when only a few generic data are available, it is important the possibility to apply the calculation procedure with only the parameters more important in the radiated noise contribution; the same method can also be applied during the vessel construction when the parameters involved become always more defined due to the selection of the equipment and to on board experimental measurements. Is then possible to continuously update the calculation's accuracy every time new, more accurate data are acquired in the progress of the construction, and if necessary to apply little modification to the defined noise treatments before the ship sea acceptance tests.

From an analytical point of view, the study of the vibration contribution to the underwater radiated noise can be found in [4] [5], and (referring to the model in Fig.1) it leads to a formulation that can be represented in a very simplified matter as follows:

$$Lp = La + 20*Log(K) + 20*Log(T) + 20*Log(P/F) + 10*Log(n) - 40*Log(f) + C \qquad (1)$$

where: Lp is the sound pressure level in water, La is a value representative of the machine vibration acceleration level, K is the considered connection stiffness, T is the foundation force transmissibility, P/F is the hull transfer function between the force arriving on the hull and the pressure in water, n is the number of the identical elastic connections considered, f is the frequency and C is a constant value that depends on the utilised reference dB values.

Considering the above formula it is interesting to note that:

1) All the parameters, except n, are in general frequency dependent.
2) Lp results linearly depending from La; to reduce Lp it is useful to install, and utilise during the silent conditions, machines with low La; due to the possible changes during the machinery life of the vibration levels, a continuos monitoring system can be usefully applicable on board. While in the design phase, hypothesis can be made on the machinery/equipments vibration levels, during the construction and the ship life, data can be directly measured and utilised as input to update the noise calculations.
3) Lp depends on the stiffness of the considered connections. To reduce Lp it useful to apply low stiffness elastic connections; moreover, it is also very important to verify the dynamic behaviour of the stiffness and to consider it in the noise calculations, due to the fact that it can produce a relevant increase in the transmitted noise at the medium-high frequencies. Fig. 2, taken from a commercial catalogue, shows, as example, the term 20*log(K) for an elastic mount. Different elastic connection, with similar static stiffness and resonant frequency, can show strong differences at higher frequencies, making necessary a proper selection of the connection itself in the design phase.

