MADYN

**Program System
for
Machine Dynamics**

Abstract
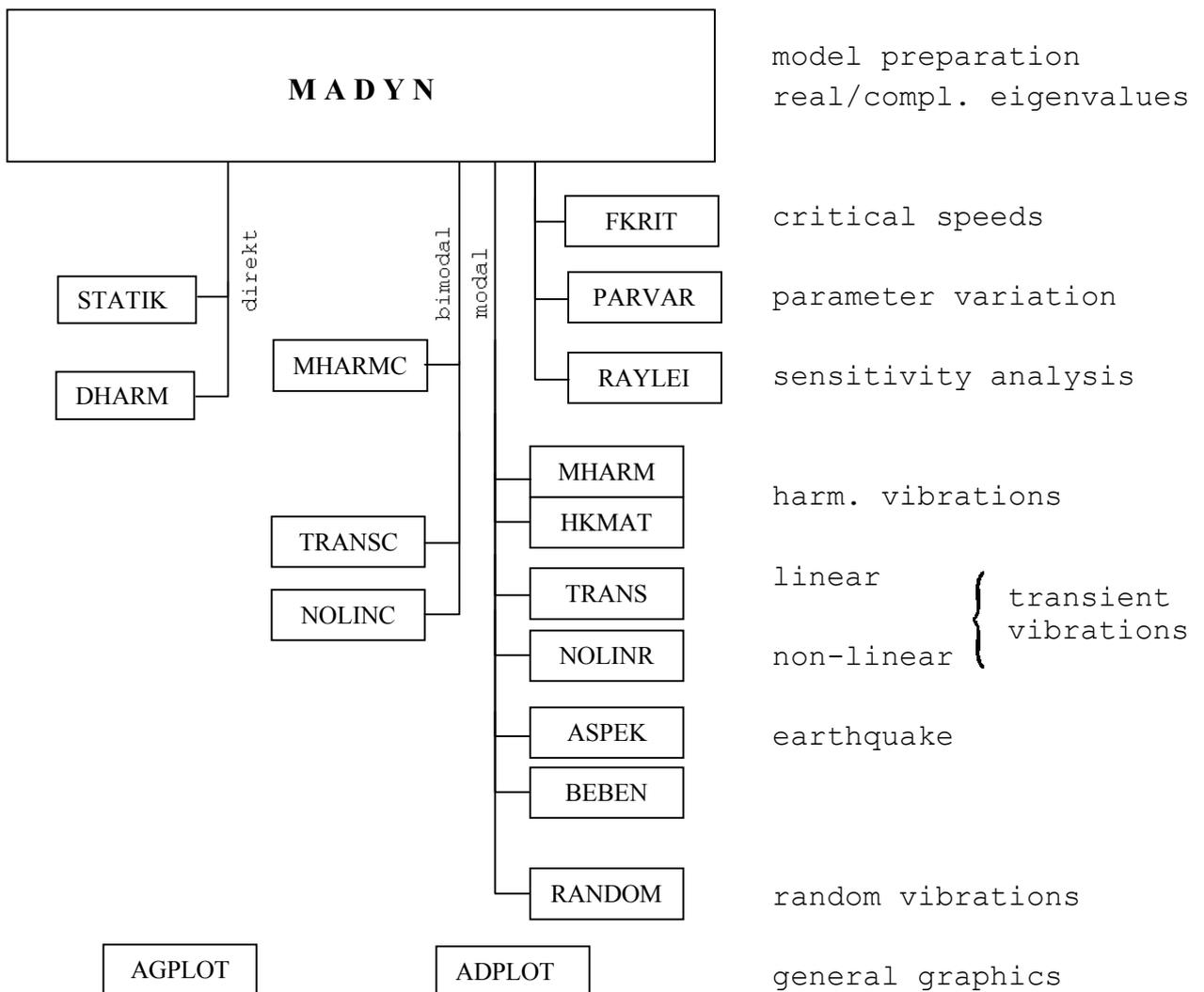
Version 5.0
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What is MADYN?

The program system MADYN was primarily developed for the calculation of rotor-foundation systems. However its concept is so variable, that it can be used for other models, such as steel constructions or pipelines. It calculates real and complex eigenvalues as well as harmonic transient (linear and non linear) and randomly induced vibrations.

Structure of the program system

The overall system consists of a set of codes, each serving a specific task (see figure). The individual program components communicate with each other via a set of files. The management of these files and calling of the codes is done by the menu program MADWIN. It also allows the representation of various graphics on the screen.

