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Elastic Structures with Snap-Through Characteristic for Closing Devices

Zusammenfassung

Instabiles Verhalten von festen und nachgiebigen Strukturen wird in den meisten Fällen der technischen Anwendung vermieden. Dennoch kann das instabile Verhalten von nachgiebigen Strukturen in Form von Durchschlag positiv eingesetzt werden. Das Durchschlagverhalten stellt eine sprunghafte Änderung von einem Gleichgewichtszustand in einen anderen dar.

Im Artikel werden signifikante Eigenschaften des instabilen Verhaltens in Form von Durchschlag beschrieben. Dies wird am Beispiel einer sphärisch geformten Struktur durchgeführt. Des Weiteren wird das Verhalten der Strukturen unter einem gleichmäßigen Außendruck und unter Berücksichtigung eines nichtlinearen, ideal elastischen Materials untersucht.

Summary

Instable behaviour of rigid and compliant structures is in most cases of technical applications an attribute which have to be avoided. Nevertheless instable behaviour of compliant structures can be used positively in form of a snap-through. An abrupt change will take place in case of a snap-through from a state of equilibrium to another state. The critical load complies with two or more states of equilibrium.

The article will show the significant attributes of instable behaviour in form of a snap-through. This will be illustrated by the example of a spherical shaped structure. In consideration of nonlinear material characteristics, the behaviour of such structures under pressurisation against geometrical properties was researched.

Keywords: compliant structures, silicone structures, instability, snap-through

Fundamentals of the snap-through behaviour of elastic structures

Fig. 1 presents the fundamental phenomenon of the nonlinear instability in the form of snap-through by force-displacement-characteristic in static case. *u* describes the displacement in a before specified point of the structure (usually this will be the apex in cases of spherical structures) and *F* displays the applied load, by which the structure is deformed.

The dependence of the displacement *u* to the lying close applied load *F*, which is shown in fig. 1, illustrates a curve with a local maximum D_2. Furthermore the axis will subtended by u=0, u=h_1 and u=h_2 [8], [10], [13]. The curve can be divided into two ranges, into the prior-critical range and into the post-critical range, whereby the prior-critical range picture the range for stable equilibrium.

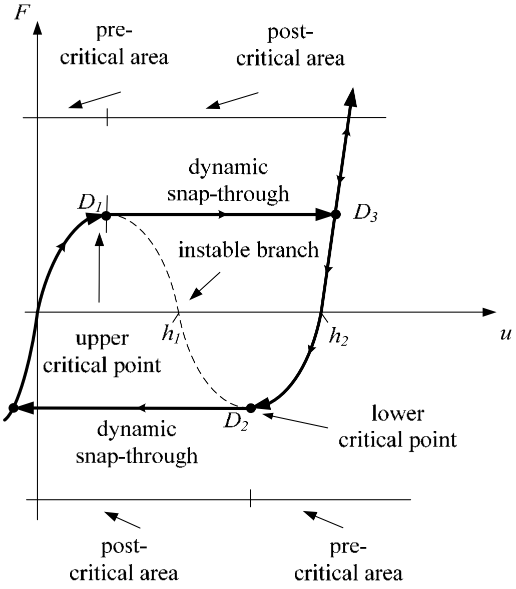


Fig. 1: Fundamental Force-Displacement-Characteristic of nonlinear Instability in case of Snap-Through

The post-critical range shows the range, which follows the local maximum D_1 and ends with D_3. This range is called unstable. In point D_1 an infinitesimally small power increase kinetic piercing is initiated [12]. During the snap-through procedure the structure is in an unstable equilibrium. A new equilibrium position D_3 follows the range of the instability, in which the system is stable during a constant load. With a further increase of the load the displacement runs again monotonous and rising; the system is on a „stable “branch.

