A ROTARY CUTTER FOR CUTTING OF GLUCOSE TEST STRIPES

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Abstract. This paper presents the design and characteristics of a rotary cutter for cutting of glucose test stripes. It comprises all needed recommendations for cutting head geometry parameters and the selection of proper bearings. Factors affecting the accuracy and working capacity of the device have been analyzed as well.

Keywords: rotary cutter, test strips, angle of cutting, accuracy of assembly

1. Introduction

Rotary cutters are used for cutting of test strips for measuring the glucose content in the human blood (figure 1).

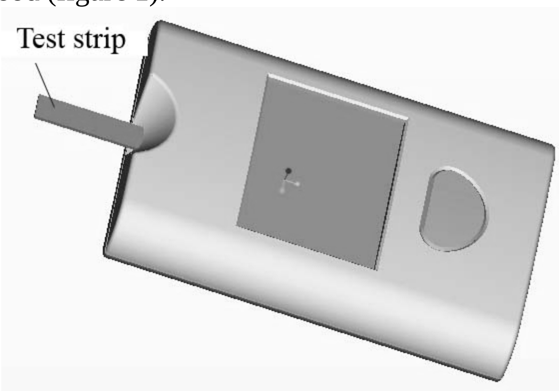


Figure 1. Blood sugar level measuring device

Analysis of the usage of those devices in Bulgaria shows a significant increase in their demand over the past 10 years. In the year 2006 the country needs 75 000 000 test strips.

The test strips are cut from a plastic multilayer active wafer ("sandwich" type with a textile grid) with dimensions 340/340 mm and thickness of 0.6 mm (figure 2).

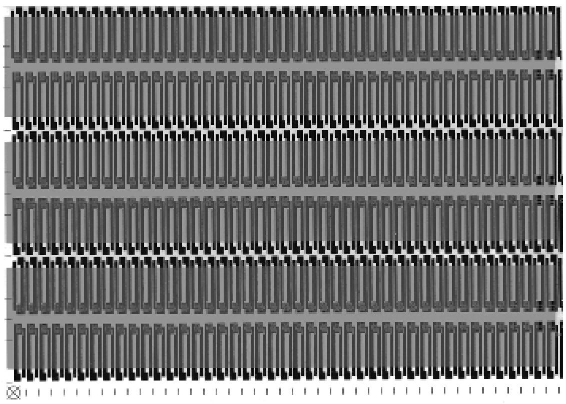
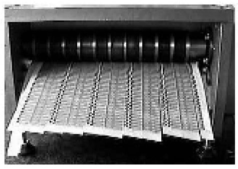


Figure 2. Wafer for test strips for measuring blood sugar level

Wafers are firstly cut out into 10 340/30 mm strips (figure 3a; 3b), and after that the strips are further divided into 50 smaller 30/6 mm pieces (figure 4a; 4b).



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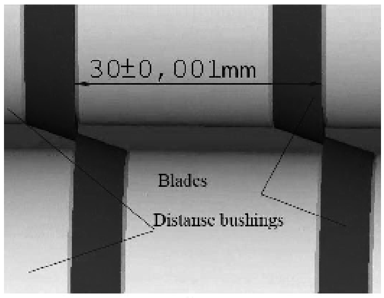

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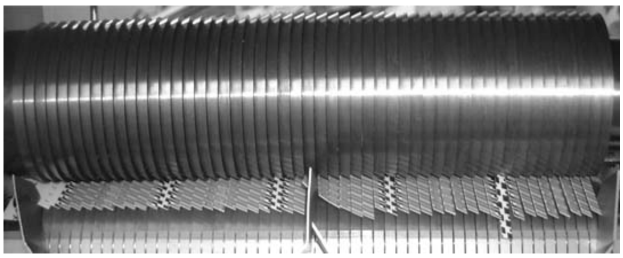
Figure 3. Wafer dimensions