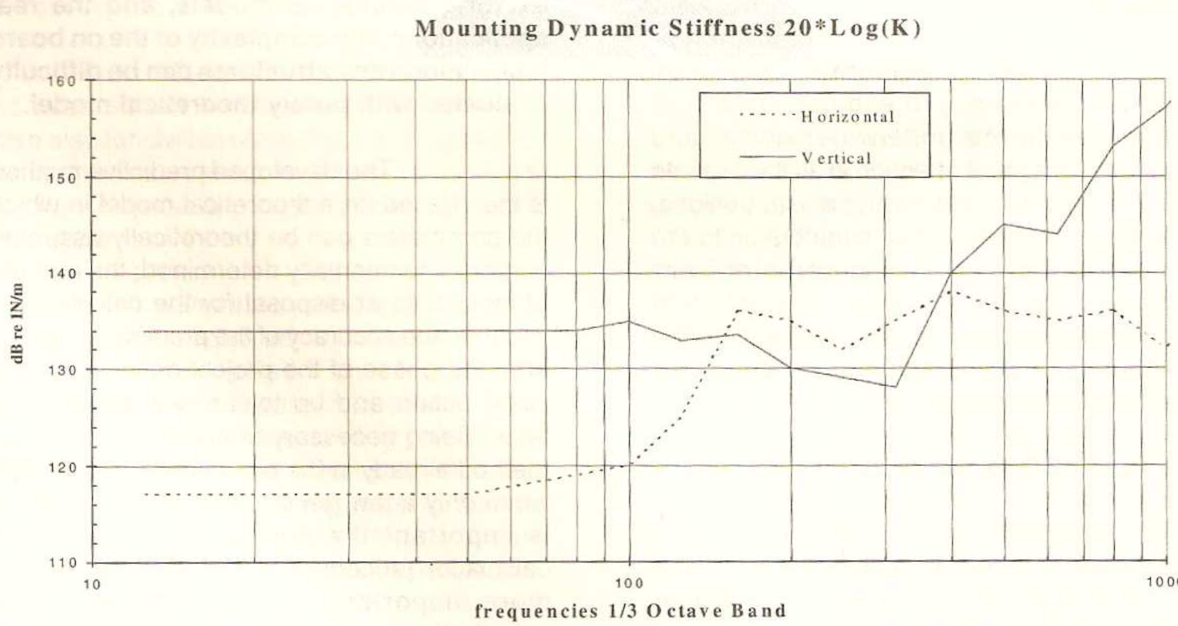

Fig 2

4) Lp depends on the force transmissibility of the foundation; to reduce T (and Lp) it is convenient to make foundations as stiff as possible; proper calculations with finite elements methods can be performed, during the design phase, in order to check the compliance of the structure stiffness with the minimum requirements. After, dynamic stiffness measurement can be performed directly on board. Fig. 3 shows an example of foundation schematisation, and Fig. 4 shows a foundation stiffness calculation.

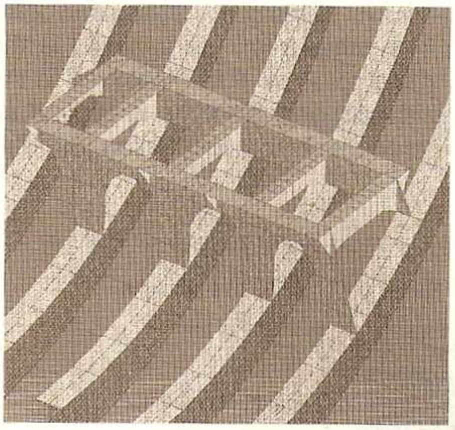

Fig. 3

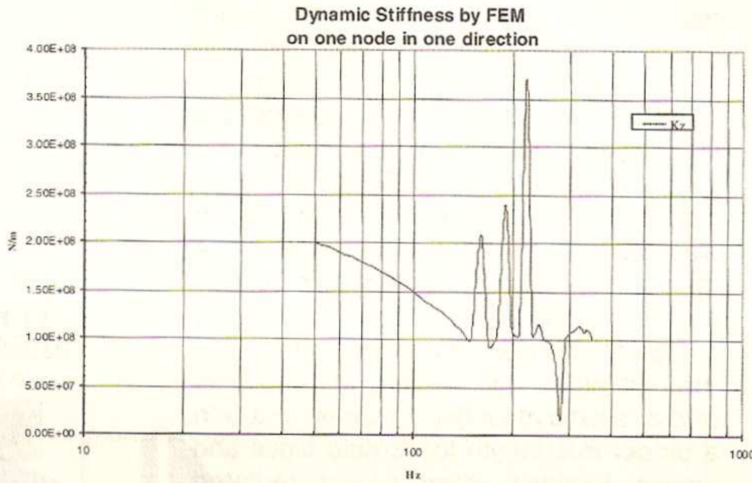

Fig. 4

5) Lp depends on the hull transfer function between the force acting on the hull and the pressure in water; generally it is difficult to modify this function that depends on the hull structure. Instead, it is possible to apply external treatments on the hull (like decoupling coatings), in order to reduce the radiated pressure. Also this function can be theoretically assumed or experimentally determined. Fig. 5 shows an example of P/F measurement compared with the calculated values.

6) Lp depends on the number of the elastic connections; it is better to reduce the number of the elastic connections.

