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# Modelling for the Shock-Impact Reactions of Potatoes

*Between harvest and consumption, the potato has to go through many procedures where the tuber is subjected to mechanical shocks. Although such blows are always damaging for the tuber substance, they are often unavoidable. Technology nowadays allows us to view the procedure from the point of view of product-protecting treatment of the potato. Here, a central role is played by the simulation of the shocks delivered to the tuber. A calculation concept for the simulation of such blows on the potato tuber is presented in the following report.*

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**Refereed paper for Landtechnik, the full-length version of which can be found under LANDTECHNIK-NET.com**

## Keyords

Simulation of food processing, shock modelling

Literature details are available from the publishers under LT 00204 or via Internet at http://www.landwirtschaftsverlag.com/landtech/local/fliteratur.htm

There is already a series of works looking into the effects of shock-impacts on agricultural products, in particular on the potato. On the one hand this work has been aimed at investigating and analysing the shock damage to such products and the requirements to avoid damage [1, 2, 3, 4]. On the other, to exploit the qualitative and quantitative damage caused by such shocks in the determination of specific mechanical material properties [5, 6, 7, 8]. Mostly, such investigations are based on the theory of the mechanical fundamentals concerning the contact of elastic bodies, in particular on the Hertz theory based on the contact of solid, elastic bodies [9], or on phenomenological linear viscoelastic theories [10, 11]. The practicability, even when limited, of attributing such homogenous properties of technical materials basically to agricultural materials and products, has been written about by different authors [2, 3, 12, 13].

The principle which is basic to the Herz theory – is that the material property of contacting bodies is linear elasticity according to the generalised Hooke Law. In the following, however, grounds are to be introduced which should force us to look for other, or for expanded, concepts than the Herz theory for the forcing-through or impacting of solid bodies consisting of real material.

- Energy dissipation (transition of an unchangeable form of energy into heat energy or vaporisation) is an important property of the problem to be tackled.
- The geometries of the surfaces of the contacting bodies do not correspond with the areas 2nd grade established as a basic by Herz, or are forced to change during the contact (scraping-off or breaking-off of material during the contact deformation).
- The elastic component in the description of the material behaviour is not only dependant on the deformation in a linear way.

### Rheological concept for potato shock-impact

Often offered as a reason for the force-deforming behaviour of bodies are concepts in the form of rheological models under phenomenological and discrete points of view of the behaviour of the body or material. As a rule, the rheological model here features combinations out of elastic terms, viscous absorbency and friction as well as out of discrete materials. While on the one hand the flexibility of this model concept can be increased to almost any extent through heightening the number of components in the combination , there is, on the other side, the difficulty of identifying the parameters of the components in this combination in a concrete application case. Additionally, there is clearly a higher effort required in the treatment of the model in the analysis and in the numerical calculations.

The following pregnant material or tissue properties are to be observed in connection with the further-development of the rheological models for raw potato tissue:

- progressive elastic line
- developed non-linear velocity-dependant absorbency behaviour
- plastic deformation in the case of low frequency, cyclical load (frequency <29 Hz) takes place primarily in the first load cycle

*Table 1: Laws of force for the terms of the rheological model*

| Model term | Force movement dependency |
|---|---|
| Plasticity I | $c_p\ (x_{II} - x_I)$ für $\dot{x}_{II} < \dot{x}_I$<br>FP,I = ((Klammer einsetzen))<br>0 für $\dot{x}_{II} \le \dot{x}_I$<br>with: cp - plastication constant |
| Viscosity I | $F_{D,I} = b_I\ (\dot{x}_{II} - \dot{x}_I)$<br>with: $b_I$ - shock absorbency constant |
| Elasticity II | $F_{E,II} = c_E\ (x_{III} - x_{II})^2\ \mathrm{sign}(x_{III} - x_{II})$<br>with: $c_E$ -elasticity constant |
| Viskosity II | $F_{D,II} = b_{II}\ 2/\pi\ \arctan\ (b_{II,S}(\dot{x}_{III} - \dot{x}_{II}))\ \lvert x_{III} - x_{II} \rvert$<br>with: $b_{II}$ - shock absorbency constant II<br>$b_{II,S}$ - constant jolt factor, $0<b_{II,S}<\infty$ |

