MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

Tagungsbericht 17/1988

Berechnung von Verzweigungen in mechanischen Systemen

17.4. bis 23.4.1988

Die Tagung fand unter der Leitung der Herren T. Küpper (Hannover), R. Seydel (Würzburg) und H. Troger (Wien) statt. Der Teilnehmerkreis setzte sich zu etwa gleichen Teilen aus Vertretern der Mechanik, der Analysis und der Numerik zusammen. Im Mittelpunkt des Interesses standen Fragen, die die drei Arbeitsgebiete gemeinsam berühren, insbesondere Probleme der Struktur- oder Strömungsmechanik, zu deren Untersuchung neuere analytische wie numerische Methoden herangezogen werden müssen. Die gegenseitige Anregung über die Fachgrenzen zwischen Ingenieuren und Mathematikern hinweg waren ein bestimmendes Merkmal dieser Tagung.

Insgesamt wurden 30 Vorträge gehalten. Zusätzlich fand ein von Herrn Wedig aus Karlsruhe veranstaltetes Tutorium über stochastische Differentialgleichungen reges Interesse.

Wegen der internationalen Zusammensetung - die Hälfte der Teilnehmer kam aus dem Ausland - einigte man sich darauf, die Vortrags- wie auch die Diskussionsveranstaltungen im größeren Kreis in englischer Sprache abzuhalten.

Gefördert durch DFG Deutsche Forschungsgemeinschaft

Vortragsauszüge

T. ATANACKOVIĆ:
Stability of a compressible elastic rod with imperfections

The stability of a compressible elastic rod axially loaded by two concentrated forces of arbitrary intensity is studied. It is assumed that imperfections in shape and loading are present. The shape imperfections are characterized by an initial deformation of the rod axis, while the load imperfections are characterized by a small distributed force acting perpendicular to the action line of the compressive forces. It is shown that - depending on the slenderness ratio - the rod could exhibit supercritical and subcritical bifurcation. Some solutions and their local behaviour are analyzed. Also a universal unfolding for the perfect bifurcation problem is determined.

W.-J. BEYN:
A mathematical model of the hydrostatic skeleton and its bifurcations

The hydrostatic skeleton is a special form of skeleton realized in many invertebrates, e.g. the leech. Basically it consists of an incompressible fluid enclosed in an elastic body wall. The shape of the body is changed by activating parts of the musculature. We present a mathematical model for the equilibria of such a system which leads to a comparatively large constrained optimization problem. Our special emphasis is on bifurcations of the equilibria for the '3D-unit worm' where the volume is taken as parameter. We show how continuation and singular point techniques carry over to sparse constrained optimization problems with parameters.

K. BÖHMER:
On the computation of bifurcating manifolds in a higher singular point

Let $x_0 \in \mathbb{E}$ be a higher singular point for an operator $G: \mathbb{E} \to \mathbb{E}^1$, with $G \in C^2(\mathbb{E})$, $G_0' = G'(x_0)$ bounded with closed range and $\dim \mathbb{N}(G_0') = m+q$, $\dim \mathbb{N}(G_0'^*) = m$. In an earlier paper by Allgower/Böhmer a general theory for the numerical approximation to x_0, $\mathbb{N}(G_0')$, $\mathbb{N}(G_0'^*)$ was presented. This information is used now to transform the classical Lyapunov-Schmidt method for the computation of the bifurcating manifold into the discrete counterparts.

The relation of consistency and stability properties is discussed and the necessary modifications and results for the discrete case are given. Thus it is possible, based on the above approximation, to compute the bifurcating manifolds numerically.

E. BUZANO:

Bifurcation analysis of a rod subjected to terminal thrust and couple

The equilibrium configurations of a rod under terminal thrust λ and couple τ are studied. This leads to a variational two-parameter bifurcation problem, which is studied by a uniform version of the so-called splitting lemma. We prove the existence of a sequence of characteristic curves $\lambda = \Lambda_n(\tau)$, from each one of which there bifurcates a continuous surface of non-trivial equilibrium configurations. Their equilibria are either supercentral or subcentral according to τ being in a neighborhood of 0 (pure compression) or in a neighborhood of a zero of $\Lambda_n(\tau)$ (pure torsion).

G. DANGELMAYR:

On the Hopf bifurcation with broken O(2)-symmetry

Translation and reflection symmetries introduce the group O(2) into bifurcation problems with periodic boundary conditions. The effect on the Hopf bifurcation with O(2)-symmetry of small terms breaking the translation symmetry is investigated. Two primary branches of standing waves are found. Secondary and tertiary bifurcations involving two different types of modulated waves are analyzed in the neighborhood of secondary Takens-Bogdanov bifurcations. The effects of breaking the phaseshift (in time) symmetry is briefly considered.