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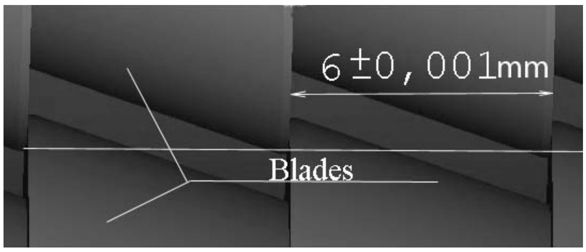

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Figure 4. Cutter blades

2. Determination of accuracy characteristics of the cutting heads

The nest of the glucose meter, in which the test strips are inserted, has an electric contact system. In order the test strip to form a contact without falling from the nest their width has to be within 6 ± 0.05 mm.

To ensure the high efficiency of the device, the head of each rotary cutter (figure 4b) contains 51 pairs of rotary blades. Since the width of each strip has to be within 6 ± 0.05 mm, the deviation of the position of a pair of blades (that perform a single cut) has to be within ± 0.001 mm (figure 4b). This is because of the accumulation of errors in positioning of blades during their production and assembly.

There are no initial limits for the tolerances for 30 mm width during the wafer initial cutting into strips (10 pieces in size 340/30 mm, figure 3a). However due to the nature of the wafer material (the presence of a textile grid on a plastic layer), the blades have to be tightly close together to ensure a quality of cut which leads to the same requirements for the production of the elements of the cutting head as mentioned above (figure 3b).

The rotary blades of both cutting devices are of the same type in order to facilitate the production (figure 5). The 30 mm cutting distance is secured by distance bushings (figure 3b). Limits in the dimension for each pair of blades that take part in the process of cutting /a total of 11 pairs of blades in the cutting head of the device/ is again ± 0.001 mm.

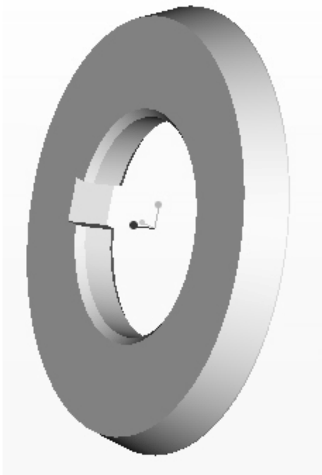


Figure 5. Rotary blade

In order to ensure the required accuracy the bases accepted for measurement during the manufacturing of the wafer (figure 2) has to be the same as the basis of the device.

Another requirement is that the bearings of the shafts of the cutting head must have an axial oscillation less than ≤ 0.001 mm as well as the possibility to modify the position of the shafts in order to ensure the blades positioned tightly close together (see figure 3 and figure 4).

Due to the significant length of the shafts of the cutting head, one of the bearing supports has to be floating in order to allow shaft elongation due to the heating. The other support has to be fixed on both sides.

Since the rotary blades have to be positioned tightly close together to ensure a quality cut, the bearings of the device have to be made with initial axial loading. This enables to use four-point contact ball bearings - a normal class of bearings for shafts support. Those bearings have to be positioned on the same side of positioning of the wafer on the device.

3. Specifics in bearings and rotary blades assembly

The minimal axial load needed for a proper operation of the bearings is given by the expression [1]

$$F_{am} = k_a \cdot \frac{C_0}{1000} \cdot \left(\frac{n \cdot d_m}{100\,000} \right)^2 \qquad (1)$$

where:

- F_{am} is the minimal axial load, N;
- k_a – coefficient of minimal load; $k_a = 1$ for bearings of the QJ2 series and $k_a = 1.1$ for bearings of the QJ3 series.
- n – frequency of rotation, min^{-1};
- d_m – mean diameter of the bearing.

It should be taken into account that a satisfactory performance of the steel balls in the bearing is achieved only when they are making contact with the rolling paths at two points, i.e. when the axial load $F_{am} \geq 1.27 \cdot F_r$ (F_r is the radial load on the bearing).