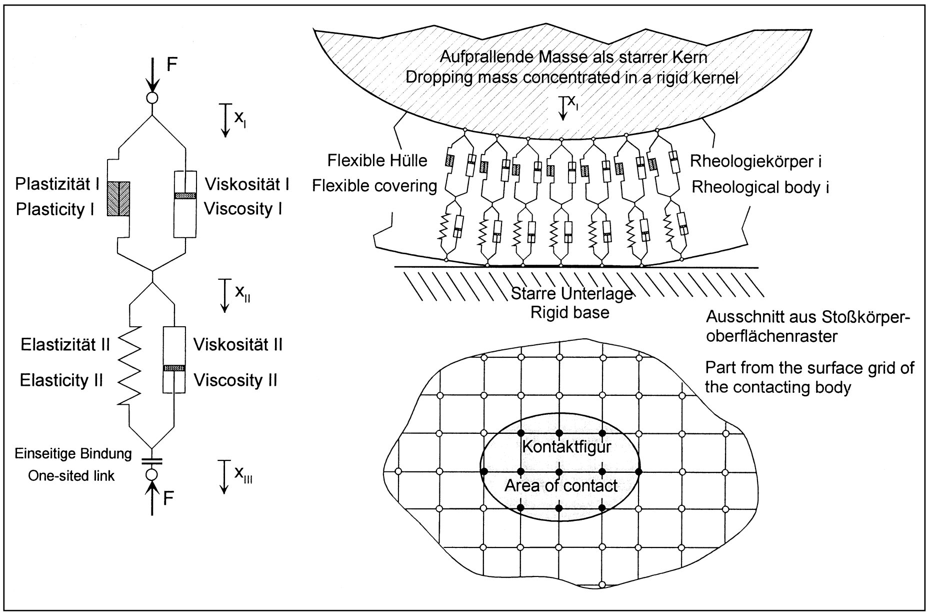

*Fig. 1: Rheological model approach and corresponding discretion of the potato tuber*

- developed long-term relaxation behaviour (stress reduction with constant deformation) with the result of permanent plastic deformation
- plastic deformation is only poorly developed in the case of high load frequencies or by impact-shock (shock length < 10 ms) itself. In other words, where shock impacts are repeated on the same tuber, a good reproducibility of the impact force-time-progress will be determined.

Based on these characteristics, the rheological model presented in fig. 1 for the description of the complex material properties of the potato tissue is suggested. The upper part of the model (Bingham body), with the terms identified through index I, serves here as the illustration of the slower moving energy dissipation and plastication. The integration of the one-sided link implies that the plastic deformation progresses only in one direction, it can, therefore, only grow larger. By high displacement velocities (or high load frequencies) the relatively large viscosity I has the effect of a'force short circuit' so that the rheological model suitable for that type of load almost takes on the appearance of a Voigt-Kelvin body (lower part of the model concept with the terms described through Index II).

In this, the individual terms of the model have the force-movement dependency as described in table 1.

The parameter of the rheological model influences the material behaviour in the following way:

- increase of the shock-absorbency constant I causes a slower-moving plastication which takes place first during the progress of a larger number of shock-impacts
- heightening the plastication constant resulted in a stress-caused lesser development of the plastic deformation
- heightening the shock-absorbency constant II led to a steeper rise in force and an earlier reaching of the force maximum in the first part of the force-time progress as well as a drop which at first also looked as steep as the rise in the curve, with a flattening out in the end
- heightening the elasticity constants led to higher reaction forces of the rheological model as well as to a shortened shock-impact length and to stronger plastic deformation.

In the next step, the geometry of the surface of the impacting bodies was brought into the picture. Here, the contact figure (pressure area) is discreted with a raster screen. Almost vertically to the pressure area , a rheological body in the form of the suggested model is brought to every raster point. Fig. 1 emphasises this action. For this reason, it has to be mentioned regarding the physical background that the three-axial tension-expansion situation which actually occurs, and is developed in the contact influence zone (as also through the Hertz theory model described), was not taken account of in this modelling. The actual force-deformation relationship available through measurements (including the dependency of the deformation on velocity) was realised through matching the parameter of the parallel-ordered, single axial loaded and deformed, non-linear rheology model. Under the presupposition that, on the contact surface, no shear tension takes place, the alternate conditions result in the integral resulting from the contact figure of the vertical tension applied on this area, being equal to the sum of the reaction forces of the individual rheological body.

With regard to the impact body geometry it can be taken that, with this approach to the modelling of the visco-elastic-plastic properties of the body, that the grid distances in the discrete raster are matched to the deformation relationships on the surface of the body.

## Key conclusions

The investigations have shown that the impact-shock properties of potatoes can be mathematically modelled to a good approximation. Limits were depicted with the use of an oscillating mechanical surface peeler on the skin. For the application of the described method it must be explained that the influence of the mechanical properties through the great variety specific attributes present with potatoes, and their dependence on length of storage and conditions of storage, has to be taken account of in the practical application of the process.

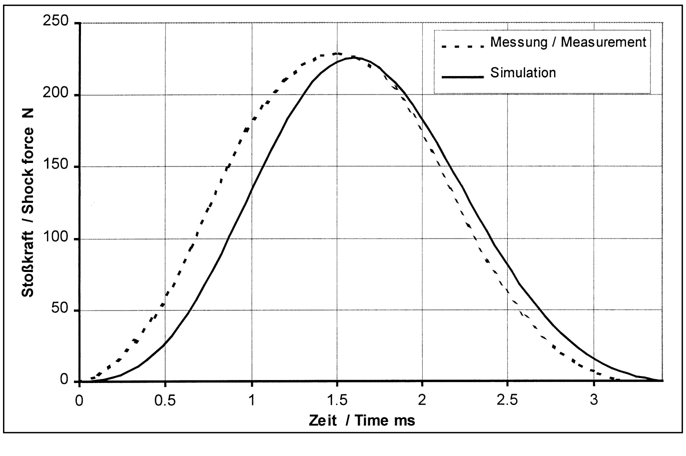

*Fig. 2: Exemplary comparison of shock force – time function by simulation and from measurement*