M A D Y N	model preparation
	real/compl. eigenvalues
FKRIT	critical speeds
PARVAR	parameter variation
RAYLEI	sensitivity analysis
MHARM / HKMAT	harm. vibrations
TRANS	linear
NOLINR	non-linear
ASPEK / BEBEN	earthquake
RANDOM	random vibrations
AGPLOT ADPLOT	general graphics

STATIK, DHARM, MHARMC, TRANSC, NOLINC — direkt / bimodal / modal — transient vibrations

The main part is responsible for the model preparation, structural matrices, eigenvalue extraction, and the plotting of the structure and mode shapes. External loads remain unconsidered. These are treated in subsequent codes.

Elements

To build the model, the following elements are available, all of which can be oriented in any direction in space:

- general beam

here $I_2 > I_3$
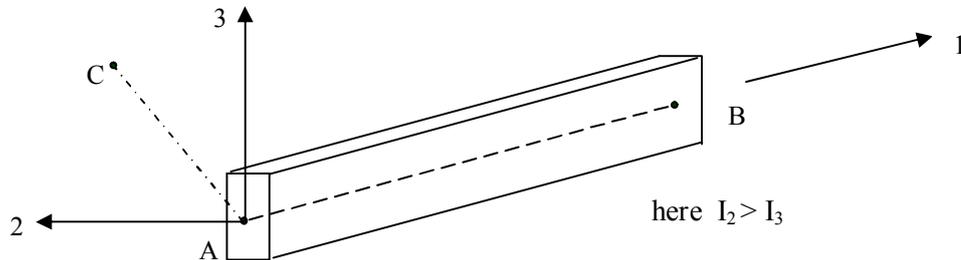
It is defined by the cross section area, the moments of inertia, shear strain factors, Young's modulus, density and additional mass per unit area.

- axial and torsional rod
  It is a simplified form of the general beam. In contrast to this it transfers no shear forces and no bending moments.

- shaft
  This element is also a special form of the general beam. The properties are defined by the outer and inner diameter. In addition, the gyroscopic effect is taken into account.
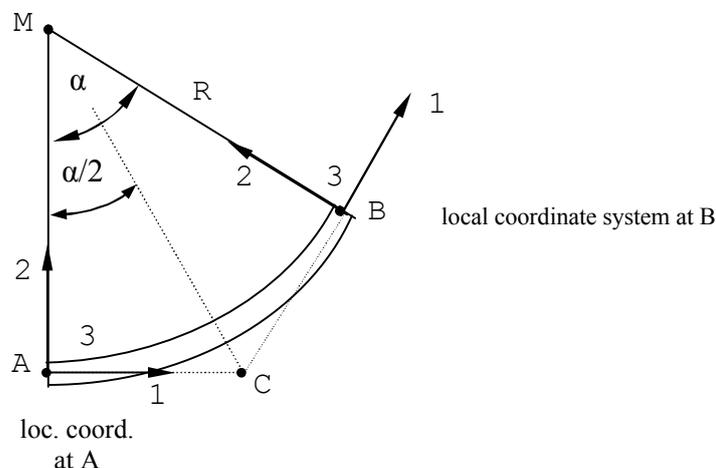
- conical shaft and rod
  The cross-sectional properties are different at the beginning and the end. The other properties are the same as in the preceding elements.

- reduced shaft
  A reduced shaft consists of a maximum of 20 sub-elements. These are assembled by a reduction process to one element.

- pipe bend

local coordinate system at B

  The specific feature of this element is the dependency of the stiffness on the inside pressure.

- spring/damper
  The spring/damper element can be oriented globally or locally.
  The stiffness and damping coefficients are valid for all six
  directions (3 translations, 3 rotations).

- journal bearing
  Journal bearings can have asymmetric stiffness and damping
  coefficients. If so, this has a significant impact on the
  subsequent calculations. The eigenvalues can be complex, even
  without damping (see eigenvalue extraction algorithms). The journal
  bearing properties can be frequency dependent for unbalance
  calculations or for the determination of critical speeds.

- additional masses
  At the nodes, additional masses and moments of inertia can be given.

- generalized element
  The user can supply the coefficients of the element directly. This
  can be used to represent special effects.

- matrix additions
  Even more generally, the coefficients of the global matrices can be
 given directly.

Additonal Elements

Additionally, one can use rigid elements for bridging gaps between
components. Kinematic couplings (a displacement is defined as a linear
combination of other displacements) can be used to create special
effects, e.g. the representation of gears or the direct calculation of
a sum or difference of displacements (striking of components). The
boundary conditions may also be specified in local coordinates.

Additional Elements from Version 5 upwards

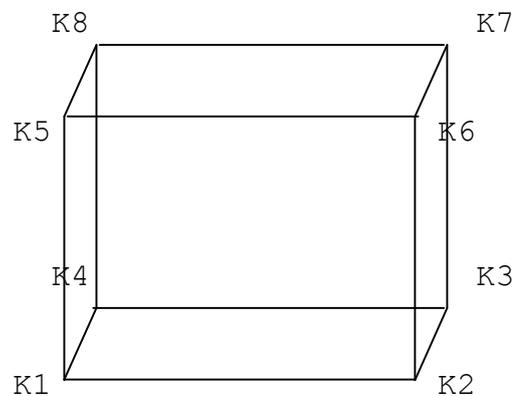As of Version 5 plates and volume elements are added.

