EAN 2019
57th conference on experimental stress analysis

Determining coefficient of friction between oilseeds and rotor blade of hulling machine using equation of motion

HOIDEKR Jan[1,a], MACHAČ Martin[1,b] and TUREK Oskar[1,c]

[1]CTU in Prague, Faculty of Mechanical Engineering, Department of Designing and Machine Components, Technická 4, 166 07 Prague 6, Czech Republic

[a]jan.hoidekr@fs.cvut.cz, [b]martin.machac@fs.cvut.cz, [c]oskar.turek@fs.cvut.cz

Keywords: Oilseed hulling, Coefficient of Friction, Equation of Motion, Hulling Machine

Abstract. This work aims to describe a method of experimental determination of a friction coefficient between oilseeds, especially sunflower seeds, and a rotor blade placed in an impact hulling machine. Firstly, the movement of sunflower seeds in rotor during hulling process is described by equation of motion. Secondly, by analysing this description and simple experimental measuring the coefficient of friction is determined.

Introduction

The hulling of oilseeds, especially sunflower seeds, is a necessary part of the oil pressing technology. The sunflower seed consists of a kernel where the oil is contained and a hull mostly composed of cellulose. It is advisable to remove hulls before pressing, even though few hulls retained might be still necessary for the proper function of the pressing process. For hulling seeds, there are mostly used the impact hulling machines.

The impact hulling machine is based on cracking the hull by high-speed throwing of seeds against an obstacle. When the seed hits the obstacle, its hull cracks and separates from the kernel. The seeds are usually accelerated by a centrifugal force in a rotating rotor with blades and thrown against outer stator which can be smooth or specially shaped.

The displacement of the seed inside the hulling machine consists of two phases. In the first phase, the seed is accelerated in the rotor. This displacement is mathematically described by equation of motion. In the second phase, the seed leaves the rotor and is thrown against the stator. The direction of trajectory of thrown seed is known thanks to mathematical description of the first phase. Experimental measuring of this direction leads in the end to determining of friction coefficient between the oil seed and the rotor blade.

Determining an equation of motion

The equation of motion is stated for the first phase of hulling. There can be considered two coordinate systems in the rotor. The global coordinate system XY is fixed to the frame of the machine. There is an additional local Cartesian coordinate system xy which is fixed to the rotor blade. The kinematic diagram of moving seed in the rotor can be though as a point slidably set on a rotating rod with constant angular velocity ω. Absolute velocity of the seed v can be broken into components v_u and v_r. This is shown in Fig. 1 as well as the directions of acceleration vectors. Considered force diagram is shown in Fig. 2.

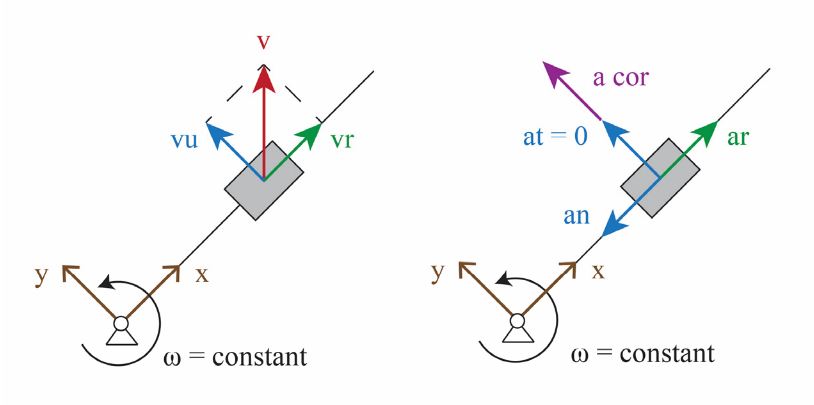


Fig. 1: Kinematic diagram of the sunflower seed displacement in the rotor

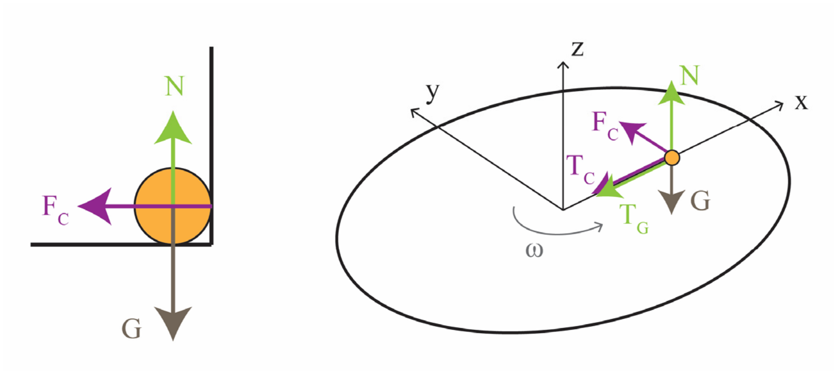


Fig. 2: Force diagram during displacement in the rotor

According to the Newton's second law of motion the equation Eq. (1) of motion is stated and expressed in local coordinate system xy [1].

