Vorlesung/Lectures by Alexander K. Belyaev

Selected topics in the vibration theory

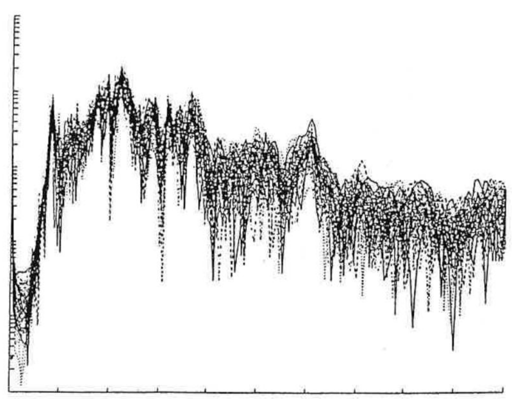
Ausgewählte Kapitel der Schwingungslehre

This course of lectures addresses the dynamic behaviour of the complex engineering structures such as vehicles, ships, airplanes, building, engines etc at high frequencies. The dynamics of such structures in the high-frequency domain is characterized by a number of specific features. First of all, it is a huge number of degrees of freedom which are needed to be included into consideration if one would like to apply numerical simulation, e.g. finite element method. Another feature is that these structures are assembled from thousands parts and each part has small variations in mechanical and geometrical properties, as well as manufacturing and assembling. As a result, any complex engineering structure belongs to class of the structures with uncertain parameters. Special approaches have already been developed for such structures at high frequencies, in particular in the acoustic frequency domain.

The content of the course is listed below with some short comments for each theme.

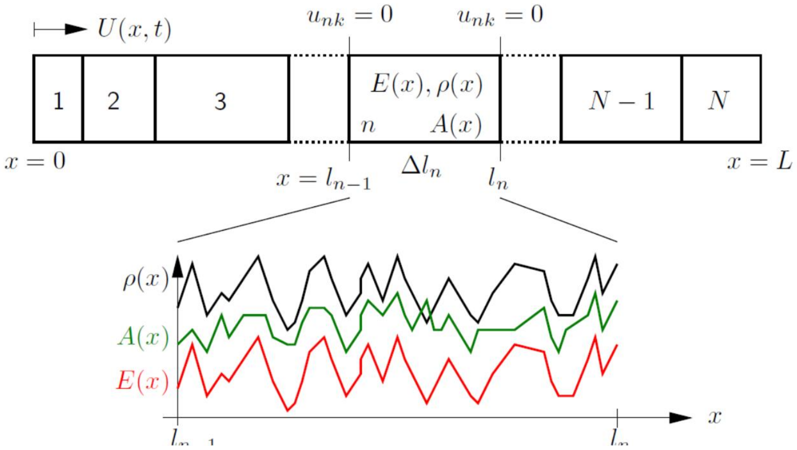
• **Introduction. (Einleitung)** Existing approaches for handling the engineering structures are discussed along with their strong and weak sides.

• Dynamic properties of the complex engineering structures as a prerequisite of the modeling. The typical properties of these structures are analysed, among them, numerous inherent variations in mechanical and geometrical properties, as well as manufacturing and assembling. Also, these structures are the so-called dynamically weakly coupled structures. Based upon these observations, some appropriate mechanical model is suggested.



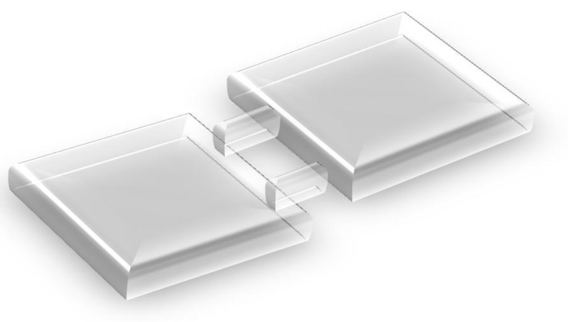
Uncertainty of dynamic characteristics is seen on example of 57 structure-borne frequency-response characteristics of pickup trucks just of the assembly line

• **Kinetic and potential energy of complex engineering structures. Work of external forces (Kinetishce und potentiele Energie. Arbeit der aeusseren Kraefte)** These types of energies are required for applying the Hamilton variational principle. The expressions are specially modified for engineering structures to catch their typical properties.