Three-node plate

K4

K3

K1

K2
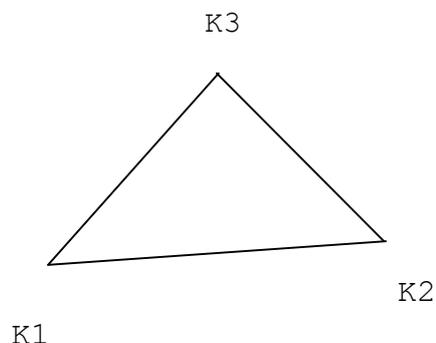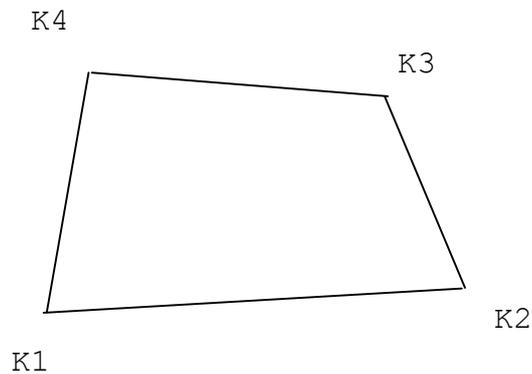
Four-node plate

Plates have 6 degrees of freedom per node just like beams.

K8

K7

K5

K6

K4

K3

K1

K2

The hexahedrons have translational degrees of freedom (3 DOF per node) only. The elements can degenerate to wedges, pyramids and tetrahedrons.

Matrices

The definition of the nodes and elements allows the calculation of the global matrices. The following types are possible:

- stiffness matrix (symmetric or asymmetric)
- mass matrix (diagonal, quasi-diagonal or symmetric)
- damping matrix (symmetric or asymmetric)
- gyroscopic matrix (skew symmetric)
- centrifugal force matrix (symmetric)

The matrices are stored in the skyline technique, i.e. the length of the rows and columns can be different for each degree of freedom. This reduces the memory requirements and computing time. An algorithm for band width optimization changes the internal sequence of the nodes. On demand, a reduction process can be performed. In this case the method of Guyan is used.

Eigenvalues

In the MADYN main part there are four real and two complex eigenvalue algorithms available. The real algorithms require symmetric matrices and ignore the damping and gyroscopic matrix. These are:

- Jacobi's method for relatively small models (up to 500 DOFs, if necessary after a reduction procedure)
- Housholder's method for medium-sized models (up to about 2000 DOFs)
- simultaneous vector iteration for large models (up to about 20 000 DOFs)
- subspace iteration for even larger models (greater than 20 000 DOF)

The complex eigenvalue extraction is performed if asymmetric coefficients (journal bearings) or viscous dampers exist in the model, or the gyroscopic effect has a dominant role. The following methods are available:

- Hessenberg's algorithm for small models (up to about 1000 DOFs)
- inverse vector iteration for all larger models

The right and left hand eigenvectors are calculated for use in subsequent programs. The calculation is performed bimodally (expansion of the modal calculation to complex eigenvectors).

In addition, the corresponding element forces to the eigenvectors are determined, as well as mean modal damping, energy distributions of element groups, equilibrium checks and forward/backward precision of the natural oscillations.


