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DYNAMIC ANALYSIS OF A SYSTEM WITH THREE DEPILATION ROLLS TO REDUCE POWER CONSUMPTION

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Abstract: *The power consumption of machines with horizontal flow to depilate pigs is estimated to maximum load. These machines are made with two or three rolls (support and depilatories). Depending on their geometrical dimensions and positioning to the animal carcass which is subjected to depilation, couple can vary within limits relatively high.*
This paperwork aims to highlight and optimize the main geometrical and dynamic elements that can favor the reducing energy consumption of these machines
Keywords: *pig depilate, slaughtering*

1. GENERALITIES

The depilating operation occurs after total or partial scalding of pigs. Depilation can be performed manually with knives and metal cones, in the case of slaughterhouses of reduced capacity (fewer than 50 pigs per day), or using mechanized machinery specialized moving horizontally or vertically the carcasses. Uprooting the hair in the depilating machines is made by means of cadmium steel scraper fixed at the free end of some rubber blades, which in their turn are attached to drums with diameters, rotation ways and different angular speeds. For driving-off the hair pulled-out by the depilatory, during the process of depilation of carcasses they are sprinkled with hot water having a temperature of approx. 65^0C. The best results are obtained only if the scalding is immediately followed by depilation, without leaving time intervals which can favor some rigid links between hair and cells where the roots are fixed.
The physical principle of depilation lies in acting upon the hairs with a force capable of hanging them out, without producing mechanical damage of skin or under skin layers.
The necessary force for depilation is obtained from the drum where there are elastically fixed scrapers which comes directly in contact with the hair. Usually the mechanical operation of depilation has duration of 20 ... 30 s.

2. PRINCIPLES OF WORK SPECIFIC TO MECHANICAL DEPILATION

As a point of view of the working way, the depilating machines can be: with discontinuous and continuous functioning.
Generally depilate used form removing the hair after scalding use the traction method by lateral contact between the working device and the animal carcass. Depilation by this method is possible because the layers of skin and the contiguous layers shows resistance to the hair removal under the action of friction forces which appears at the surface between hair and skin, it is slipping being stopped by the skin which is more elastically and can be easy stretch.
Hair being rougher, takes a greater effort than the one expanding the skin under the normal force pressure upon the active working device, for the same specific elongation ε (Figure 1).
Therefore, when the traction force of hair is greater than the restraint force, it comes out from the skin.
In the case of lateral depilation, the normal size of pressing can be determined for two separate cases:

a. In the case where we can take into consideration only the restraint force of hair , and the inertia one and the friction one;
b. In the case we take into consideration, besides the forces mentioned above, the ones of skin stretching and the ones of slipping of working device of the machine

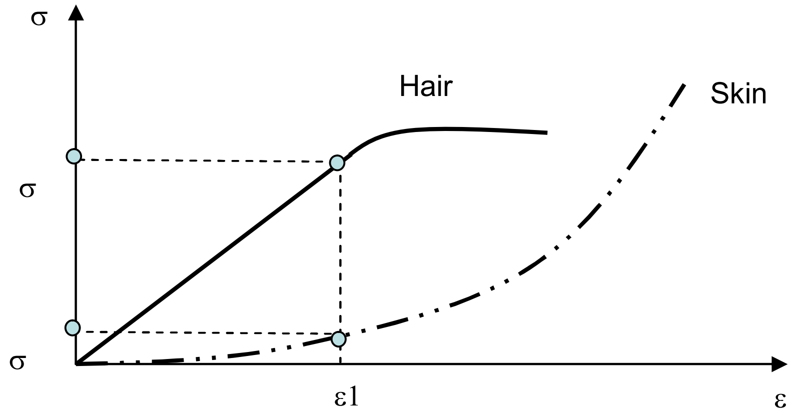


Figure 1. The unitary effort variation of σ depending by the specific length ε

Since in the first case are introduced simplifying hypothesis that do not take into account the extent of skin and the active slipping device of depilation upon the surface of carcass, for a complete dynamic analysis these effects can not be neglected.
Simplified loading scheme figure 2. It follows that the strength of hair wrench is:

$$F = \mu \cdot N = k \cdot (F_r + F_i) \cdot z + \mu_0 \cdot N\,, \tag{1}$$

where: N – is the normal force of pressing, N; μ - friction coefficient between hair and working device of the depilating machine; k – substitute coefficient for the pulling-out force (k=1,1…1,3); F_r – the restraint force of a hair, N; F_i – the inertia force of a hair, N; z – the number of hairs simultaneously pulled-out by the working device (take into account the number of threads per length unit, and by the width of the working device and its performance); μ_0 – friction coefficient between hair and pig skin. [1,2]