Examined structures

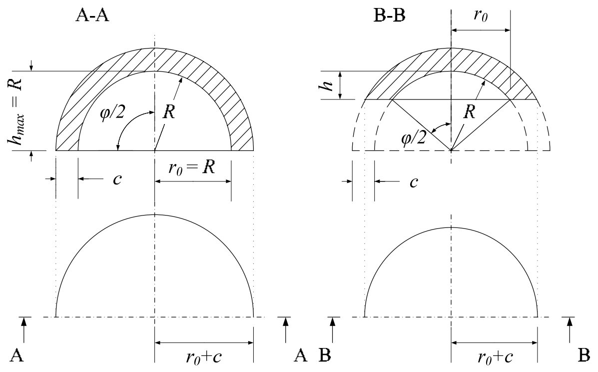


Fig. 2: Description of the examined Structures

The examined structures are *rotationally symmetric loaded spherical structures*. The geometrical dimensions are shown in fig. 2. The parameters drawn in fig. 2, are systematically modified in the course of the research, in order to determine the influence of the individual parameters on the critical load. On the one hand the height h of the sphere is being varied with constant wall thickness *c* and constant basic radius *R*. Thereafter the basic radius R and subsequently the wall thickness *c* will are changed, whereby in the respective case the two not regarded values are kept constant.

The research is accomplished with the FEM program system ANSYS 11 by using the arc-length method, how it is suggested by Crisfield [11, 15].

Moreover the structures will be calculated two - dimensional. Whereas the structures are all together rotationally symmetric, these can be provided with the software as 2D-Modell and will be defined as rotationally symmetric. This procedure saves substantial arithmetic performance and time. The material is defined in the program system with the material law after Mooney-Rivlin.

Results of FEM-calculation

The already existing researches at thin walled spherical shells were partially restricted to linear, ideally flexible materials to flat shells The following considerations take place under the use of a nonlinear, ideally flexible material at partly high ($h>R/2$) and thick ($r/c<10$) spherical structures.

On behalf of this analysis reference geometry with h=10 mm, c=1 mm and R=10 mm will be specified. All determined results are checked against the calculation of this reference. The geometrical ratio *height of the sphere to the wall thickness h/c* which is shown by Θ and the ratio *basic radius of the sphere to the wall thickness R/c* is displayed by *Ω*. Moreover dimensionless parameters have been used.

The geometrical ratio *height of the sphere to the wall thickness h/c* which is shown by *Θ* and the ratio *basic radius of the sphere to the wall thickness R/c* is displayed by *Ω*.

Fig. 4 and 5 show the curves of the critical load by that it comes to instability in the regarded structures. The graphs show the run of the load as a function of *Θ* for *Ω* from 3 to 8 in fig. 4 and for *Ω* from 9 to 16 in fig. 5. The curves start in each case with *Θ*, which corresponds to the snap-through able structures.

It can be seen in tab. 1 that *Θ*, with which the structures first snap-through, is rising with *Ω*. Furthermore fig. 4 and 5 show that a local maximum exist in the first third of the processes. The value for *Θ*, with which this minimum arises, grows likewise with the rising *Ω*, q.v. tab. 1. After the achievement of the local minimum, the critical load will increase again. For values of 6-16 the developing will branch out. These branching points show that there are theoretically several critical loads with the respective structure. The structure will snaps-through with increasing pressure two times, whereas the first snap-through has a local character and the following one is simply global.

