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Modelling of cutting technique for dry peeling of potatoes

A large proportion of potatoes are peeled fresh before cooking preceding shipment to the consumer. A newly conceived peeling method has the potential of minimising current high losses and environmental pollution. Modern peeling utilises knife-type cutting. Further to an investigation of mechanical peeling with spatially oscillating knife plate, a modelling calculation for simulation of cutting is presented. This is closely associated with a modelling of impact reactions of potato tubers already presented in this publication [1].

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Through normal angular geometry of blade entry into an object when cutting, extreme local tension-deformation conditions result, leading to breakage or destruction of tissue and to progress of the cutting action. This features a very complex spatial tension situation in the influence zone of the cut. The engaged tension-deformation conditions are, alongside the macro and micro geometry of the cut, influenced by parameters such as friction of the cut object tissue on the cutter surface (especially the blade flank), the visco-elastic flexible properties of the cut object tissue, tissue density distribution within the cut object and through the actual cutting action (direction and amount of relative velocity between blade and cut object).

Many investigations into this subject, and especially on cutting of agricultural products, assume a defined relationship for the blade and its movements as well as for the cut object and its movement [2, 3, 4]. But the cutting action of a controlled active blade through a free- moving potato tuber gives a movement direction primarily from interaction of forces between the blade and tuber. Therefore simplified assumptions which finally establish these interactive forces in relationship to momentarily relative movement condition between blade and tuber are required.

Theoretical calculation and assumptions

In principal it can be assumed that the blade is much firmer than the cut object and thus the blade form does not change. Additionally, the modelling calculation used here is based on the assumption that the cutting action can be sub-divided into tissue destruction directly at or before the blade front, and destruction mainly on the blade flanks, but also on the destruction-free tissue deformation taking place before the following part of the blade, a round cross section blade (cutting wire), cut or destroyed the tissue and the defined geometry of the blade flanks deformed the newly-created surfaces caused by the cutting and also the underlying tissue. Parts of the cut object further away from the cutting influence zone remain uninfluenced. If it is considered that in the special case of potato peeling on a fast-moving knife plate with relatively small cutting holes, the possible thickness of the peel is very limited because of reduced through-pressure making the peel almost flexible, it suffices for an agreement on the interactive forces between tuber and knife plate to determine the relationship at the blade front and the upper blade flank. Not considered here is the effect of the tensioned cutting angle caused by the blade flanks.

As long as the envisaged cutting wire moves vertically to its axial direction, it cuts the tissue (marked tissue texture not considered) completely consistently independently of the direction (normally executed cut).

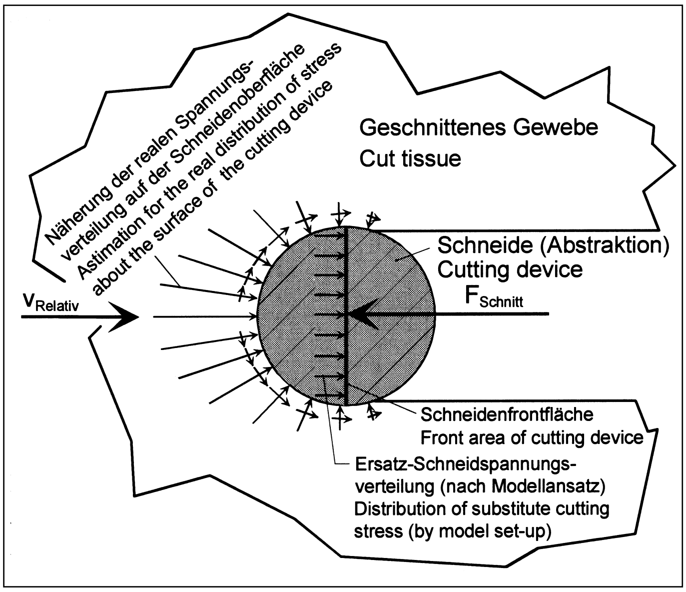

Fig. 1: Diagram of actual tension distribution before the cut and of substitute cut tension

However, should movement components be added in an axial direction (pulling cut), the cutting action is substantially altered. On the one hand strong shear tensions are then created on the affected surface between tissue and blade front, on the other an absolute tissue abrasion occurs through the roughness of the blade material. In the special case of the circular hole blade it can be expected that here the normally carried-out or „hacking“ cut occurs much more commonly than the pulling cut. Because of this, a calculation was used for the determination of cutting forces based only on the force and movement components acting vertically to the blade front.