B. FIEDLER:

O(3)-symmetry breaking in variational problems

(Joint work with K. Mischachow, Michigan State University)
We consider symmetry breaking bifurcations from the trivial solution $u \equiv 0$ of

$$u_t = \Delta u + \lambda f(u), \quad f(0) = 0, \quad f'(0) = 1.$$

Equivariance with respect to the orthogonal group O(3) arises naturally when we consider this equation on an O(3)-invariant domain (ball, shell, sphere) with appropriate boundary conditions.

Typically, several branches of stationary solutions with nonconjugate isotropy can bifurcate simultaneously because, due to equivariance, high-dimensional kernels occur. We address dim = 5, 7 here. We determine the unstable dimensions associated to these solution branches, and we find heteroclinic connections between them. Our principal tool is Conley's connection matrix.

D. FLOCKERZI:

Singular perturbations and control theory

It is shown how 'global' invariant manifolds for singularly perturbed systems $\dot{x} = f(x,\varepsilon)$ (possessing for $\varepsilon=0$ an invariant manifold $\mathcal{M}_0 \subset \{x: f(x,0)=0\}$) can be used in control theory. The applications to nonlinear control problems are directed towards (i) generating a larger domain of attraction for a positve invariant set (e.g. global stabilization) by high-gain feedback and (ii) identifying an unknown function v(t), $t \in [t_0,t_1]$ in

$$\dot{x} = f(x, v(t)), \quad x(t_0) = x_0, \quad y = c^T$$

without measuring $\dot{y}$ (t).

K. KIRCHGÄSSNER:

Resonant forcing of nonlinear surface waves

Der Einfluß von Druckwellen auf Oberflächenwellen reibungsfreier Flüssigkeitsdichten führt - im Rahmen der Eulergleichungen - auf das Studium gestörter homokliner Orbits in Funktionenräumen. Die Wirkung periodischer Druckwellen wird analysiert, ebenso wie diejeniger mit endlichem Support. Im ersten Fall tritt räumliches Chaos bei großen Perioden auf, im zweiten Fall gelingt eine vollständige Charakterisierung der Lösungen mit kleiner Amplitude.

B. KRÖPLIN:

Energy measures for the stability of structures in statics and dynamics

When thin walled shells buckle, a sequence of rapidly changing buckling patterns is passed, while the structure is moving from the prebuckling to the postbuckling range. Dynamic analysis of the phenomenon is cumbersome and the final buckling pattern depends on the in general not known damping of the structure. Static analysis can rely on equilibrium states, but has to deal with a large number of partly unstable solution paths on bifurcations.

Both methods do not give estimates on the stability of the solutions obtained.
In order to derive a stability estimate a perturbation strategy is lined out. It is based on accompanying eigenvalue calculation and enables to estimate the degree of stability of a selective path either in static or dynamic cases.

T. KOPPER:
Feedback stimulated bifurcation

Bailey and Kuszta were the first who suggested to use bifurcation theory for the purpose of systems identification in situations when other methods fail. Assume that an experiment has been modelled by two different dynamical systems and that standard methods (comparison of steady states, transient response) do not allow to discriminate among these models. Then a feedback procedure may be set up to force Hopf bifurcations such that a qualitative difference between both systems appears. Several feedback procedures are discussed which lead to Hopf bifurcation; for example static and dynamic feedback as well as feedback with delay where the delay term is used as a parameter to force bifurcation. In addition to this qualitative criterion we propose to set up equations which can be used for the calculation of unknown quantities in the system. The equations are derived through a comparison of measurements with the asymptotic expansion of the solution.

W.F. LANGFORD:
Modulated rotating waves in O(2) mode-interactions

The interaction of steady-state and Hopf bifurcations in the presence of O(2) symmetry yields generically a secondary Hopf bifurcation, from the primary 'rotating wave' branch, to a family of 2-tori. Explicit formulae for the bifurcation coefficients which determine the direction of bifurcation and stability of these tori are presented. The tori are determined by third degree terms in the normal form equations, evaluated at the origin. The flow on the torus near criticality has a small second frequency, and is topologically conjugate to a linear flow, without resonances or phase locking. Existence of an additional SO(2) symmetry as found in the Taylor-Couette problem, implies that the flow is exactly linear. We have computed bifurcation coefficients for the Taylor-Couette problem, directly from the Navier-Stokes equations, over a wide range of gap widths. These show that the 2-tori are always unstable at onset in the Taylor-Coutte case. More generally, these 2-tori may manifest themselves as slowly modulated rotating waves, for example in reaction-diffusion systems or in fluid flow through an elastic hosepipe. The computations reported here may be adapted easily to other such applications.

