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# Non-smooth forced oscillations of a delaminated sandwich beam

*Forced oscillations of delaminated sandwich structures are dominated by impacts. During motion the gap between the two adjacent parts of the structure opens and closes periodically. Each contact gives rise to an impact, which leads to energy loss. A 4 DOF beam model with concentrated masses allows discussion of principle on the influence of internal dissipation due to the impacts on the non-linear system's response and the evolution of impacts near resonance points. Experimental investigations confirm the numerical results.*

## 1 Introduction

Sandwich materials are used in engineering applications. However, the presence of damage, in particular delaminations between adjacent laminaes, degrade severely the mechanical properties. Therefore the non-destructive identification of delaminations becomes an important issue. Dissipation in delaminated structures is used frequently as a damage indicator, but its reason has not yet been sufficiently explained.

Investigations show that oscillations of delaminated structures are dominated by impacts [1] between adjacent layers, which causes internal dissipation. The observation of the response, especially the consideration of the number and intensity of the impacts near resonance, yields informations about the actual condition of the structure.

## 2 The real structure and its mechanical model

Let us consider a sandwich beam with rectangular cross-section 47mm / 49mm, which is suspended by soft springs in the nodes of the lowest natural mode of the undamaged beam. It consists of three laminaes (ramin wood), with a symmetrical delamination at a length of 1390mm along the lowest lamina and an extremly small gap between the layers. Vibrations are induced by an unbalanced rotating mass. A counter mass is fixed at the other end of the beam (fig. 1).

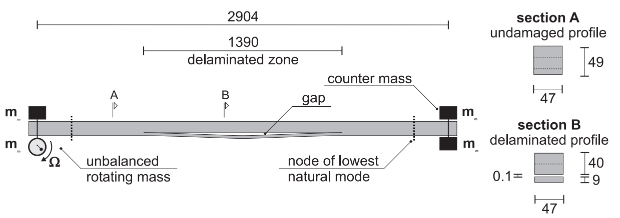


figure 1: delaminated sandwich beam

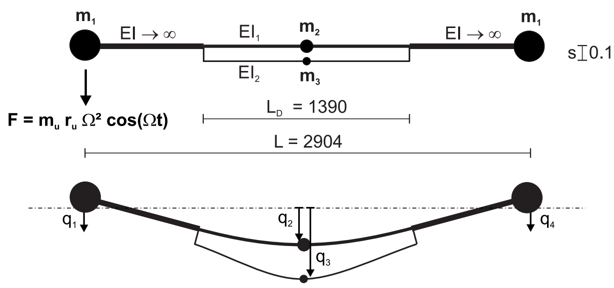


figure 2: mechanical model

A simple description of the mechanical behaviour is given by a 4 DOF beam model with lumped masses. As shown in fig. 2, rigid parts are assumed at both ends. Opening and closing the gap and occuring impacts lead to a non-linear behaviour of the system.

A simple approximation for the law of impact is NEWTON's assumption. Experimental investigations show impacts of different intensity and yield coefficients of restitution in a range of 0.2 (low velocity impact) up to 0.5 (high velocity impact). Only the velocity of the delaminated layer is influenced by an impact.

The integration of the non-smooth dynamical system leads to a sequence of smooth systems, whose analytical solutions are known. They must be patched together at those times when irregularities due to contact occur [2]. The motion is characterised by three partial states: a separate motion of remaining cross-section and delaminated layer, sudden impacts and a motion in permanent contact of both parts.

# 3 Experimental and numerical results

Optical position sensors give the mid-displacement of the remaining cross-section and the delaminated layer, respectively. Additionally, the trigger signal from the unbalanced drive yields the frequency of excitation and the reference of an excitation period. The investigated frequency range from 12.0Hz to 17.0Hz is chosen in the vicinity of the lowest resonance point.

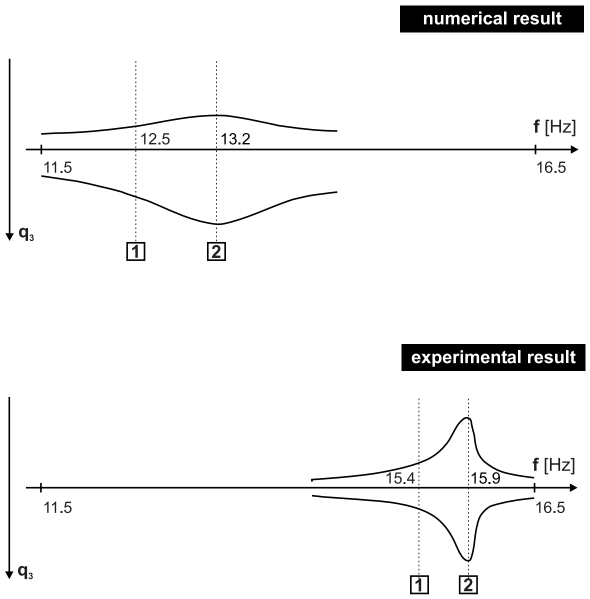


figure 3: frequency response

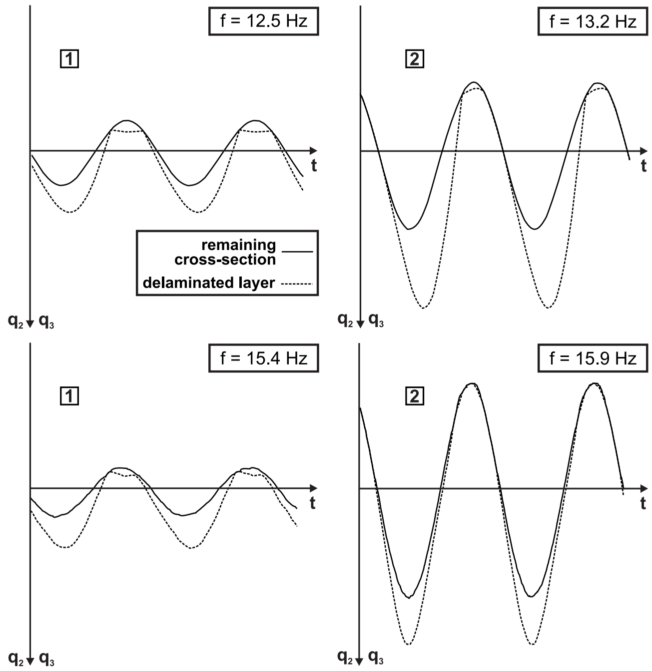


figure 4: experimental (lower row) and numerical (upper row) examples of two types of motion

A comparison between the experimentally and numerically gained frequency response of the delamineted layer can be seen in figure 3. The shifting of the computed result to lower frequencies is caused by the simplifying assumptions. Exemplarily two typical kinds of motion are considered. An excitation below resonance (section 1 in fig. 4) gives a stationary response showing two impacts during one response period. At resonance (section 2 in fig. 4) one impact and a part of motion in permanent contact occurs.

# 4 Conclusions

Oscillations of delaminated structures are dominated by impacts. The simplified 4 DOF beam model gives qualitatively an excellent confirmation of the main phenomena. In a qualitative sense it allows a discussion of the different types of motion and the corresponding number of impacts. The experimentally gained frequency responses confirm that the presence of damage leads to a significant change of the system's properties. The internal dissipation is caused by impacts.

### 1. References

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