Complexity of the engineering structure is taken into account for derivation

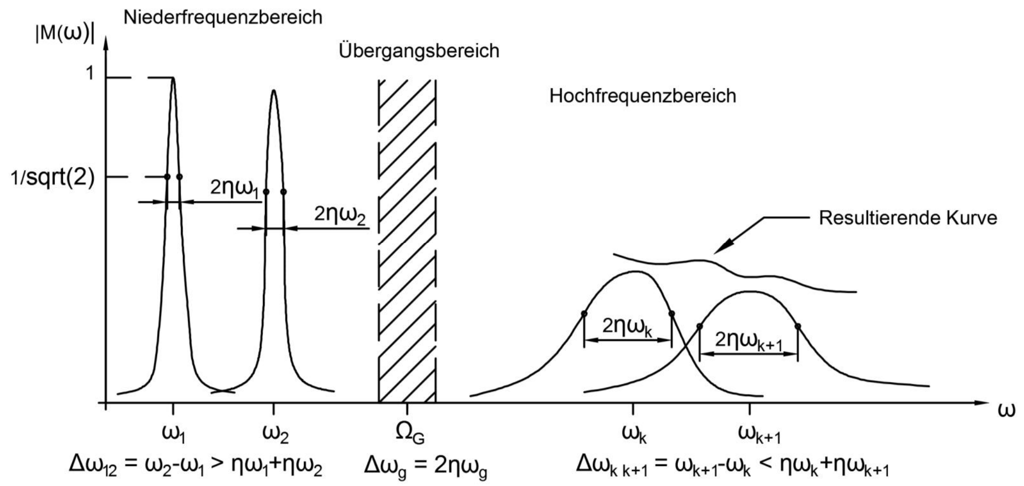
• **Derivation of dynamic equations for complex engineering structures in time domain (Herleitung der Gleichiungen fuer die komplexen Konstruktionen im Zeitbereich)** The Hamilton variational principle is applied to derive the equations for the primary structure and substructures. The latter describe the dynamics of substructures attached to the primary structure, e.g. various equipment, devices etc.



Example of the feedback kinematic excitation of substructures

• **Dynamic equations for complex engineering structures in frequency domain.(Gleichiungen der komplexen Konstruktionen im Frequenzbereich)** The equations derived above for the time domain are transformed into the frequency domain. It allows us to split the frequency domain into two ones: low frequencies and high frequencies. Simple formula is derived for the frequency that separates these domains. It is shown that at high frequencies the secondary systems act as a set of dynamic absorbers for the primary structure. The secondary systems, among them some sensitive electromechanical and/or mechatronic equipment, can be damages since they absorb the energy at their eigenfrequencies,

• **Harmonic vibration in complex engineering structures (Harmonische Schwingungen in komplexen Konstuktionen)** This is an example which allows one to obtain simple equations, analyse the unusual properties of high-frequency vibration in complex engineering structures and draw the conclusions. It is shown that the derived equations are equally applicable for structures under single frequency excitation, periodic and random external loading.



Low frequency and high frequency domains. The boundary frequency

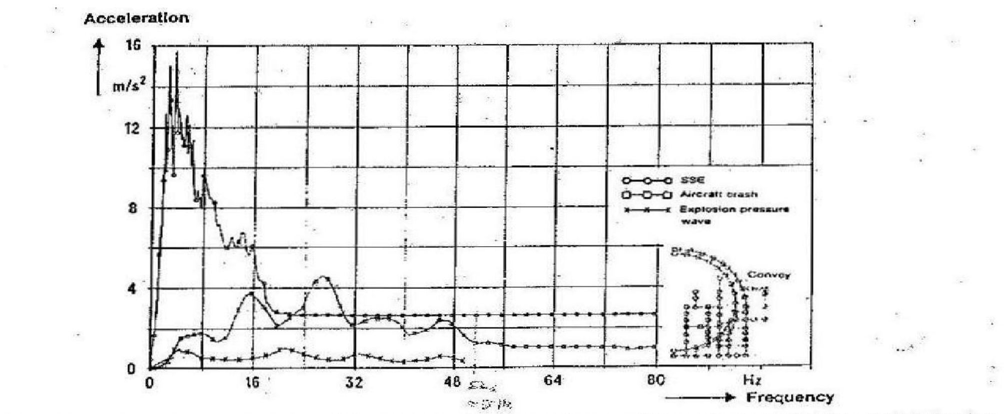


Fig. 4. Comparison of structural responses induced by natural and external man-made hazards, reactor building, vertical direction.