X3
X2
X1

29. EIGENFORM 74.321 Hz

BILD 32 Maschine 1
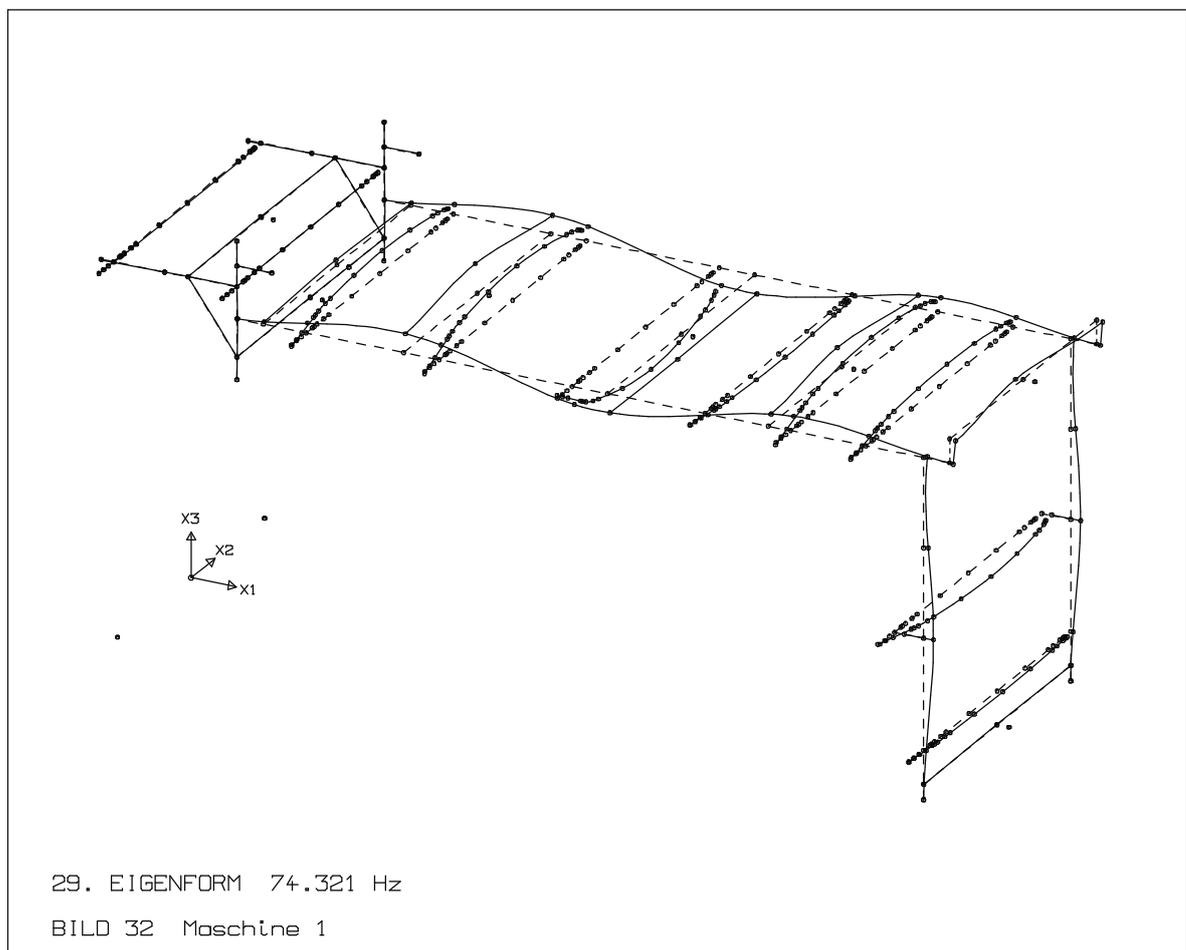
Additional Analysis

The program FKRIT allows the determination of critical speeds. It is consistent with the classical codes of rotor dynamics, which work with the transfer matrix method. Here, a determinant search method is used.

The program RAYLEI is used for a sensitivity analysis. By means of the Rayleigh quotient and the already known eigenvectors, the change in natural frequencies due to variation of the stiffness or mass of single elements or a group of elements can be calculated.

The program PARVAR investigates the influence of a parameter (rotor speed, damping, relative stiffness and/or damping of selected elements) on the eigenvalues. There are three eigenvalue algorithms available: the determinant search method, the Hessenberg algorithm and the inverse vector iteration method. If the rotor is isotropically mounted, a special type of determinant search method is used, which is much faster due to this particular boundary condition.