P. LAURE:

Symbolic computation and equation on the center manifold: application to the Couette-Taylor problem

Reduction on the center manifold and computation of the amplitude equation is now well known. We present here two cases where it is necessary to obtain the expansion of the amplitude equation at higher order. In the second case we consider a degenerate Hopf bifurcation where it is necessary to compute numerically the seventh order term. Then we describe a method which allows us to make this computation by using a symbolic system (MACSYMA).

MEI ZHEN:

Splitting iteration technique for the computation of the corank-2 bifurcation points

A splitting iteration method is discussed here to compute the corank-2 bifurcation points and the null spaces of the corresponding derivatives of nonlinear problems. The various unknowns are divided into different groups and the iteration procedure is carried out in a block way. The iteration needs small computational effort, provides much information about the bifurcation point and converges with an adjustable rate. Numerical examples are also discussed.

G. MOORE:

Direct solution of bifurcation equations

We consider the computational linear algebra problem associated with solving the extended system which characterises some particular singular behaviour. The matrix M representing the linearisation of this extended system (required for Newton's method) will generally consist of a large but structured leading principal sub-matrix A (which may be ill-posed) plus some augmented dense rows and columns. To solve such linear equations efficiently one should make use of the structure present in A while mitigating the ill-posedness. Three possibilities for doing this are:

(a) explicit deflation of M by manipulating rows/columns,

(b) making use of the expected position of small pivots in the LU-decomposition of A,

(c) block Gauss elimination of M together with implicit stabilization by means of
    (i) implicit deflation of A, (ii) iterative refinement.

G.P. OSTERMEYER:

Chaotic motion of rail - wheel - systems

Investigations in nonlinear dynamics of railway wheel systems concentrate on the stability behavior of bogies. A typical bogie model consists of three rigid bodies, a bogie frame and two wheelsets, which are connected by viscoelastic elements. The wheelsets couple the bogie and the rigid track. Main nonlinearities are to be found in geometry and contact behavior of rail and wheel. Kaas-Petersen (Acta Mech. 1986) studied some bifurcation phenomena. He too found chaos in a 7 DOF bogie model via computation of the largest Ljapunov number. Numerical investigations show high dependence of bogie parameters on the described phenomena in the highly stiff equations of the mathematical model. For a rigorous analysis modern reduction methods (centermanifold theory) seems to be necessary. For physical reasons the rails have to be taken into account for modelling bogie-rail interactions.
Describing the rail by an infinite beam on viscoelastic foundation leads to new instability behavior in linear approximation. Classical reduction methods for the investigation of the bogie-rail model (studies on bifurcation behavior) fail by the existence of the continuous spectrum of the beams. What is to be done in such cases?

M. POTIER-FERRY:

Cellular bifurcation. Application to plate and shell buckling

We study bifurcations of real periodic solutions that appear in many physical problems: convection, plate buckling, shell buckling. These problems are studied by multiple scale expansion. So one gets amplitude equations that are spatially modulated. In the supercritical case, the second order amplitude yields the existence of many solutions that are characterized by their wavenumber. The same amplitude equations are obtained for any 'reversible' system that satisfies some spectral assumptions.

G.W. REDDIEN:

Computation of cusp singularities

A defining system for cusp points is given, allowing for undetermined problems of arbitrary index. The approach allows the treatment of cubic turning points, winged cusps and degenerate minimizers in the same framework; the two parameters are treated symmetrically. The defining system can be solved effectively by Newton's method since explicit expressions are given for all the needed derivatives. Finally, a discretization error analysis is given for projection methods applied to the system.(Joint work with A. Griewank).

D. ROOSE:

Parallel algorithms for continuation of partial differential systems

We discuss how continuation procedures for partial differential equations can be adapted to local memory parallel computers (e.g. hypercubes). If a finite-difference discretization on a fixed grid is used, one can apply a 'classical' predictor-corrector continuation procedure in which the linear systems are solved by a parallel algorithm. The problems associated with this approach are indicated.

Recently some interesting continuation procedures based on multigrid methods were developed. It is shown how these procedures can be parallelized. Some preliminary estimates of the efficiency of such a parallel algorithm are given.