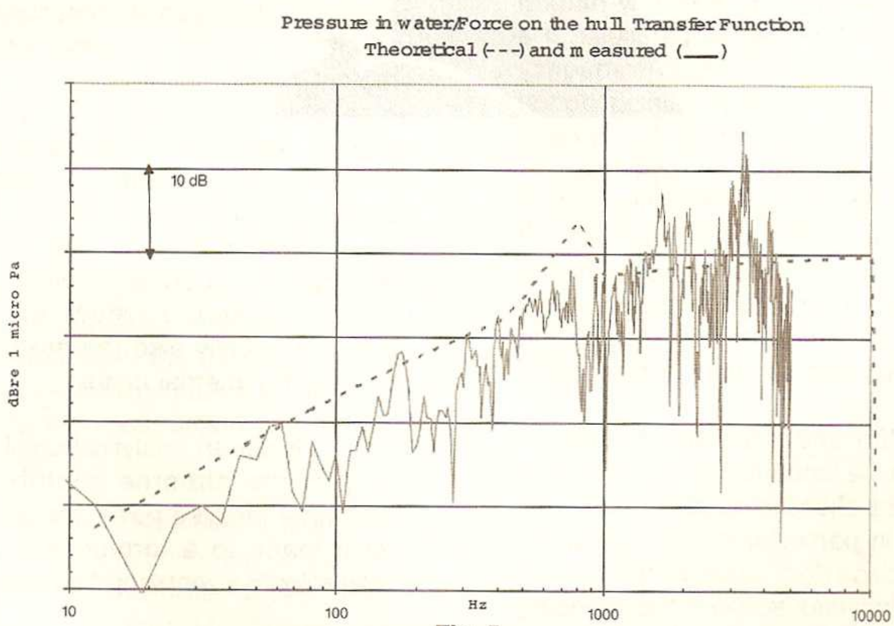

Fig. 5

If the considered connections are the elastic mounts, considering the relation $K=4p^2f_n^2(M/n)$ between the mount stiffness K, its natural frequency f_n and the machinery weight M, the above mentioned formula becomes:

$Lp = La + 20*Log(M) + 20*Log(T) + 20*Log(P/F) - 10*Log(n) + 40*Log(f_n) + 40*Log(f) + C'$
(2)

and it can be noted that:

7) Lp depends on the machine weight. To reduce Lp is useful to utilise low weight machines; in particular, if a machinery with double weight respect to another is used, maintaining the other parameters unmodified, 6 dB more in the radiated noise can be expected. Especially for the lower machines, the contribution through the elastic mounts can become lower than these through the other connections (like bellows and flexible pipes). It is then necessary to pay great attention also to the propagation through pipes and cables, utilising also proper elastic mounting systems, and with a proper free length for flexible pipes and cables. Besides, when a lower radiated noise is to be obtained switching off as much machines as possible, the greatest improvement can usually be reached if the more weighting machines are switched off; not great noise reduction can usually be achieved if low weight machines are switched off.
8) Lp depends strongly on the natural frequency of the mounts; to reduce Lp is useful to utilise mounts with low natural frequency (soft mounts). In particular, if a mounting with double natural frequency respect to another is used, maintaining the other parameters unmodified, 12 dB more in the radiated noise can be expected.
9) Even if Lp seems to be a few reduced by a higher number (with lower stiffness) of elastic mounts, in order to simplify the mounting and to reduce the maintenance costs it is always better to reduce the number of the mounts to the minimum value.

Small differences in the theoretical procedure can be applied for the vibration contribution to the airborne noise in the internal ship's spaces; in particular it is necessary to add the propagation losses along the structures, taking into account the damping treatments that can be applied to reduce the vibration propagation, and the receiving room characteristics. The effect of the propagation and of the damping treatments must be considered also for the machines radiation in water, especially if the mounting is not directly on the pressure hull (but for example on decks).

The above mentioned formulas (1) or (2) can, instead, be used directly when, during the construction, the transfer function P/F is experimentally measured; in fact, the propagation losses as well as the receiving room characteristics (in terms of absorption and noise radiation from structures), are included in the term P/F if the pressure P is measured in the interesting space, and the force is applied on the considered machinery foundation (Fig. 6).

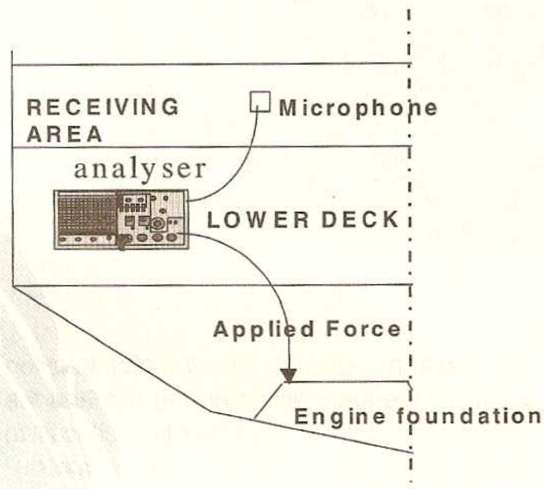

Fig. 6

It can be noted, than, that the close connection, between the measures needed to reduce the underwater noise and the internal ambient noise, assures that a low radiated noise objective levels will guarantee, in general, also a low internal ambient noise. On the contrary, treatments applied on the structures for only the reduction of the inside ambient noise can be ineffective on the reducing the underwater noise; besides, the techniques used to reduce the underwater noise are usually also the most efficiency in reducing the internal noise.