N-ALPHA-DIAGRAMM mit Determinantensuche
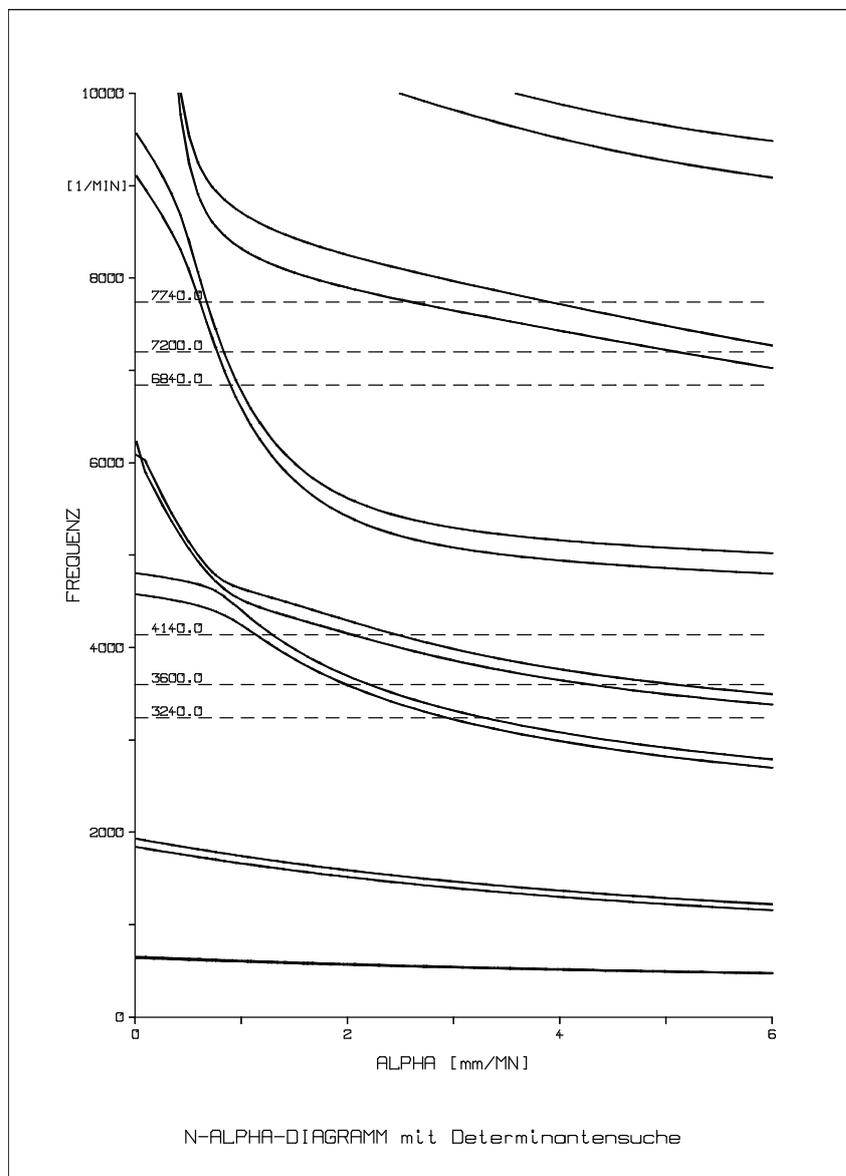
Static

The static load cases are nodal forces, dead load, temperature loads and pressure (pressure from version 5 upwards only). The calculation of unrestrained systems, i.e. the torsion of shaft lines, is possible if the external loads are balanced. Load case combinations are also possible.


Steady-state harmonic Vibrations

To calculate steady-state harmonic vibrations (resonance curves) there are three different codes available, so that the best possible method can be chosen for a particular problem. For conservative systems (real eigenvalue extraction was possible) a modal analysis is used. The damping is supplied as modal damping to the mode shapes. The use of the rest-mode method allows a calculation to work with a small number of eigenvectors, while still yielding good results (s. figure).

For non-conservative systems (complex eigenvalue extraction) with constant rotor speed or without gyroscopic effects a bimodal analysis can be used. The damping is already enclosed in the eigenvalues. However, an additional modal damping can be given by the user.

If the properties are frequency dependent (journal bearings, gyroscopic effects) a direct solution (complex Gauss algorithm) is used. Instead of the modal damping an additional structural damping can be given. The structural damping has a similar effect to the modal damping.

In all cases the loads are nodal point harmonic forces, imbalances and base excitations. The results are displacements, element forces and stresses as absolute value and phase.
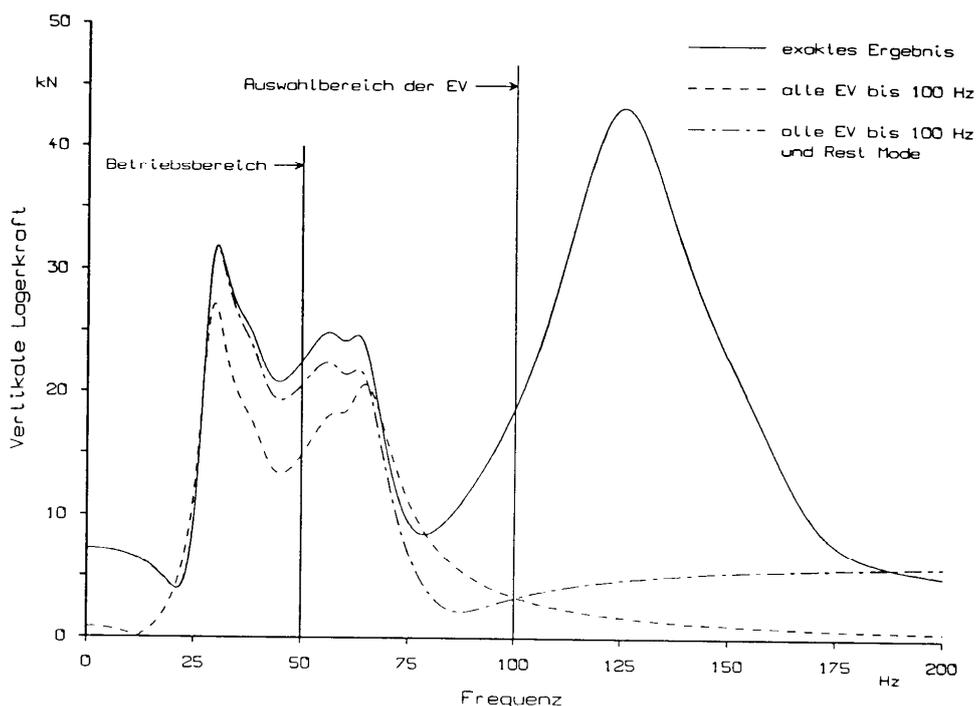
Transient Vibrations