J. SCHEURLE:

Exponentially small splitting of separatrices and bifurcation

For systems with a homoclinic orbit that are forced with a term having amplitude δ and frequency $1/\varepsilon$, it is known from work by Phillip Holmes, Jerrold Marsden and myself that under suitable conditions, for sufficiently small δ, the separatrices split, if at all, by an amount of the form $C \exp(-r/\varepsilon)$ for constants C and r. Moreover, if $|\delta| \le \varepsilon^p$, where p is a sufficiently large integer and ε sufficiently small, Melnikov's method is applicable to detect the splitting and also the transversal intersection of the separatrices implying chaos. Besides motivating and reviewing this theory we discuss an application in bifurcation theory.

K.R. SCHNEIDER:

Invariant Cantor sets in singularly perturbed systems

Consider singularly perturbed systems of the type

(*) $dx/dt = f(x,y,\varepsilon,\alpha)$, $\varepsilon dy/dt = g(x,y,\varepsilon,\alpha)$

where ε is a small parameter, $x \in R^n$, $y \in R^m$, $\alpha \in R^k$. Assume that $g = 0$ has the solution $y = \varphi(x,\alpha)$ and that the degenerated system

(**) $dx/dt = f(x,\varphi(x,\alpha),0,\alpha)$ has for $\alpha = \alpha_0$ a homoclinic orbit γ to the equilibrium point $x = 0$ such that (**) has an invariant Cantor set near γ. In the two cases

(a) rank $f_x(0,0,0,\alpha_0) = n$, $\dim(T\mathfrak{M}^s_x \cap T\mathfrak{M}^u_x) = 1$ for $x \in \gamma$
where $T\mathfrak{M}^s_x$ $(T\mathfrak{M}^u_x)$ is the tangent space of the stable (unstable) manifold of γ at x

(b) rank $f_x(0,0,0,\alpha_0) = n-1$, $\mathfrak{M}^{cs}$ and $\mathfrak{M}^{cu}$ intersect transversally where $\mathfrak{M}^{cs}$ $(\mathfrak{M}^{cu})$ is the center-stable (center-unstable) manifold of γ

we derive sufficient conditions that the singular perturbed system (*) has also an invariant Cantor set near γ for ε and $|\alpha-\alpha_0|$ small.

P.R. SETHNA:

Bifurcations of surface waves

Surface waves in a nearly square container subjected to vertical oscillations are studied. The theoretical results are based on the analysis of a a derived set of normal form equations, which represent perturbations of systems with 1:1 internal resonance.

and with D_∞ symmetry. Bifurcation analysis of these equations shows that the system is capable of periodic and quasiperiodic standing as well as travelling waves. The analysis also identifies parameter values at which chaotic behavior is to be expected. The theoretical results are verified with the aid of some experiments. Implications of the analysis to other physical problems are discussed. Global bifurcations of a system with 1:2 resonance are also discussed.

R. SEYDEL:

Bifurcations in a Marangoni problem

Zone refining of cylindrical rods of silicon material is strongly affected by surface-tension-driven convection. Under some symmetry assumptions a 2-D Navier-Stokes problem is set up and solved numerically. Various branching diagrams are presented, reporting on the dependence of solutions on the Nusselt number and the Marangoni number. Based on the computational experiences, difficulties inherent to continuation are discussed. Several postulates on continuation are stated, some of which recommend to double-check computational results carefully.

A. SPENCE:

On the calculation of paths of Hopf bifurcations

Consider a two-parameter nonlinear problem whose linearization has a double zero eigenvalue with only one eigenvector. In the talk a theoretical and computational analysis of the bifurcating branches at this singular point is given using a symmetry in the system used to calculate Hopf bifurcations. The result is that standard branch-switching techniques can be used to jump on to the path of Hopf bifurcation points emanating from the singular point.

A. STEINDL, H. TROGER:

Coupled Hopf and divergence bifurcation of pipes conveying fluid under O(2)-symmetry

Following the investigation by Bajaj and Sethna, the bifurcations of the trivial steady state solution of an elastic pipe conveying fluid is considered. In the model damping and gravitational forces are included; in addition a rotationally symmetric elastic support with stiffness K is introduced. By fixing K and varying the fluid velocity U either a Hopf or a divergence bifurcation occurs. For a certain value of K an interaction of both bifurcation types takes place. Studying the equations of motion on the 6-dimensional center manifold for small variations of the critical parameter values K and U rotating waves, standing waves, stationary states and different interactions of these solution types, e.g. modulated waves, are found.