Frequency domains of the nuclear power plant (Siemens KWU Group)

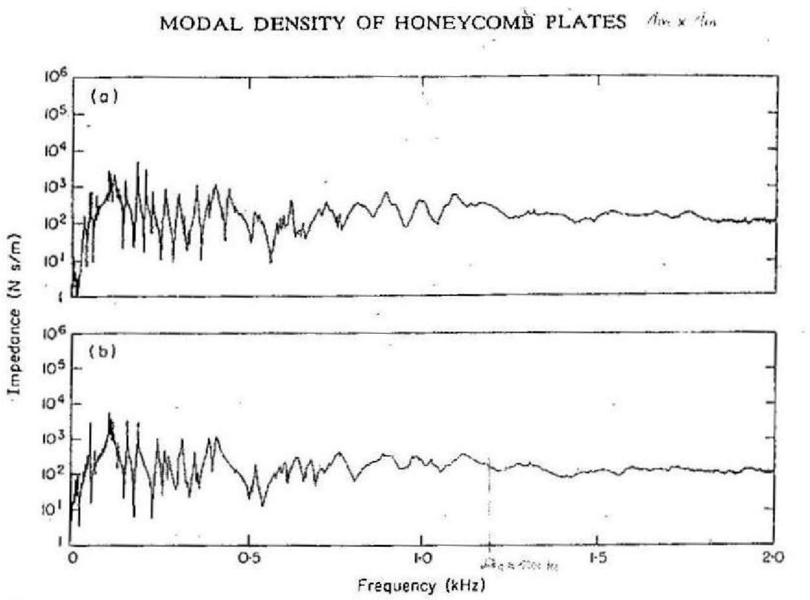


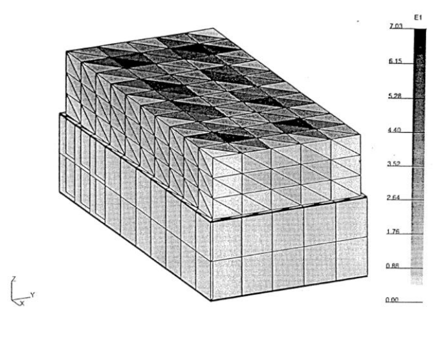
Figure 18. Modulus of driving point impedance for MAROTS side wall panels. (a) Sidewall panel 1; (b) sidewall panel 2.

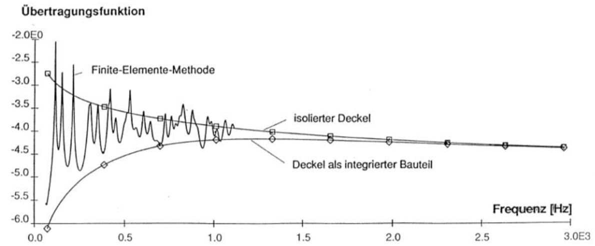
Frequency domains of the honeycomb plate

• **Non-stationary vibration in complex engineering structures (Instationaere Schwingungen in komplexen Konstuktionen)** Non-stationary loading is a special case of external loading. The analysis shows that the acceleration is primarily dependent on the time rate of external loading rather than the magnitude of the loading. Examples are provided.

• **Local vibration in complex engineering structures (Lokale Schwingungen in komplexen Konstuktionen)** A number of examples are provided, namely, broad-band vibration of cover of engine, instability of electrodynamic shaker etc.