The programs TRANS und TRANSC are available for transient forces and base accelerations. Some standard exciting functions are predefined, other exciting time histories, i.e. for earthquake loads, can be given on tables in a file. Arbitrary initial conditions are possible, as well as continuation runs. As in the above section for MHARM/C a modal or bimodal analysis is possible with the same definitions of damping.

The results are displacements, velocities, accelerations, element forces and stresses. In an extra section of the program a Fourier transformation can be performed, if necessary just for excerpts of the time histories.

The programs NOLINR and NOLINC offer the same features, but can also account for nonlinearities. The following options are provided:
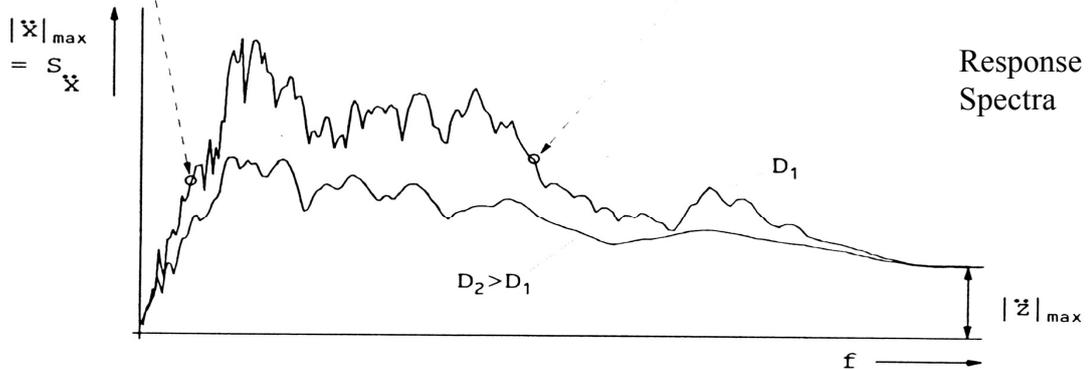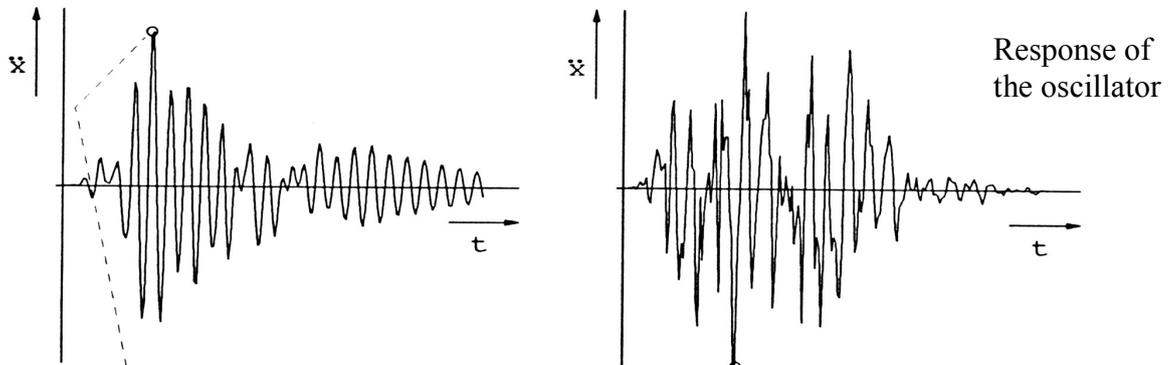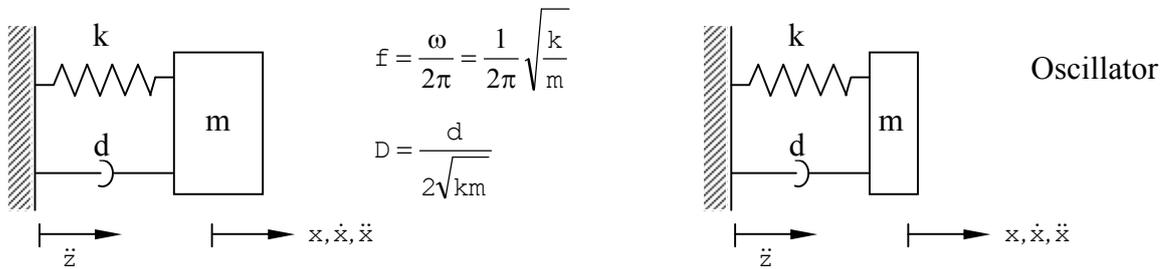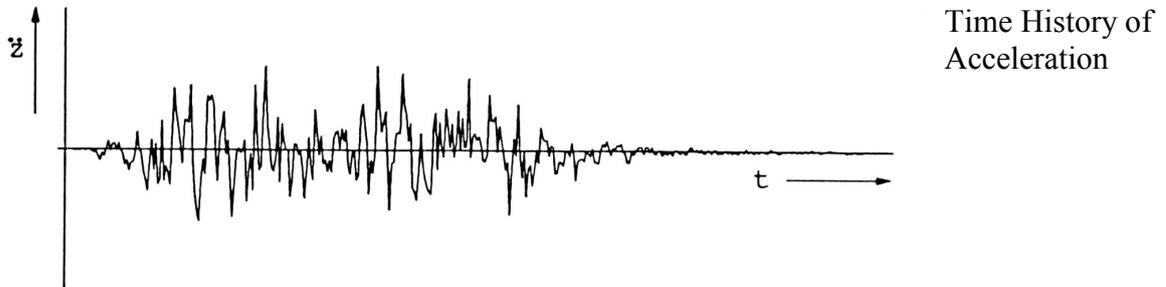
- journal bearings
- springs and dampers with freely definable characteristics
- one- and two-dimensional Coulomb friction
- user-defined non-linearities in added subroutines