C.A. STUART:
Bifurcation of homoclinic orbits and bifurcation from the essential spectrum

For a nonlinear 2nd order ODE over $\mathbb{R}$, bifurcation of solutions in terms of the $L^p(\mathbb{R})$ norm was discussed. The solutions tend to zero at $\pm\infty$, so that they are associated with homoclinic orbits. The method used amounts to making an appropriate rescaling of the problem and then continuing a homoclinic orbit of the rescaled equation. Conditions for doing this can be found via bifurcation from a simple eigenvalue using the phase of the basic solution as eigenparameter. The result reduces to finding simple zeros of a Melnikov function. Related work is due to Robert Magnus.

E. LINDNER, A. STEINDL, H. TROGER:
Bifurcations in the motion of robots

The periodic motion of a single DD-robot, i.e of a plane double pendulum with drive moments acting at its joints is studied. The motion of the endpoint of the double pendulum is supposed to be on a circle and having constant speed ω_0. For a fixed control system ω_0 is increased quasistatically until the periodic solution looses stability. Calculating the Poincaré mapping and making use of the center manifold reduction, all three one parameter losses of stability which occur generically are found and analyzed. They are (i) transcritical (ii) Flop (iii) Hopf bifurcations. The corresponding physical behavior of the robot is shown to be (i) a small shift (ii) a double periodic motion (iii) the motion on a torus.

K. ULRICH:

Higher order predictors in continuation schemes

For numerical continuation schemes variable higher order polynomial predictors are presented which allow for simultaneously monitoring step size and direction. Only first order derivatives have to be calculated, no numerical differentiation process is required to compute the additional corrector terms.
This kind of predictor process can also be viewed upon as a special reduction method using polynomial approximating subspaces. Moreover, it allows for directly handling snap-through behaviour. An ellipse normalization condition is suggested to automatically monitor step length and direction adjustment in the subsequent corrector process.

M. VAN VELDHUIZEN:

On the numerical approximation of an invariant curve

The lecture discusses several numerical algorithms for the approximation of a smooth invariant curve. Among others are mentioned the algorithms of Thoulouse-Pratt, Chow and Doedel, Kevrekidis et al., Kaas-Petersen, and the author. Convergence results for the method of Kevrekidis with piecewise linear interpolation are briefly discussed.
In the second part of the lecture we discuss the approximation of the rotation number. Given an approximate invariant curve, an approximate circle map is defined, an algorithm for the approximation of the rotation number is mentioned. Finally, a convergence result is briefly mentioned and discussed with respect to the absence of superconvergence.

W. WEDIG:

Bifurcations in stochastic systems

In practical environments ergodic perturbations are generated by wind turbulences or rough surfaces in such a way that the system parameters are superimposed with corresponding time fluctuations. The paper gives some simple examples in structural, aero or fluid dynamic problems where multiplicative fluctuating terms are involved.

The stability analysis of such non-autonomous systems is based on Lyapunov exponents and rotation numbers which substitute the eigenvalues of time-invariant linear systems. For a stochastic modelling of parameter excitations they are calculable by introducing cyclic Lyapunov coordinates and taking the expected values via orthogonal expansions. For increasing noise intensities the deterministic solution, e.g. the equilibrium position of the dynamic system, becomes unstable and bifurcates into turbulent motions. They are bounded by cubic dissipation terms. Associated silent and noisy limit cycles are simulated by means of a Euler scheme. Normal forms are discussed.

B. WERNER:

Computational methods for bifurcation problems with symmetries

It is shown how group theoretical methods can be employed to utilize the symmetry of a bifurcation problem in numerical computations. The essential numerical point is the utilization of certain reduced instead of full systems, involving appropriate subgroups of the underlying symmetry group. The group theoretical tool is an a priori knowledge of the interaction of certain subgroups at (in general) multiple steady state bifurcation points. A bifurcation graph is introduced which shows graphically this information: its edges represent possible symmetry breaking bifurcations. The main numerical aspect presented here is the efficient detection of bifurcatio points. A 4-box and a 6-box Brusselator model (with dihedral symmetries) have been chosen to discuss the numerical procedure.

Inhaltsangabe des Tutorials

W. WEDIG:

Tutorial on stochastic differential equations

1. Stochastic processes:
   Stationary characteristics, white noise and Wiener process, linear time-invariant systems
2. Ito calculus:
   Stochastic differential equations, correction terms, Ito formula, diffusion equations, applications
3. Analysis and simulation:
   Taylor- and Hermite moments, generalized Hermite analysis, noise generator, cyclic coordinates.

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