The four-point contact ball bearings have a limited ability to compensate misalignment of the axes of the bearing rings. Therefore, the same specifications have to be followed during the manufacture of the bearing nodes as for the axle nodes of metal cutting devices (axial misalignment with respect to a common axis ≤ 0.004 mm, the inner ring has to be fixed with a tightness of 0.001 … 0.005 mm on the axle-journal of the bearing, the outer ring construction has to have clearance in its opening) [2].

For the floating support, a regular ball bearing could be used with an inner ring tightness of

0.001 … 0.005 mm and an outer ring construction with clearance in the opening.

The rotary blades (figure 5) are mounted with a joint with clearance onto the shafts and are fixed in the axis direction by a nut [2]. Through this nut, preliminary axial load is introduced on the blades on each shaft in order to achieve the required size (figure 3b and figure 4b). This is done at the expense of elastic deformation at the contact planes of the rotary blades. This requires the manufacture of thicker blades due to the elastic deformations after the preliminary axial load.

4. Methods of determining the geometry parameters of the blade heads and the deice technical data

The main points in the design of the rotary cutters cutting head is the determination of the periphery velocity of cutting and the cutting force that originates in each blade. This force is further used for calculation of the required power of the engine, parameters of the gearing that perform the kinematical link between shafts of the cutting head (distance between the axes a – figure 6), and for the determination of parameters of geometry of the blades and the cutting head.

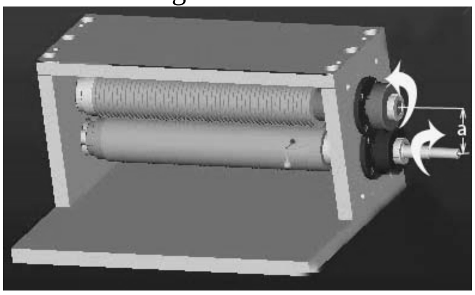


Figure 6. Design of the rotary cutters cutting head

The periphery velocity of cutting is determined from the perspective of the efficiency of the device as well as its ability to collect the strips in containers by specially designed groove (figure 4a). These grooves divide the stream into two parts with 25 strips each. On the base of analysis conducted on similar devices and the possibility of using worm reducer gear [3] and electric motors [4] that are offered on the market to drive the shafts of the cutting head, the commonly accepted periphery velocity of cutting is $V = 0.088$ m/s.

For easy manufacture and operation, the driving mechanisms of both devices (figure 3a and figure 4a) are made the same. This design decision is made after the precision analysis of the process of cutting. This analysis shows that the periphery force Q that appears in the area of cutting could be split into two components: P – the normal force of cutting, and F – the pulling force (figure 7).

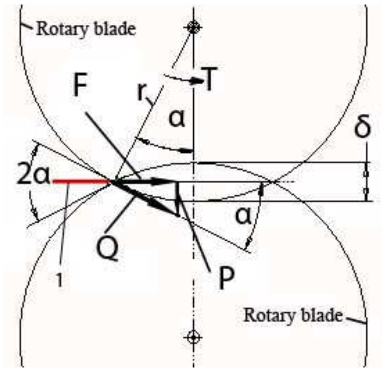


Figure 7. Forces in cutting process

To ensure the safe operation of the device, it is required that the pulling force F is able to move the wafer from position 1 from the beginning of cutting to its finish. This is possible only if the angle 2α ("angle of cutting") is smaller than its limiting value $2\alpha_b$ (where $2\alpha_b$ is the limiting angle of "biting" of the wafer by the cutting edges of the pair of rotary blades). Determining the value of $2\alpha_b$ is achieved by experiments, in accordance with figure 8, by observing a cutting of the wafer by a pair of ordinary scissors with point of contact between the cutting edges and the wafer that coincides with the point of intersection of the outer (edge) circumferences of the rotary blades. When $2\alpha \geq 2\alpha_b$, the wafer is pushed by the cutting edges of the scissors. At the point of "biting" of the wafer by the cutting edges of the scissors and the beginning of the process of cutting, the value of the angle $2\alpha_b$ is determined, which is taken into account when designing the geometric dimensions of the blades and the axes distance between the shafts in the cutting head.