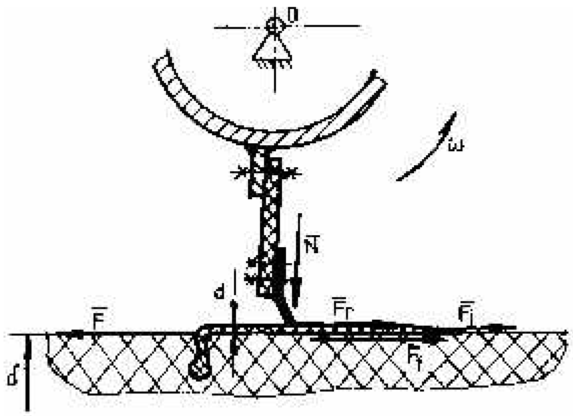


Figure 2. The principle scheme of mechanical depilation [1]

The inertia force and the one of restraint of hair are determined by the relations:

$$F_i = \frac{m \cdot v^2}{2 \cdot l_0}$$
$$F_r = \frac{\ln v_1 - \ln b}{a \cdot n}\,, \tag{2}$$

where, v – represents the tangential speed of deeply rollers acting device, m/s; v_1- the pulling-out speed of hair, m/s; m – the hair mass, kg; l_0 – the distance crossed by the hair during pulling-out, m; a, b – experimental constants which depends by the kind and the hair length pulled-out, with the following experimental values: a = 3,3 for big and thick hair and 7,3 for hair of middle dimension and b = 10^{-6}; n – weakness coefficient of restraint force after scalding (n = 8…10).
From the relation 1 results the normal expression force:

$$N = \frac{k \cdot (F_r + F_i) \cdot z}{\mu - \mu_0}\,. \tag{3}$$

If we take into account the slipping force between the active device and skin and also by the stretching of skin during the working process, the pulling-out force becomes:

$$F = k \cdot (F_r - F_i) \cdot z + F_f + F_p + F_a\,, \tag{4}$$

where: F_r and F_i, - have the same meaning, and they are determined in the same way just like in the precedent case; F_f – the friction force between skin and hair, N; F_p – the stretching force of skin during pulling –out the hair, N; F_a- the friction force by slipping between the surface of skin and the working device, N. The calculus expressions of those are:

$$F_f = \gamma \cdot \mu_0 \cdot N$$
$$F_p = \gamma_1 \cdot \sigma \cdot \delta \cdot l \quad , \tag{5}$$
$$F_a = (1-\lambda) \cdot \mu_1 \cdot N$$

where: γ - represents the u coefficient which takes into account the reaction of inner layers at pressing exerted by the working device; γ_1 – the coefficient which takes into account the stretching degree of skin to the inner layers ; σ- the unitary effort of skin stretching, N/m^2; δ - the medium thickness of skin layer, m; l – the width of working device of depilation, m; μ_1 – the friction coefficient by slipping between the skin surface and the working device of the depilating (μ_1 = 0,4…0,5 for the metallic working device and μ_1 = 0,5…0,6 for a working device made of plastic or rubber mass); λ - the fraction of normal force exerted upon hair (λ = 0,2…0,25); (1-λ) – the fraction of normal force exerted fraction upon skin (at pulling-out the hair of big and middle we consider λ = 1 and in the case of thin hair λ = 0,1…0,15).
But the pulling-out force caused by the pressing force is the resultant of friction forces between the working device, skin and hair:

$$F = N \cdot [\mu \cdot \lambda + (1-\lambda) \cdot \mu_1] \tag{6}$$

With the relations 4 and 5 result:

$$N = \frac{k \cdot (F_r + F_i) \cdot z + \gamma_1 \cdot \sigma \cdot \delta \cdot l}{\mu \cdot \lambda - \mu_0 \cdot \gamma} . \tag{7}$$