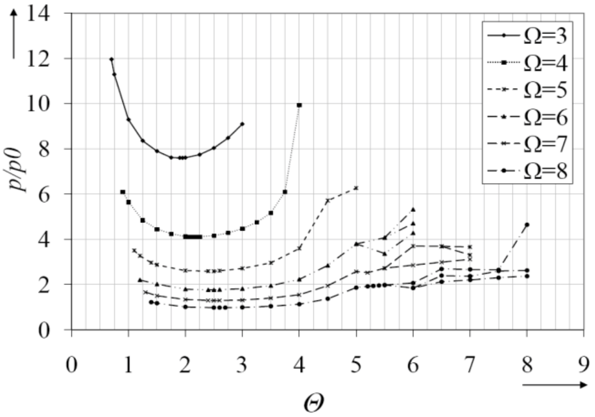


Fig. 3: Developing of the critical Loads against *Θ* for *Ω*=3-8

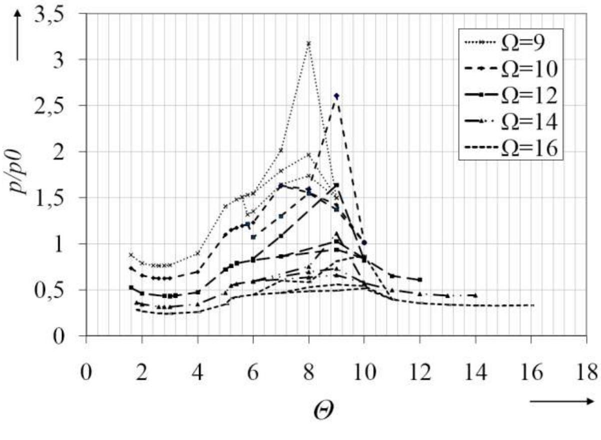


Fig 4: Developing of the critical Loads against *Θ* for *Ω*=9-16

Ω	Θ Beginning of the snap-through-ability	Θ Local minimum	Θ Local maximum	Θ First point of branching	Θ End of branching
3	0,7	1,9	0,7	-	-
4	0,9	2	4	-	-
5	1,1	2,5	5	-	-
6	1,2	2,5	6	5,5	-
7	1,3	2,5	6	6	-
8	1,4	2,6	8	6	-
9	1,6	2,6	8	6	9
10	1,6	2,8	9	6	10
12	1,6	2,8	9	7	10
14	1,8	2,8	9	7	10
16	1,8	2,8	10	7	11

Tabelle 1: List of the significant Data from Fig. 4 und 5

The value Θ, with which these branching points starts, grows with increasing Ω, q.v. table. 2. Moreover it can be recognized that the critical loads increase very strongly, and in 9-16 achieve a global maximum and drop very strong afterwards. This maximum of the load will be staggered rightwards with the increasing of Ω in cases of the researched structures.

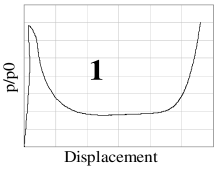
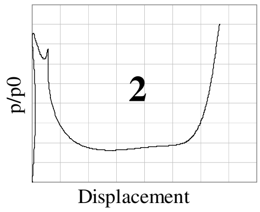
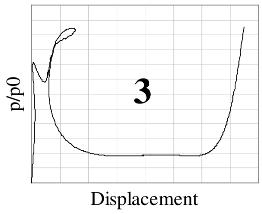
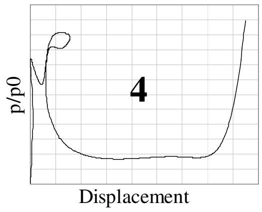
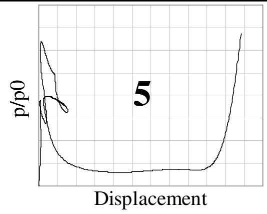


Fig. 5

Fig. 5 is schematic a typical load-displacement-curve of the researched structures, which is shown under the monitoring of the apex of the sphere. This run possesses a critical load. Again fig. 6 and 7 show a load displacement curve that reveals two critical points. In fig. 8 and 9 further load displacement runs are shown. These curves display three critical local maxima.

During further monitoring of the developing shown in fig. 4 it can be revealed that there is an intense decrease of the critical load after the local maxima and only one critical point exists from a specified Θ. Thus this means that there is a range in which the structures possesses more critical points for Ω=9–16. The values of the critical loads in the case of branching points are higher, than in the case without branching.

