5aEA9. Acoustic analysis of turbine generator to predict overall noise using statistical energy analysis methodology

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In the growing regions across the globe, products are being differentiated not only by their performance but also on characteristics like noise, aesthetics, ergonomics, etc. Noise norms are getting more and more stringent and customers are looking for quieter products. Engineers and technicians now face the challenge of developing effective products for lower noise emissions in addition to enhanced performance. As generators are a major noise source in a power plant, it is essential to contain generator noise well within the limit to meet statutory requirements. The major contributors to generator noise include cooling fan, rotor jet, electromagnetic excitation and vibrations. These sources should be configured properly for reducing the overall noise. Therefore, it is essential to establish a robust process to predict the generator noise accurately. This paper describes the process for predicting generator noise by using Statistical Energy Analysis methodology. Correlation of the predictions with test data is also discussed.

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INTRODUCTION

In today’s competitive environment, technologists face the challenge of developing quieter machines due to more stringent noise regulations. It is important to identify the components making the noise and quantify their impact on overall noise in the development stage itself. A reliable prediction of noise is the first step towards the objective of engineering components for reduced noise. Various computational techniques like Finite Element Analysis (FEA), Boundary Element Method (BEM), and Statistical Energy Analysis (SEA) are available for acoustic predictions. A comparison of these techniques is discussed in the next section.

COMPARISON OF COMPUTATIONAL TECHNIQUES

Figure-1 depicts the frequency range covered by the existing analysis techniques. FEA deals effectively with the problem when a distinct mode (single mode) of the structure exists and such situations are possible only in the low frequency region. At higher frequency, where the number of modes increases, FEA would become complex and time consuming due to the increase in number of elements needed to capture the lowest wavelength [1]. In such situations, BEM can be a good alternative. This technique requires only boundaries to be meshed, thus removing the cumbersome exercise of meshing a 3D object. BEM solves a very populated, nonsymmetrical matrix, which generally takes much longer than symmetric matrix for a given dimension. Hence, even with boundary meshing, there is a constraint on number of elements. With BEM it is possible to extend the analysis capability beyond FEA, but it is still not feasible to do a high frequency analysis [1]. SEA can be a good option in such cases.

![FIGURE-1: Transition from FEA to SEA (Source: Presentation by Vibro-Acoustic Sciences, Inc)](image)

SEA is a method of analyzing the flow of dynamic energy in a system, based on the statistical coupling of the dynamic modes of response of the system. This method involves the following three steps:

1. Determine the statistics of the dynamic response of systems. (Mean value and variance)
2. Make the dynamic energy flow as the primary response variable. (Vibration and sound levels are derived)

3. Estimate the vibration, sound power level and energy transfer path for current machines.

SEA works on the principle of gross average responses. At higher frequencies the modes are distributed statistically and the responses can be represented by a single averaged value which makes SEA suitable. SEA works with the energy flow concept, and energy loss occurs via structural damping and coupling loss. It gives reasonably good results quickly at medium and high frequency, making it a better choice over FEA or BEM [1]. VaOne is commercially available software based on SEA and has been used in the current study.

**GENERATOR MODELING USING VAONE**

A typical power plant generator is shown in Figure-2. A generator is a large structure consisting of a stator, a rotor, windings, cooling fans, and cooling pipes. These components are housed in a complex steel frame, but only a few contribute significantly to noise transmission. Therefore, it is important to identify and model these critical parts correctly, so that all paths of energy transfer are accurately defined. Simplification of geometries is necessary to build a workable SEA model, with assumptions made for defining the connection types. Figure-3 shows the SEA model of a generator with important noise transmission paths built into it.

![Figure-2: A typical Generator (Source: http://inside-pg.energy.ge.com/home/)](image-url)
FIGURE-3: Generator model in VaOne (Source: GE internal report)

The paragraphs below explain the details of the various generator components shown in Figure 3.

**Modeling of Mechanical Components**

Side wrappers of a generator are made of a single steel plate and are joined by multiple steel section plates. These section plates have a central circular hole to support the stator core, creating junctions at multiple locations. Such junctions are important for noise transmission and should be modeled correctly.

