

# Flow-Induced Vibrations of Pressure/Temperature Sensors

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**Flow-induced vibrations of sensors are traditionally predicted through use of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code Section III Appendix N-1300. For an Euler–Bernoulli beam, this code provides engineers with a dynamic response prediction for a given sensor–fluid environment. Engineers can use this information to estimate fatigue life of a particular probe design. However, this tool provides no estimation of shear stresses experienced by the sensor under fluid–structure interaction and can give very conservative results in some cases. Because shear stresses are significant, especially for a low aspect ratio, minimally intrusive sensors or those which vibrate with very high frequencies, shear stresses must be included in the response prediction method. This can be achieved by moving away from Euler–Bernoulli to Timoshenko beam models. Upon making this step, American Society of Mechanical Engineers guidelines must be modified to allow inclusion of shear stresses. A modification to the code is presented which includes not only shear stresses experienced by the sensor, but also the mean response. The use of elliptical sections in preference to circular sections is also explored.**

## Nomenclature

$A$	=	area of cross section, $m^2$
$A_L$	=	lift amplification factor
$C_D$	=	mean drag coefficient
$C'_D$	=	fluctuating drag coefficient
$C'_L$	=	fluctuating lift coefficient
$C_n$	=	reduced damping coefficient
$C_R$	=	turbulent forcing coefficient
$E$	=	modulus of elasticity, Pa
$f_s$	=	vortex shedding frequency, Hz
$G$	=	shear modulus, Pa
$G_f$	=	single-sided power spectral density, $(N/m)^2/Hz$
$I$	=	moment of inertia, $m^4$
$J_{nn}$	=	joint acceptance
$L_e$	=	correlation length, m
$M_n$	=	generalized mass
$m_t$	=	total mass per unit length, kg/m
$S_t$	=	Strouhal number
$S_y$	=	joint acceptance
$y_n$	=	displacement amplitude of $n$ th mode, m
$\alpha$	=	slope due to bending
$\beta$	=	slope due to shear deformation
$\xi_n$	=	modal damping coefficient
$\rho$	=	density, $kg/m^3$
$\Phi$	=	normalized power spectral density
$\phi_n$	=	$n$ th mode shape
$\omega_n$	=	natural frequency of vibration, $rad^{-1}$

## I. Introduction

**F**LUID structure interactions, in particular, the vibration of a circular cylinder in a fluid flow, have been investigated for more than a century [1]. In recent times, attempts have been made to introduce design guidelines for engineers, most notably in the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (N-1300) [2]. The subject gained particular attention as a result of a sodium leakage incident at a fast breeder reactor, Monju in 1995, caused by high cycle fatigue of a thermometer well subject to flow-induced vibration. Many studies followed [3–6], primarily in Japan, to attempt to improve and validate the analysis methods cited in ASME N-1300. The analysis method presented by ASME requires knowledge of the structural natural frequencies and mode shapes. These natural frequencies and mode shapes are primarily generated using exact solutions of Euler–Bernoulli (EB) beam theory. As is well known, this theory neglects both the shearing of a beam’s cross section and the contribution of rotatory inertia. The ASME code applies only to beams for which the length is significantly greater than its depth, usually a 10:1 ratio. Existing sensor designs tend to satisfy this requirement such that Euler–Bernoulli beam theory can be used in the generation of response prediction data with the ASME codes. However, such sensors as studied previously [3–6] have the disadvantage that they are somewhat slender which is not an ideal characteristic when considering fatigue life. Fatigue failure is undesirable as more often than not the broken sensor can contribute to significant foreign object damage, which can lead to significant environmental issues such as that experienced at Monju. The problem has been experienced extensively in cryogenic applications where foreign object damage leads to rocket failure. With these considerations in mind it is advantageous to design a sensor that is minimally intrusive to an internal flow for which the fatigue life is extended while maintaining adequate measurement characteristics. ASME also neglects the startup and shutdown effects through their selection of turbulence model. Although the complete study is beyond the scope of one paper, the first step is the improvement of the analysis tools to deal with less slender, lower aspect ratio sensors in addition to sensors with a noncircular cross section. Shortening the sensor means that shear and rotatory inertia effects now become very important and results generated via integration of the EB theory with ASME guidelines [2] are less reliable for predictions. The mechanism through which the analysis can be improved is through use of the Timoshenko beam theory which is implemented through an energy methods approach. Using this modification, the response prediction can be decomposed into bending and shear stress contributions and

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