the normal force pressing expression of working device without simplifying hypothesis.
The normal pressing value is limited by the tearing resistance of skin, respective of hair:

$$N < \frac{\sigma \cdot \delta}{\mu_1}$$
$$N < \frac{\sigma_1 \cdot \pi \cdot d^2}{4 \cdot \lambda \cdot \mu} \cdot z \tag{8}$$

where σ_1 – is the unitary effort of tearing of hair, N/m^2, and d – the middle diameter of hairs, m.
As a point of view after ending the operation of scanding, the pigs are raised by means of mechanical forks and putted on the active devices of depilating machines. In terms of number of rollers (cylinders), depilating machines can be: with one, two or even three rollers scraper for uprooting hair.
In figure 3 is presented the principle scheme of depilating machine with two rollers. It is observed how the animal body is supported on a corrugated roller 1 and one with elastic elements of depilation (scrapers), 2. In order to limit the motion of the animal carcass 3 to right, it is used a support lattice 4, made of steel pipe. The roller with scrapers presented in the figure has the surface covered by a rubber coating with textile insertion 5, where are fixed the steel scratching plates 6. During the depilation operation, the carcasses are being washed with warm water thorough a shower system 7. Some machines are equipped to the inferior part with gathered hair. In a, b, c details of figure are presented different constructive shapes with rollers (with scrapers putted on the elastic coating of roller, with scrapers putted on blades and with flexible nonmetallic scrapers).

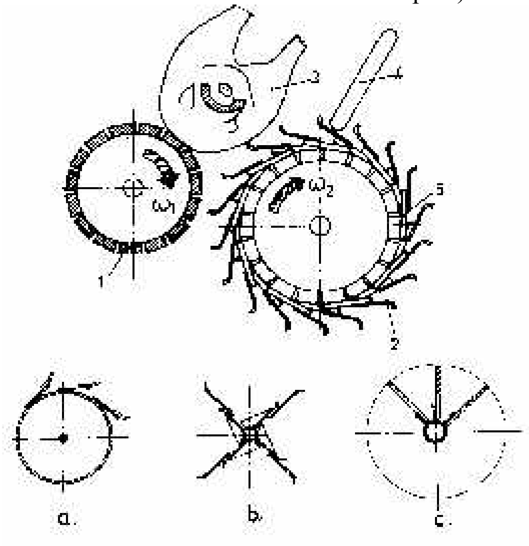


Figure 3. The principle scheme of depilation machine with two rollers [1]

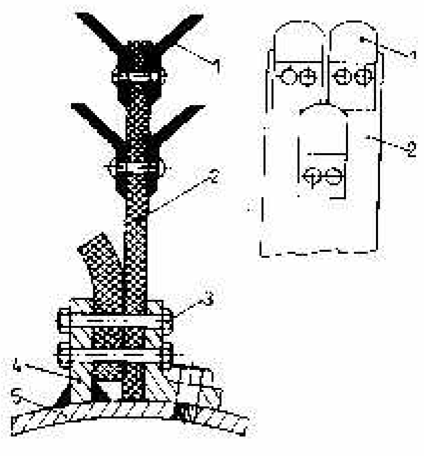


Figure 4. The assembly of scrapers on the depilation roller

In figure 4 is presented the way of assembly of a roller. In the presented case, the metallically scrapers 1 are assembled by riveting on rubber blades with textile insertions 2, and these, to their turn, are assembled by the help of screws 3 on the metallic blades 4 welded on the surface of steel cylinder 5. The ratio of rotaries speed between the supporting roller and the one of depilation is of ½ (for example 70, respectively 140 rot /min.). The supporting roller also realizes a preliminary cleaning of the carcass. The duration of depilation operation in a machine with discontinuous functioning is 18…40 s, being influenced by the resistance of hair and by the number of depilating rollers.
Given a number of shortcomings related to the efficiency of depilation of some machines with two depilating rollers, the paper aims to analysis the dynamic process of depilation using 3 rollers dimensioned and positioned properly.