The solution is carried out by a modal analysis with a predictor/corrector procedure. In this way, the quality of the solution can be monitored.

BILD 4   Fourier-Analyse eines Zeitabschnitts
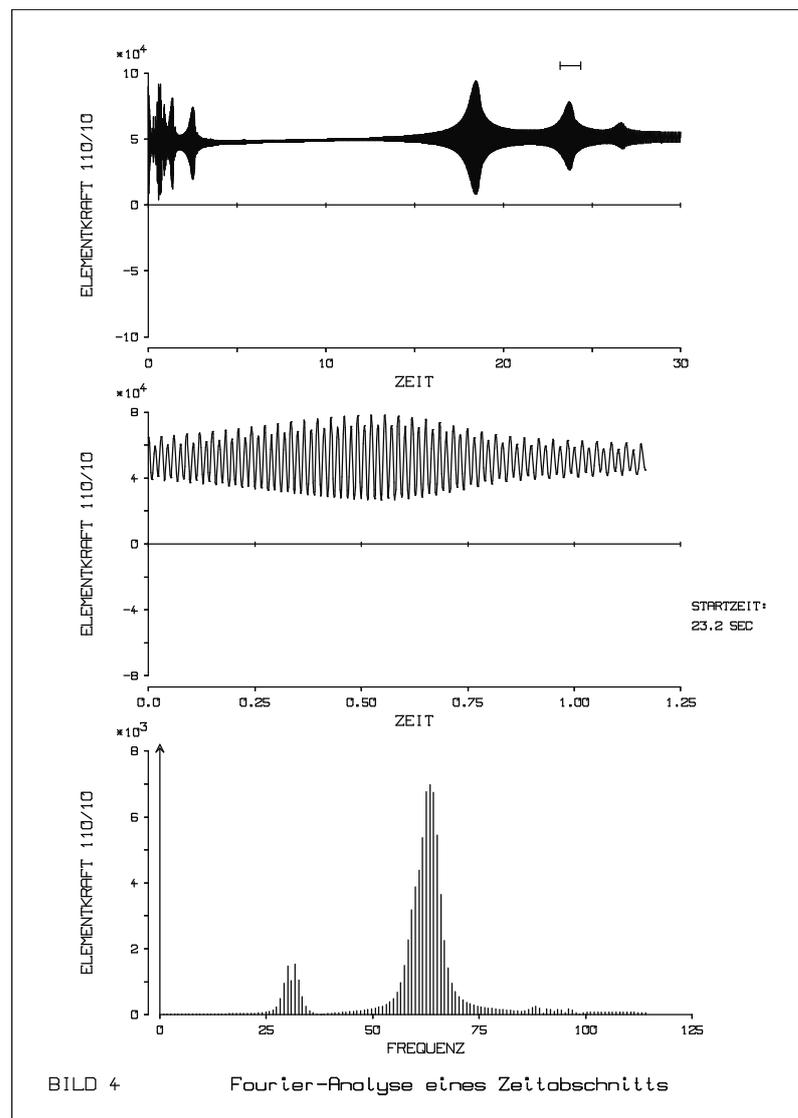
Response Spectra

ASPEK calculates response spectra for acceleration time histories created by TRANS or NOLIN or can be set directly. In addition to the normal algorithm, which is also used in other programs, there is a quick version that can be used up to a damping ratio of about 0.05. At higher dampings, the result is only an approximation.