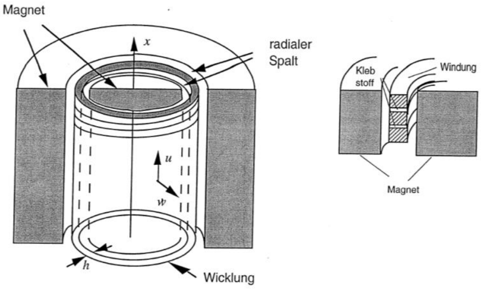
Breitbandige Schwingungen eines Zylinderkopfdeckels



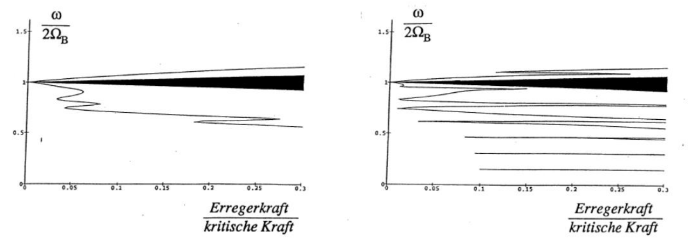


Räumliche Verteilung der Oberflächengeschwindigkeiten bei der "rain-on-the -roof" Erregung

Broad-band vibration of cover of internal combustion engine, comparison with the FE analysis



Schematische Darstellung eines elektrodynamischen Schwingungserregers



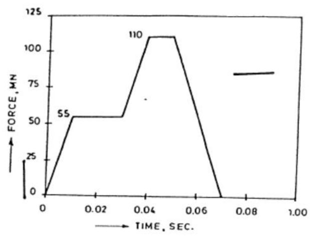
Instabilitätsbereiche der Wicklung für verschiedene Prüflinge

Schematics of the electrodynamic shaker and stability chart of the shaker coil

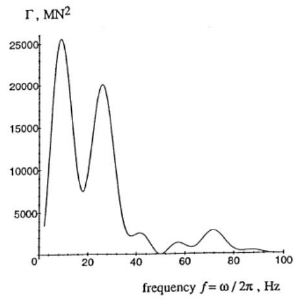
• **High-frequency dynamics of structures (Hochfrequenzstrukturdynamik)** A concept of a new dynamics, referred to as the high-frequency dynamics is introduced. The borders of this dynamics are determined and the properties of structures at high frequencies are indicated.

• **Thermodynamic methods in high-frequency dynamics of structures. Vibrational conductivity approach (Schwingungsfortleitungstheorie)** It is shown that the approaches of thermodynamics are applicable for describing the dynamic behaviour of structures at high frequencies, since, for example, the temperature is a measure of high-frequency thermal vibrations. This analogy allows one to apply the thermal conductivity equation for modeling high-frequency vibration of structures by modifying it in a proper way and obtain the vibrational conductivity equation to this end. The merits and shortcomings of new approach are discussed and a number of examples, e.g. modeling a military jet crash on nuclear power plant, are provided.

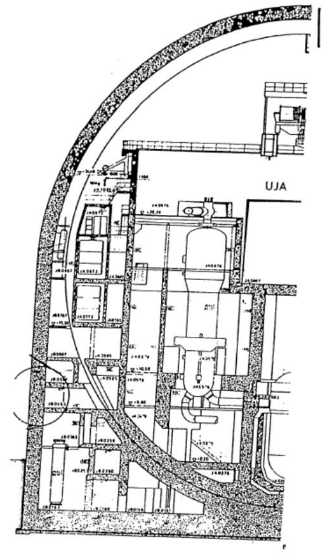
Schwingungen in einem Atomkraftwerk zufolge eines Flugzeugabsturzes



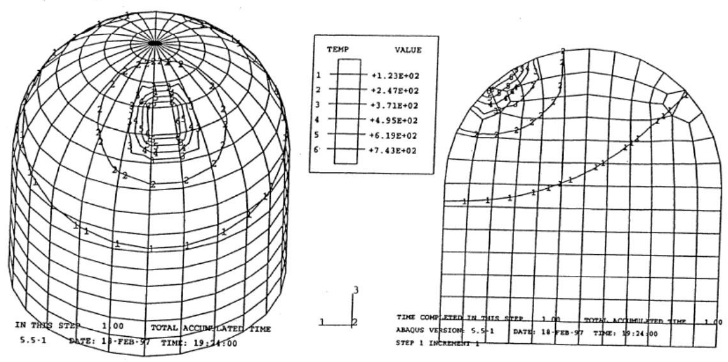
verifizierte Flugzeugabsturzbelastung
(Flugzeug Fantom)



Fluß der Schwingungsenergie



Atomkraftwerk



Schwingungstemperatur im Atomkraftwerk

Field of vibrational temperature in the nuclear power plant due to aircraft crash