It was assumed that the required forces for the advance of the relative movements between blade and cut object remained in balance with the product of the blade front surfaces and a substitute tension applied at tissue break *(Figure 1)*. The relative velocity influenced the amount of tensions and forces in the model through its direction only and not through its force. The size of this substitute tension can be regarded as a specific value for real tissue and real cutting and to be determined in special trials featuring flat blades with limited flank lengths. In the case where the relative movement of the tissue compared with the blade does not take place in the direction of cut angle caused by the blade flanks but instead vertical to the blade flanks, the visco-elastic tissue properties created as part of the impact model produce a pressure working against the movement on the total contact surface, or an appropriate force.

Conversion into a model

The basis of the cutting model is a discretised surface. The same discretisation is also necessary for the impact model. The result of the discretisation is tissue elements with longitudinal rectangular shapes. The totality of these tissue elements creates the external flexible hull of the tuber to be cut. *Figure 2* outlines the cutting action on the discretised structure.

The visco-elastic element A transmits the movement of the core in an undeformed, force-free environment through its kinematic coupling with the rigid mass core. With the advance of the movement in terms of time, it is pressed against the blade front. The appropriate reference point serves for determining position, velocity and deformation on the surface area side ends of these elements.

The fore-lying element B is being entered by the blade at that moment. At first movement of the blade into the tissue represented by this element, a fixing of the point of insertion takes place in a radial direction through applying a radially-moved cutting reference point. After the cut has taken place through the total element, the element reference point is set on the cut reference point for the actualisation of the tuber surface geometry. The visco-elastic tissue characteristics were ignored in the modelling of the cutting forces which was based purely on velocity according to the type of a friction (direction of velocity).

The visco-elastic elements C, D and E are already cut whereby their element reference points were radially moved. The element C touches, in observed condition, the blade flank. Through this, it is deformed in radial direction which, because of the conversion of the impact results to normally adjusted reaction forces through the visco-elastic terms thereby also leads to tangential directed frictional forces on the blade flanks. The elements D and E lie outwith the contact figure and are therefore force-free.

The cutting force comprises two components. The first component $F_{\text{Schnitt, Front}}$ lies at a tangent to the knife plate thus positioned normally on the blade front and shown within the level tensioned by the plate depending on the cutting reference point of the elements along the direction vector u in the direction of the middle point of the blade hole. The second force component $F_{\text{Schnitt, Flanke}}$ results during the cut from the relative movement between tuber and knife plate vertically to knife plate level and progresses in this direction. This remains under the influence of the blade flank effect and is suitably corrected.

Final remarks

Within the conducted trial on peeling action through hole cutting which features many individual cuts on the tuber surface, the demonstrated model application proved practicable. Many trials were carried out, particularly for determining breaking-tension values and directional factors. A sign of the correct presentation of the cutting forces and, in association, also the impact forces, is the movement path of the unrestricted tuber on which calculation and trial agree to a great extent which was created by these forces. On the basis of the model for the cutting as well as the impact procedure, calculation of the peeling depth distribution over the tuber surface is possible.

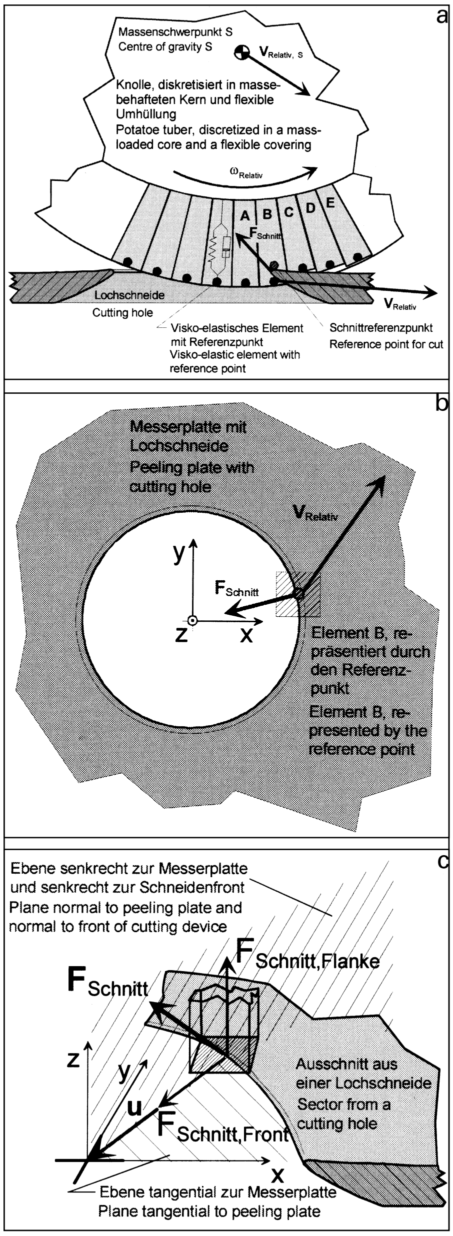

Fig.2: Determination of forces during cutting of discretised tuber model
a) side view, b) plan view, c) cutting force components

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