3. THE GEOMETRY AND DYNAMICS OF DEPILATION EQUIPMENT WITH THREE ROLLERS

In order to determine the influenced factors upon the dynamics of depilation system with three rollers, in figure 5 is presented the geometrical model of disposing the rollers and of the carcass and also of the forces which occurs during de depilating process.
It is taken the carcass 1 of cylindrical shape, arranged horizontally on the lower rollers 2 and 3. The roller 2 is one grooved and the 3 one with depilating scrapers. Finishing operation of the carcass is made with the help of roller 4 equipped with eliminating scrapers of hair rests and of cells detached from the superficial layer of skin. Thus the carcass evacuated from the depilating machine will have a very high degree of depilation and of cleaning of superficial layer.

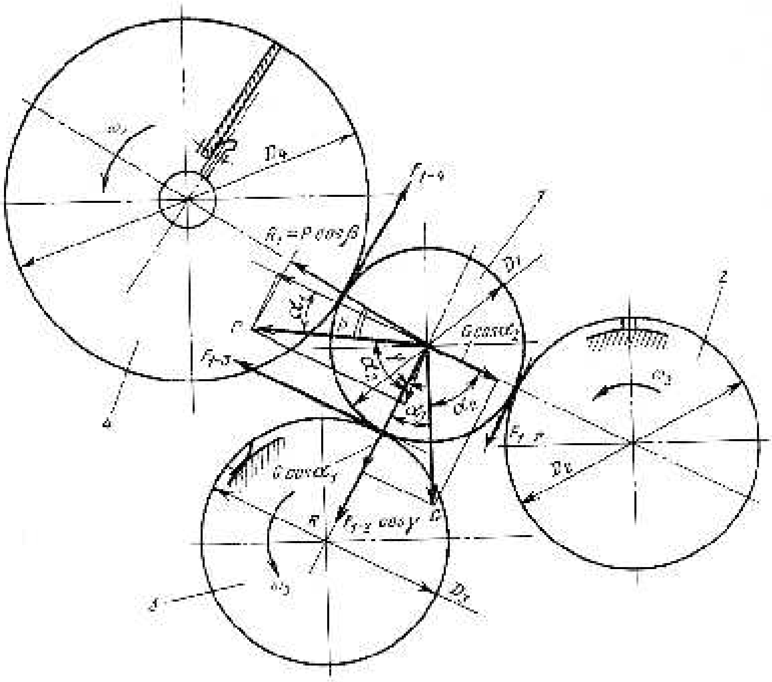


Figure 5. Physically model

In order to determine the total power consumption to depilation is analyzed the interaction between the carcass and each roller to which that has a direct contact.
In the tangent point of the carcass with the roller 2 disposed to an angle α_2 from the vertical support of the carcass weight G begins the friction force F_{1-2} of which expression is:

$$F_{1-2} = \mu_2 . G . \cos\alpha_2 \tag{9}$$

where μ_2 represents the friction coefficient between the carcass subjected to depilation and grooved roller 2.Taking into consideration that the diameter of this roller is D_2, the resistant moment of this force becomes:

$$M_1 = F_{1-2} \cdot \frac{D_2}{2} \tag{10}$$

Let it be R the normal force which acts upon the roller with scrapers 3. It is observed from the figure that this force is composed by the component of weight G and by the tangential force F_{1-2} towards the direction of vector R. So the expression of normal force upon the roller 3 can be expressed:

$$R = G \cdot (\cos\alpha_1 + \mu_2 \cdot \cos\alpha_2 \cdot \cos\gamma) \tag{11}$$

where α_1 represents the disposing angle of roller 3 towards the weight support G and γ the angle between the forces directions F_{1-2} and R.
With this value, the tangential friction force becomes:

$$F_{1-3} = \mu_3 \cdot G \cdot (\cos\alpha_1 + \mu_2 \cdot \cos\alpha_2 \cdot \cos\gamma) \tag{12}$$

