4 Structure-borne sound

4.1 Introduction

Vibrations and waves in solid structures, like, for example, vibrations in plates and beams, walls, ships and buildings, etc., are summarized by the term ‘structure-borne sound’. Structure-borne sound has major importance with respect to solving noise control problems: the air-borne sound into (or from) the aforementioned solid structures is caused by motion in the structure’s surface. In many cases it is the structure-borne sound that is responsible for the resulting sound in air (or sound in liquids). Even the transmission through walls, ceilings and windows, etc. is essentially a structural problem.

A vital and fundamental difference exists between sound waves in air and sound waves in structures. A gas (or a liquid) reacts with a change in pressure if its volume is changed. A mere change of the geometrical shape of the gas mass has no influence on the pressure at all (apart from losses due to friction). The boundaries between elements of volume in a gas therefore only transmit forces normal to their surface.

As illustrated by means of a simple example, a bendable thin beam (such as a ruler), solid structures not only try to resist a compression of the volume they fill, but also a deformation of their shape. The boundaries in solid structures therefore transmit tangential forces, or shear tension, as well. By means of the example, the bendable beam, the existence of forces normal to its axes can easily be observed: these shear forces keep the beam in its bendable shape. It would otherwise be impossible for it to stay in this shape.

Instead of only the normal component of the tension, which appears in gases, three components of forces have to be taken into account at the boundaries when dealing with elements of volume in solid structures (Fig. 4.1). Just as one uses the force exerted onto the surface (pressure) for the purposes of definition in the case of airborne sound, one uses tension to formulate the the force laws under the circumstance of structure-borne sound. The tension is equal to the ratio of force to surface area. Furthermore, a distinction has to be
made between normal tension (normal to the imaginary boundary) and shear tension (tangential to the boundary).

All external tension components result in an elastic deformation of the structure which reacts with a resilient oscillation to its equilibrium position when the external tension is removed. The observed oscillation can be explained by a continuous conversion of potential energy which is stored in a change of shape and volume, into kinetic energy of the involved masses and vice versa. This ‘reciprocal transformation’ of the stored energy is not only taking place continually with time, but is also spatially distributed in such a way that vibrations occur as waveforms. In beams, for instance, the three-axial state of tension leads to different sorts of waves for each direction of motion. In beams

- bending waves, where the displacement is normal to the beam axis and therefore also normal to the propagation direction of the wave (Fig. 4.2a),
- the likewise transverse torsional waves, produced by torsion of the beam cross-section and
- the longitudinal waves caused by strain, where the displacement mainly appears along the beam axis (Fig. 4.2b)

occur.

The circumstances become even more complicated by the fact that bending waves with displacement can occur in both of the directions pointing normal to the beam axis. Only in the case of circular cross-sections (or quadratic cross-sections) do both types of bending waves show the same behavior. As can easily be observed in a beam with a flat, prolated cross-section (a ruler), the bending stiffness generally depends on the direction of the tension.

In addition, there are many more waveforms in beams and plates if the finite cross-sectional dimensions are taken into account. In the same manner