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SOURCE LOCATION IN MARINE GEARBOXES AS A MEANS TO VIBRATION REDUCTION IN NEW DESIGNS

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Introduction

A common problem in ship machinery is the existence of strong tonal content in the machine vibration and consequent airborne noise spectra. These tones represent a major source of annoyance, even if they can be tolerated in terms of safe machine operation. Tones at tooth contact frequency tend to feature strongly in measured spectra associated with gearbox operation. Considerable work has been done to try to reduce the tonal content by attention to factors such as manufacturing tolerances and optimal profiling of gears. However, the manufacturing problems are extraordinarily difficult, not least because of the sheer size of the gearwheels in the propulsion gearbox for a large ship. Even though new machine tool technology might provide the capability to reduce tolerances, while theoretical developments provide deeper insight into the significant source parameters, consistent reductions in source strength are not easy to achieve.

Optimisation of Structural Properties

A complementary approach is to optimise the structural design of the gearbox so that acoustic power which is transmitted to the environment is reduced to an acceptably small value. However, a very real difficulty in making correct design decisions has been lack of understanding of the way in which forces and acoustic power are transmitted to the gearcase structure via the various pinion and wheel bearings. If we could establish how large these forces and power inputs are in existing machines, and how they are distributed in space, it should be possible to establish how we might distribute mass, stiffness and damping in the gearbox structure to give the best overall acoustic performance with a given layout.

General Properties of Gearbox Vibration

The physical size of a propulsion gearbox, and the relatively high frequency (typically a few hundred Hz upwards) of tooth contact, mean that simple classical methods for dynamic analysis tend to be inappropriate. Commonly, the ratio of half power bandwidth of resonances to spacing of resonances is of the order of unity at frequencies of interest and the gearbox structure will have passed through several tens of resonances before tooth contact frequency is reached. In these circumstances, the observed vibration due to a point force is the result, not of resonance of a single mode, but of simultaneous excitation of a large number of modes. Also, there are likely to be several bearings which transmit significant forces to the gearcase at a given tooth contact frequency. Statistical methods for analysis of structural behaviour are of obvious relevance, but there is another important implication of this type of behaviour which can be exploited for source location.

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At a fixed tooth contact frequency and operating condition, the fluctuating forces applied to the gearcase have a fixed phase relationship, so that we are dealing with the problem of a spatial distribution of force and power inputs with unity coherence. However, we can still hope to estimate the spatial distribution of forces, if the number of forces to be determined is smaller than the number of spatial degrees of freedom, or number of modes excited, in the structural response. In principle, all we have to do is determine the Green's functions for all possible positions and frequencies of force excitation and then to deduce the combination of forces which could account for structural response (Reference 1).
In practice, we can measure the vibration pattern which arises on the gearbox structure at a given frequency, including the coherence and relative phase of vibration at different positions. It is usually possible to apply forces to the outside of a gearbox structure, or to the ship structure itself, using various types of shaker, with or without the gearbox in operation. Vibration transducers might be fitted to the bearings of a gearbox, for in-service monitoring, but it is usually unreasonable to expect that any part of a gearbox can be dismantled to allow shaker trials.

Estimation of Green's Functions for the Gearbox

If reciprocity is assumed, the Green's functions for forces applied at bearings can be deduced by applying shaker forces to accessible external structure and by measuring induced response at the bearing locations. However, we can only expect to deduce the Green's functions for forces applied at bearing locations in the presence of the gears and shafts. The Green's function for a force applied to a bearing in the presence of the shafts will only be equal to that for a force transmitted across the oil film if the bearing impedances are high in relation to those of the shaft or oil film (Reference 1). Fortunately, forces transmitted to bearings for relatively light pinions are likely to be more important than those transmitted via the bearings for heavy wheels. Thus, the case where the bearing impedance is at least as high as the shaft journal impedance is relevant to gearbox source location, even though it is not possible to assume that the oil film impedances are small at tooth contact frequencies.

Effect of Operating Condition on Green's Functions

One of the most basic questions we have to answer, is whether the Green's functions for excitation of bearings in the presence of shafts are independent of operating conditions. Clearly, it is much easier to measure structural properties in conditions of low background noise than it is to determine properties when the gearbox is transmitting thousands of horse power. Some experiments to test the assumption of invariance of Green's functions at a given frequency with gearbox operation, have been undertaken. These suggest that measurements with the shaft stopped are adequate if broad features of structural response, such as modal density, are required. However, measurements with the gearbox running are necessary if detailed transfer function magnitude and phase measurements are required at a specific frequency. Typically, variations with speed and torque are sufficiently weak that only approximate equality of tooth contact and shaker frequencies is necessary. This allows electrodynamic shakers of modest size to be used in conjunction with coherent processing in order to extract the required Green's functions from the machine vibration.

Estimation of Forces and Power Inputs Due to Gearbox Operation

Once the set of Green's functions appropriate to possible positions of force transmission in the running gearbox have been deduced, data on the machine induced vibration at tooth contact frequency can be used to derive an "equivalent" force distribution for each frequency. This distribution provides the best approximation to the observed vibration pattern under given operating conditions. Established regression techniques can be used to estimate that distribution. Measurements of vibration at the points of assumed force input, at tooth contact frequency,can then be used to estimate the acoustic power inputs of the various bearings. These are the essential source characteristics, which can be used to build a complete acoustical model of a gearbox and of the interactions with its environment.

Reference

1. R. KINNS 1979 Proceedings of Euromech Colloquium 122, Paris, September 3-5. The deduction of bearing forces in rotating machinery.