Ω	Θ	Curve	
6	5.5 6	2 4	 **Fig. 6**
7	6 7	3 4	
8	6 7 8	2 4 5	 **Fig. 7**
9	6 7 8	2 4 5	
10	6 7 8	2 3 5	 **Fig. 8**
12	7 8 9	3 4 5	
14	7 8 9	3 4 5	 **Fig. 9**
16	7 8 9 10	3 4 5 5	

Tab. 2: Characteristic Load-Displacement-Curves according to Θ and Ω

Application

Spherical structures with hyperelastic material properties and snap-through behaviour are outstanding suitable for the application in novel valve systems. The verification of the operability is realised by means of a test system with an integrated safety closing device.

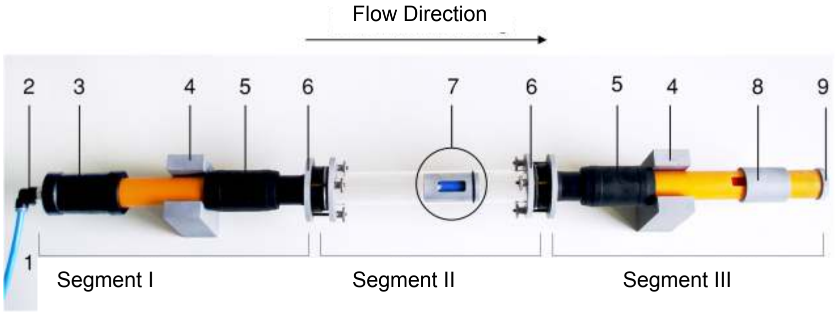


Fig. 10: Assembly of the Testsystem. 1 Pressure feed Pipe, 2 Compressed Air Connection, 3 Pipe End Cap, 4 Supporting Feet, 5 Pipe Flange, 6 Flange Connector, 7 safety closing device, 8 Sliding Sleeve for a Leakage, 9 Reducer

Fig. 10 shows the assembly of the testsystem which consists of three segments and shall represent a part of a gaspipe with integrated safety valve. Gas is filled in the first segment of the construction.

After this the gas flows through the safety closing device, which is located in the second one. Afterwards the gas issues the system on the end of the third segment.

In sector III of the testsystem a closable leakage is scheduled. The leakage shall adjust a damage of a gaspipe, for example in case of a digger attack. This clarifies the mode of operation of the safety closing system.

Fig. 11 shows the assembly of the safety closing device. This important functional component of the closing system is a closing body with hyperelastic material properties and snap-through behaviour. It has a duplex arched design on one of its frontend.

Fig. 11: Integrated Closing Device. The tnap-through body of silicone is fixed on part 1. The part 1 is inserted in part 3 and can adjust with a thread.

The unloaded initial position of the snap-through body represents a stable state. Loading the structure with an internal pressure a snap-through effect can be observed at a critical load. The initially inwardly vaulted face side of the closing body is reversed abruptly. The therewith associated translation is fundamental for the realisation of a valve function. A reduction of the internal pressure implies a snap-through effect again. The valve body passes into its initial stable state.

Fig 12: Snap-Through Body with Hyperelastic Material Properties.1 Initial State without Inner Pressure, 2 Under Pressure Load 3 After Decreasing the Load

To verify the operability of the snap-through body in the safety valve system, the testsystem is initially situated in the “normal state”, that means, the leakage is closed and gas flows through the complex. Subsequently the leakage is opened. Caused by the leakage, the flow speed in the safety valve is rising because there is an abrupt descent of the system’s pressure. It takes place a snap-through effect on the closing body of the safety closing system, whereby the valve passes into the closed state. Gas cannot flow through the testsystem anymore.

The operability of spherical shaped structures with hyperelastic material properties for the realisation of a valve function is demonstrated.