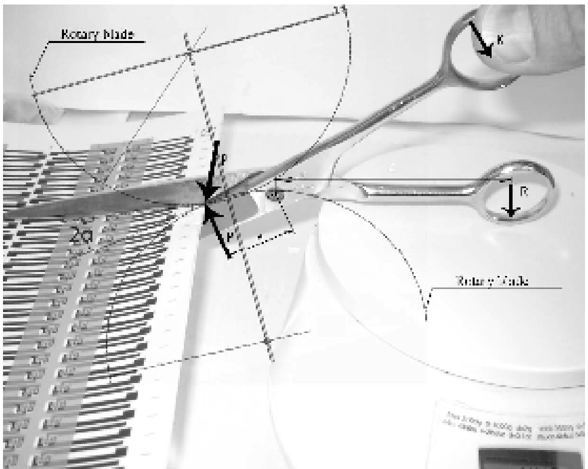


Figure 8. Measuring of cutting force

The force of cutting P is determined in the same experimental way. One end of the handle of the scissors is positioned on the working surface of electronic scales, which serves for determination of the normal reaction R in the support when a force K acts on the other end of the handle (figure 8).

From figure 7 and figure 8 it follows that:

$$Q = R \cdot \frac{L}{A} \cdot \frac{1}{\sin\alpha}, \quad \text{[N]} \tag{2}$$

$$F = R \cdot \frac{L}{A} \cdot \cot\alpha, \quad \text{[N]} \tag{3}$$

$$P = R \cdot \frac{L}{A}, \quad \text{[N]} \tag{4}$$

If we accept that the motion of the shafts in the cutting head is conducted by an electric motor through a worm gear drive, the power of the engine is calculated with the following expression [5]

$$N_m = 1.047 \times 10^{-4} \frac{T_{pn} \cdot n_{dv}}{i \cdot \eta}, \quad \text{[kW]} \tag{5}$$

where:

- T_{pn} is the torque of the shaft on which the rotary blades are mounted,

$$T_{pn} = Q.r, \quad \text{[N·m]} \tag{6}$$

- r – radius of the rotary blade, m;
- η – efficiency of the worm gear drive;
- i – speed ratio of the worm gear drive;
- n_m - angular speed of the electric motor, min^{-1}.

The determined values of $2\alpha_b$ and R are valid for the given geometry of the cutting edges of the scissors, which have to be taken into account during the design of the cutting edges of the rotary blades.

When calculating the torque T_{pn}, the forces of friction between the flat sides of the blades and the already cut part of the wafer have not been waken into account (see figure 3b and figure 4b). Therefore, the calculated power N_m has to be higher. Experimental verification shows that the overall torque in the process of cutting is many times higher than the calculated due to the forces of friction (in this case it is higher about 4 times for the device shown in figure 4).

With the experimentally found angle of $2\alpha_b$ (angle of "biting" of the wafer by the rotary blades) and an accepted value δ (of overlapping of the blades – figure 7), with regard to the thickness of the wafer and the number of times the blades are sharpened during the operation of the device, the radius r of the rotary blade can be determined as:

$$r = \frac{\delta}{2(1 - \cos\alpha)} \tag{7}$$

5. Analysis of the factors that affect the selection of rotary blades parameters of geometry

From the requirement $2\alpha \geq 2\alpha_b$ the value of 2α has to be determined. From the relation $r = a/(2\cos\alpha)$ it is seen (figure 9) that small fluctuations of the value of the radius r correspond to large fluctuations of the value of the angle α when a = const. (1 - for a = 55 mm; 2 - for a = 60 mm; 3 - for a = 65 mm). Therefore, inaccuracies during the manufacture of the blades could significantly alter the value of the angle α for a given axial distance a.