Time History of Acceleration

$$f = \frac{\omega}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

$$D = \frac{d}{2\sqrt{km}}$$

Oscillator

Response of the oscillator

Response Spectra

Definition of the Response Spectra

Earthquake

The purpose of the program BEBEN is the calculation of earthquake loads using the modal response spectrum method. The superposition of the results of the mode shapes can be done absolutely, according to the RSS formula or using a combination of these two methods. The latter method is used if the natural frequencies are equal or very close to each other. In addition to the base excitation typical for earthquake loads the program can also be used for a force excitation.

Random Vibrations

RANDOM calculates the RMS modal responses to excitations that are defined in terms of power density or Fourier spectra. In an analysis section time histories are transformed into spectra and frequency distributions are determined.

Graphic Output

The programs described above have plot routines to show all necessary plots. These only require relatively little user input. However, an individual configuration is not possible. To do this, there are two more general graphic programs.

With ADPLOT various different types of figures can be designed according to the ideas and wishes of the user. Nearly all details can be manipulated. Sketches and texts can be added. Results of various investigations can be combined in one figure. A manipulation section is available for converting stored vectors.

AGPLOT allows the creation of detailed drawings of structures, i.e. the stiffness or mass distribution. Especially for rotor dynamic calculations there is a section „shaft plot", which allows the user to plot the shaft line similar to a technical engineering drawing without much input effort.

Fundamentrahmen mit Rotor (Wellenplott)
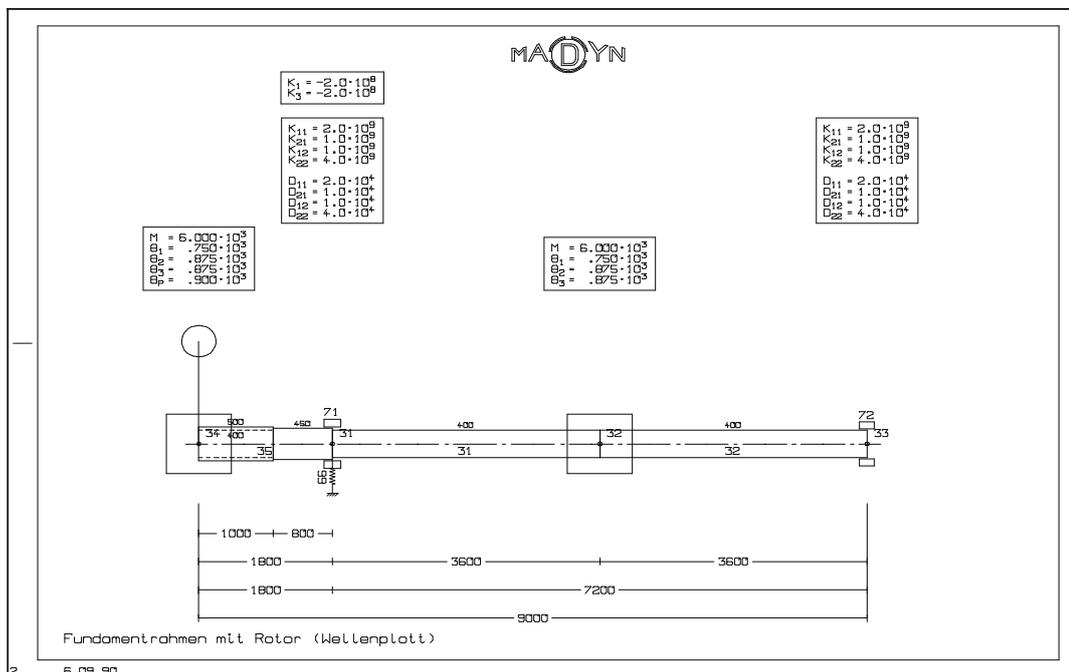
Utilities

In addition to the programs mentioned above, there are a number of assistance programs for special tasks, e.g. GLKOEF determines the coefficients of journal bearings, and FILEX lists the contents of binary files. POSTB allows the subsequent resizing of plots and the combination of multiple figures on a new page.

Menu Program MadWin

For Windows computers, the menu program MadWin is used to call the calculation programs. The program also administers the various files used by the MADYN programs. An important function is the visualisation of plots on the screen with zoom capability. The neutral plot file is prepared for different output formats, such as HP-GL, PostScript, EMF files or output directly to a Windows printer.

BILD 1   Bruecke Kira