Because the diameter of this roller is D_3, the resistant moment will be:

$$M_2 = F_{1-3} \cdot \frac{D_3}{2} \tag{13}$$

To determine the normal force which acts upon the finishing roller 4 is necessary the preliminary composition of forces F_{1-2} and F_{1-3}.
Results:

$$\vec{P}_1 = \vec{F}_{1-2} = \vec{F}_{1-3} \tag{14}$$

with the module:

$$P_1 = \sqrt{F_{1-2}^{\;2} + F_{1-3}^{\;2}} \tag{15}$$

The normal force for the roller 4 force becomes

$$R_1 = P_1 \cdot \cos\beta \tag{16}$$

where angle β is made by the direction of roller centers 1 and 4, collinear with the rotation centre of the carcass and the support of the resultant P_1.
Thus, it is estimated the value of friction coefficient μ_4, and we can write the expression of tangential friction force between the carcass and the finishing roller 4:

$$F_{1-4} = \mu_4 \cdot R_1 , \tag{17}$$

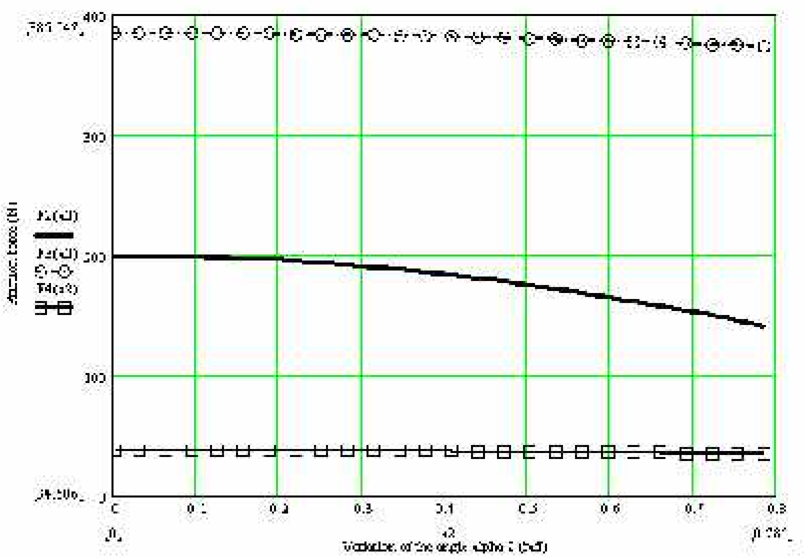
Respectively of the consumed momentum by this friction:

$$M_3 = F_{1-4} \cdot \frac{D_4}{2} \quad . \tag{18}$$

It can be observed that through this approach of the dynamics of apparatus of depilation it could be determined by the expressions of the moments of resistance by friction for each of the three rollers.
If the angular speeds are respectively ω_2, ω_3, ω_4, the total power consumed by the rollers of depilation will be:

$$P = M_1 \cdot \omega_2 + M_2 \cdot \omega_3 + M_3 \cdot \omega_4 . \tag{19}$$

Taking into consideration the power excess needed for starting the electric engine and the afferent efficiency it can be written the expression of power needed to put on the electric operating engine:



$$P_{mot.el} = \frac{P \cdot k}{10^3 \cdot \eta_m \cdot \eta_{rot}} \tag{20}$$

As a result of analyze us made, can establish that the power consumed depends on the following factors:

a. the rollers diameter for depilation and the driving off of the carcass;
b. the disposal angles of rollers towards the carcass subjected to depilation;
c. the carcass weight

The mathematic model presented above was implemented in the program MATHCAD. It was adopted as a variable the angle formed between the direction of axis centers of rotation of the rollers 2 and 4 and weight direction of G. As a result of using the program had resulted the variations of friction tangential forces the weight of running the resulting variations tangential friction forces F1-2, F1-3 respectively F1-4 (figure 6).
After this pattern can be realized different models with the following variable sizes: diameters of rollers, friction coefficients, the angles formed by each of the forces components which occur during the dynamics of depilating process, etc.

3. CONCLUSION

As a result of the analyses of the dynamics of depilation process when we are using three rollers we establish the following:

a. by changing the position of grooved roller 2 takes place greater reduction of friction force with the carcass at the same time with the increasing of the angle α_2;
b. the friction forces between the carcass and the rollers 3 and 4 are reducing for the increasing angle α_2;
c. the model allows finding some proper positions for the three functioning rollers depend ending on the middle diameter of the carcass, so that the consumed energy can be reduced significantly;
d. the angular speeds must be chosen so that they can assure the scraping of carcass surface without producing more damage to the skin or under skin layers

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