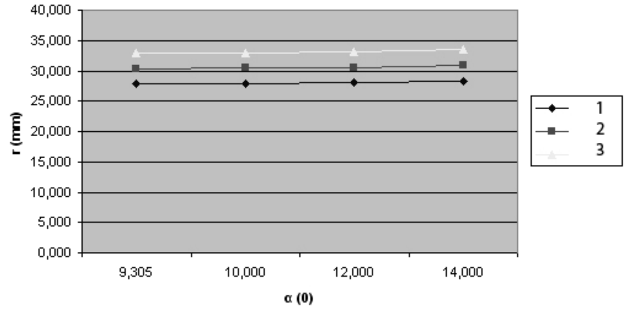


Figure 9. Variation of r with angle α

From the equation $\delta = 2r(1-\cos\alpha)$ it is obvious (figure 10) that when change angle α (when a = const.) the value of δ changes significantly in a non-linear manner (1 - for a = 55 mm; 2 - for a = 60 mm; 3 - for a = 65 mm).

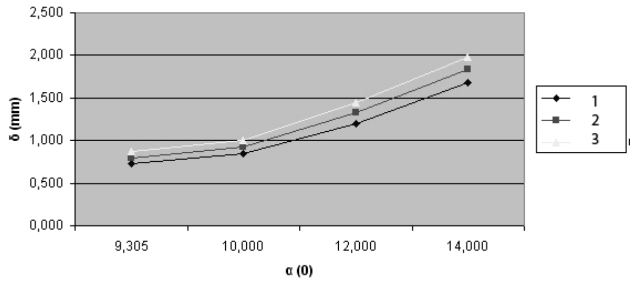


Figure 10. Variation of angle δ with angle α

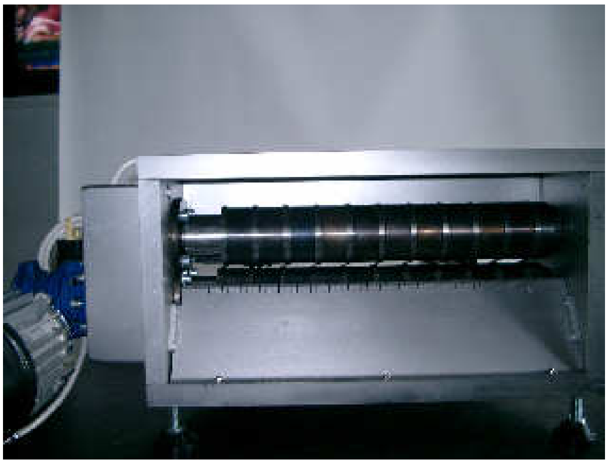
Hence, each sharpening of the rotary blades leads to a change in the angle α which will decrease its size.

6. Conclusions

From the information supplied so far it follows that during the machine design radius r of the rotary blades has to be determined initially according to the cutting head calculated deformation.

Later this value has to be further specified for a chosen δ in such a way that the relation $2\alpha \geq 2\alpha_b$ is valid.

In order to avoid breaking the necessary condition $2\alpha \leq 2\alpha_b$, due to errors during the production and assembly, the value of 2α should be 20…30% less than $2\alpha_b$. Smaller values will lead to a significant drop in the pulling force F in assembly of the rotary cutters (figure 11).



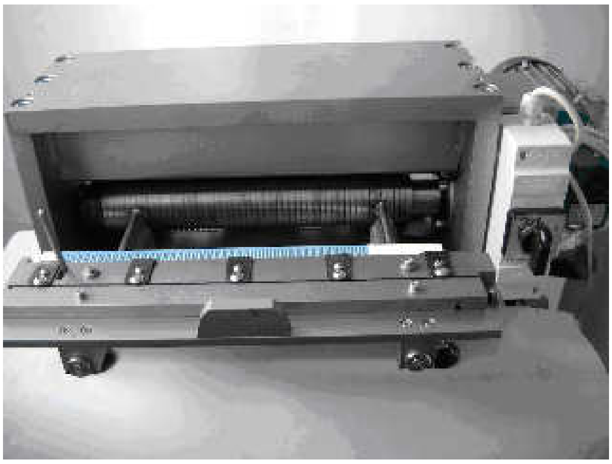


Figure 11. Rotary cutter

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