The rotor is supported on bearings. However, these bearing junctions are not considered in the current study, as they are not the major noise sources. Hence, the rotor is modeled as a solid steel cylinder.

**Modeling of Acoustic Cavity and Acoustic Ducts**

VaOne requires a medium through which sound can pass. This medium in VaOne is called an acoustic cavity [2]. In the current study, the medium is air so we call it air cavity. This is a major subsystem to model in VaOne. Acoustic cavities are volume-modeling subsystems used to predict sound pressure levels in a VaOne model. An acoustic cavity consists of a set of at least two faces that encloses a volume of acoustic fluid. Acoustic cavity faces are defined by closed "loops" of node points or by faces of other subsystems in the 3D window. An acoustic cavity should not be open and should not have any free edges. An acoustic cavity is connected to the other subsystems via area junctions [2].

**DEFINITION OF OTHER PARAMETERS IN VAONE**

In addition to the above modeling features, several other parameters should be defined for solving the model.

**Auto Junctions and Manual Junctions**

Junctions are the physical connections between subsystems and are a significant factor in SEA. VaOne features a sophisticated mechanism for determining junctions between subsystems, which have been created from the same geometric node points or the same geometric face [2]. This feature of VaOne, called auto
junction, gives a point, line or an area junction as per the type of contact that exists. VaOne itself evaluates the property of the junctions, taking into consideration the flexibility and other structural properties of the subsystem. The model can have some regions where junctions are required to be established. For such instances the option of manual junction can be used. This feature helps the user to define the damping loss or coupling loss properties on his own.

**Damping Loss Factor**

The value of the damping loss factor $\eta$ is an important SEA parameter. Over- or underestimation of this frequency-dependent property can have significant effect on the predicted vibro-acoustic response of subsystems at these frequencies. The damping property of a built-up structure tends to remain constant up to a frequency range of 1 to 2 kHz, and then decreases at some monotonic rate at increasing frequencies [3]. Typical damping loss factors for various configurations are included in VaOne and can be used to specify the loss factors for various joints in the model.

**Significant Noise Sources**

A generator has many different noise sources associated with it. Predominant among them are listed below

1. Fans, located on either end of the generator, are the primary noise sources in generators. The measured noise spectrum of these fans is given as an input in VaOne.
2. A rotation of a series of cooling jets generate the dynamic pressure signal that is two and four times the rotor running speed, causing a secondary source of noise, called rotor jet noise.
3. The harmonic rotation of the electromagnetic field at the operating frequency gives rise to another source of noise in the form of vibrations. These vibrations act as tertiary source of noise in a generator.

**Microphone Location**

During the factory test of a generator, noise measurements are done at a distance of ~1 metre from the generator surface and ~1.5 metres above the ground. In VaOne, this is defined as a semi-infinite fluid. It is an exterior acoustic radiation device used to predict the sound pressure level radiated from a number of plates or shells.

**RESULTS AND DISCUSSION**

The analysis results show a good match of the predicted detailed noise spectrum compared to the test data. Many of the trends and peaks, as well as the overall shape of the curve, are captured in the analysis. A comparison of the prediction with test data is shown in Figure-4. Examination of the curves shows that the fan blade passing frequency (the main noise peak) is correctly predicted, though somewhat higher in sound level.
The SEA prediction does not match the test results at the higher frequencies, in fact the data can be seen to be under-predicted. This indicates a requirement for better understanding of the damping loss factor (DLF) and transmission loss values, which are difficult to ascertain for a structure as complex as a generator frame. In the lower frequencies, the SEA prediction follows the test data reasonably well. However, the first two prediction points seen in Figure 4 do not match with the test data, mainly due to the fact that at lower frequency, the number of modes in the band are less and the statistical energy analysis is no more valid in that zone.

CONCLUSIONS

A process for acoustic analysis of Generators using SEA has been established using VaOne. The predictions match reasonably well with the test data. Efforts need to be focused toward the improvement of predictions at higher frequency.

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