Summary

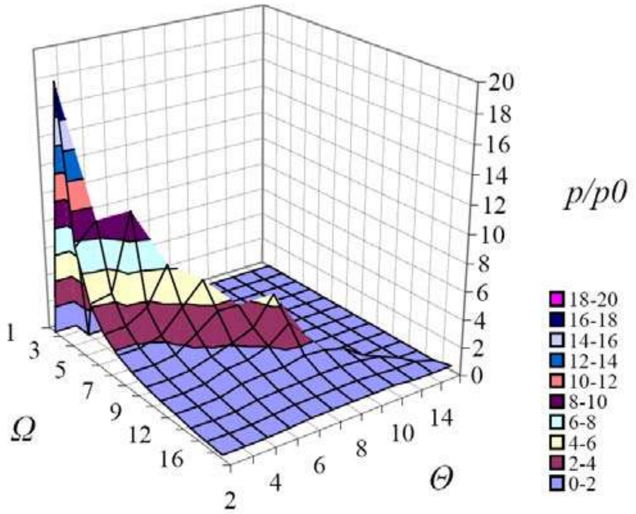


Fig. 13: Dependence of the Parameter Θ and Ω again the critical Load

The parameters Θ and Ω determine the snap-through ability of the examined structures. This coherence is displayed by fig. 10 once again. The diagram allows a local maximum Ω=4 and Θ=4 and/or with Ω=8 and Θ=8 and recognises a local minimum with Ω=7 and Θ=7. Furthermore it can be ascertained that the critical loads depend on Θ and Ω. In addition dependence of the load shift characteristic on the parameters Θ and Ω can be recognised. This coherence figures out that there are structures, which show several critical loads in the load-displacement-diagram of the apex. Further on it was possible to determine scopes of the parameters Θ and Ω, in which a clear snap-through effect was identified and areas in which an ambiguous snap-through effect has occurred.

The previously mentioned researches and results were made to provide a basis for the development of novel valves with snap-through for the application in piping systems for instead. These analyses are realized in the context of the project “Safe Pipe” and funded by the BMBF.

References

[1] R. Zoelly, Über ein Knickproblem an der Kugelschale, Dissertation Zürich, 1915

[2] Th. von Kármán, H. S. Tsien, The buckling of spherical shells by external pressure J. Aero. Sci.,(1939)

[3] B. Budiansky, Buckling of clamped shallow spherical shells Proc. Symp. On theory of thin elastic shells, Delft, 1959

[4] G. A. Thurston, A numerical solution of nonlinear equations for Axisymmetric bending of shallow spherical shells J. appl. Mech. 28 (1961)

[5] N. C. Huang, Unsymmetrical buckling of thin shallow spherical shells J. appl. Mech., 31 (1964)

[6] H. Weinitschke, On asymmetric buckling of shallow spherical shells J. Math. Phys.44 (1965)

[7] H. Kinkel, Durchschlaglasten elastisch eingespannter, flacher Kugelschalen unter Außendruck Dissertation Darmstadt, 1970

[8] A. Pflüger, Stabilitätsprobleme der Elastostatik, 3. Aufl., Springer-Verlag, Berlin, Heidelberg, New York, 1975

[9] M. Wessels, Das statische und dynamische Durchschlagproblem der imperfekten flachen Kugelschale bei elastischer rotationssymmetrischer Verformung Mitteilungen des Instituts für Statik der Technischen Universität Hannover, Nr. 23 (1977)

[10] H. E. Leipholz, Stability of elastic systems, Sijthoff & Noordhoff, Alphen aan der Rijn u.a., 1980

[11] M. A. Crisfield, A fast incremental iterative Solution procedure that Handles „Snap-Through“ Comp. & Struct., Vol. 13 (1981)

[12] Schneider, Verbesserung des Pfadverfolgungsalgorithmus für plastische Durchschlagprobleme mit abruptem Abfall des Tragvermögens LACER No. 2, 1997

[13] N. A. Alfutov, Stability of elastic structures, 2. Aufl., Springer-Verlag, Berlin, Heidelberg, New York, 2000

[14] Patent DE 10 2006 057 502.4

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