From an analytical point of view, the study of the airborne contribution to the underwater radiated noise can be found in [5], and it leads to a formulation that can be represented in a very simplified matter as follows:

$Lp = Lw - TL - R = Lw - 10*Log[30 + (M*f/2.4*10^5)] - R + C''$

where: Lp is the sound pressure level in water, Lw is the internal source sound power level, TL is the hull transmission loss, R is the attenuation due to the added acoustic treatments, M is the hull surface density, f the frequency and C" is a constant value that depends on the utilised reference dB values.

Considering the above formula it is interesting to note that:

10) Lp results linearly depending from Lw; to reduce Lp it is useful to install, and utilise during the silent conditions, machines with low Lw.
11) The transmission loss TL increase with the frequency only for high values of the product M*f (Fig.7).

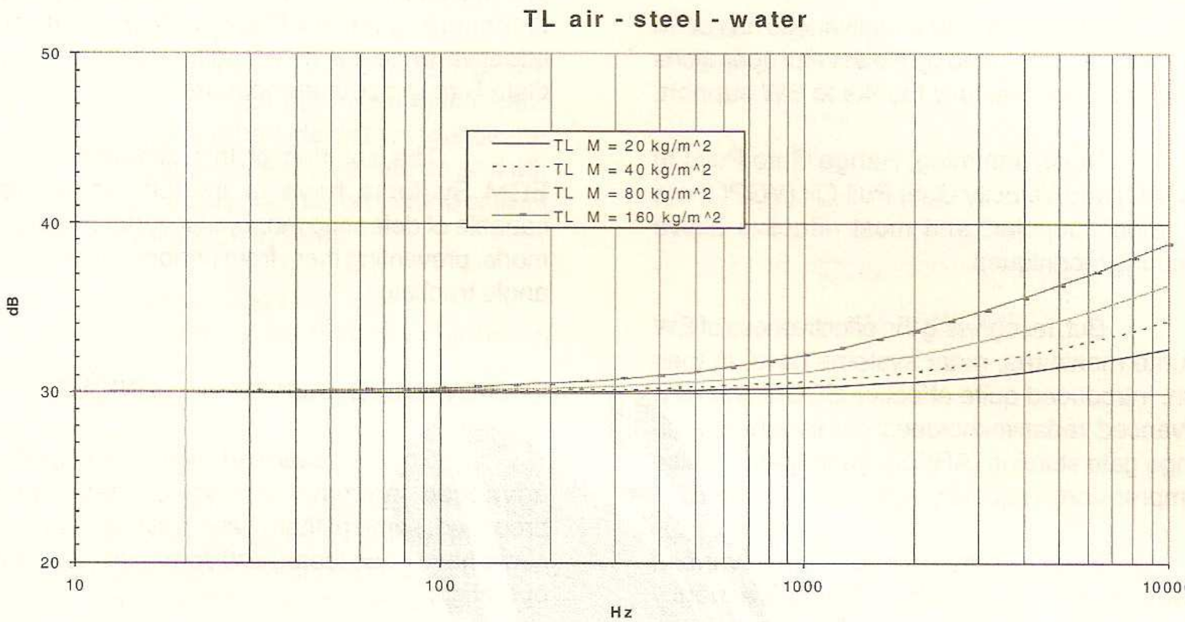

Fig. 7

CONCLUSIONS

A prediction method for the underwater radiated noise is useful to identify if the objective levels can be meet, and/or to define the necessary noise treatments to obtain the requested levels.

The predictive method presented is based on theoretical model in which the parameters can be experimentally determined; the amount of data at disposal for the calculations, and then the accuracy of the predictions, varies from the phase of the project definition up to the construction and the sea acceptance tests.

Particularly important is the close connection between the control of underwater radiated noise and the noise levels in the internal spaces of the ship; in fact the measures needed to reduce the underwater noise assure, in general, also a low internal ambient noise.

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