$$\ddot{x} + (2\omega\mu) \cdot \dot{x} - (\omega^2) \cdot x = -g\mu \qquad x_{(t=0)} = x_0, \; \dot{x}_{(t=0)} = 0 \tag{1}$$

It is a second-order differential nonhomogeneous equation with constant coefficients. Solving this equation analytically out gives a seed trajectory description in the rotor as a function of a time

$$x_{(t)} = C_1 \cdot e^{\lambda_1 \cdot t} + C_2 \cdot e^{\lambda_2 \cdot t} + C_3 \tag{2}$$

where λ_1, λ_2, C_1, C_2 and C_3 are constants containing an initial conditions, machine dimensions, friction coefficient and angular speed of the rotor. The trajectory of the seed in the rotor in global coordinate system XY is shown in Fig. 3. There is a tangent of angle β defined as v_u divided by v_r which is generally dependent on time. For analyzing dependence of angle β_{out} on angular speed ω and friction coefficient μ there is a need to solve Eq. (3)

$$C_1 \cdot e^{\lambda_1 \cdot t} + C_2 \cdot e^{\lambda_2 \cdot t} + C_3 - x_{out} = 0 \tag{3}$$

where x_{out} equals to x coordinate of outer diameter of the rotor. Solving this equation numerically for certain friction coefficient and angular speed in MATLAB gives a t_{out} time of moment when the seed leaves the rotor blade [2]. Afterwards for the range of defined angular velocities and friction coefficients a Table 1 can be calculated. The region of interest for the speed of the rotor is between 1000 and 2000 rpm, for the friction coefficient it is between 0 and 1.

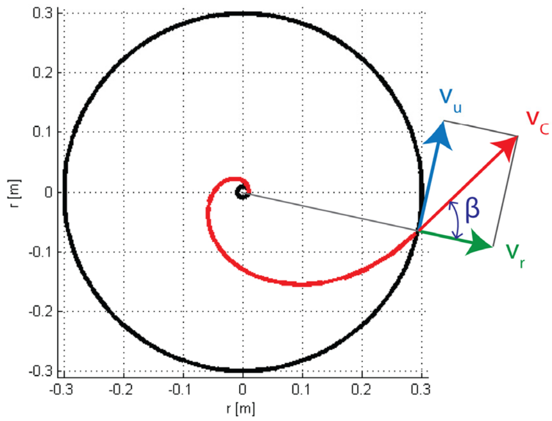


Fig. 3: Trajectory of the seed displacement in the rotor during the hulling process

Table 1: Dependence of angle β_{out} on the rotor speed and friction coefficient

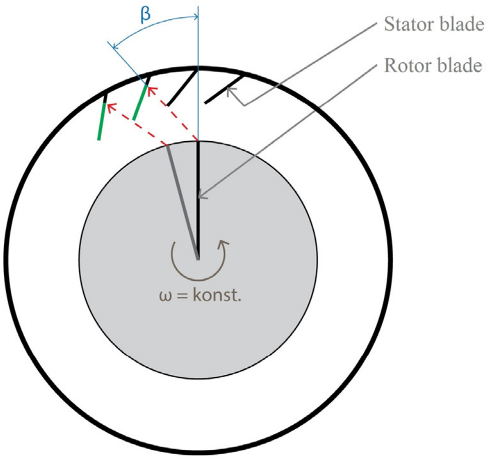
coef. of friction [1]	angle β_{out} 1000 rpm [deg]	angle β_{out} 1100 rpm [deg]	angle β_{out} 1200 rpm [deg]	…	angle β_{out} 1900 rpm [deg]	angle β_{out} 2000 rpm [deg]
0.0	45.1793	45.1791	45.1790	…	45.1785	45.1784
0.1	47.9794	47.9794	47.9793	…	47.9792	47.9792
0.2	50.7328	50.7327	50.7327	…	50.7327	50.7327
0.3	53.3932	53.3932	59.3932	…	59.3933	59.3933
0.4	55.9225	55.9225	55.9224	…	55.9223	55.9223
0.5	58.2923	58.2922	58.2922	…	58.2921	58.2921
0.6	60.4859	60.4858	60.4858	…	60.4856	60.4856
0.7	62.4977	62.4976	62.4975	…	62.4973	62.4973
0.8	64.3307	64.3306	64.3305	…	64.3303	64.3303
0.9	65.9942	65.9941	65.9940	…	65.9938	65.9938
1.0	67.5006	67.5004	67.5003	…	67.5001	67.5001

Determining the coefficient of friction

According to the Table 1 it is obvious that for the region 1000 – 2000 rpm of speed of the rotor there are only small changes of angle β_{out}. Therefore it is acceptable to consider dependence of angle β_{out} on angular speed omitted for this region of velocities of the rotor. Considering this assumption the angle β_{out} is a function of only one variable, namely friction coefficient.

Experimental measurement of angle β_{out} then provides the friction coefficient between the sunflower seed and the rotor blade. The angle β_{out} is measured during the second phase of hulling process when the seed is thrown against the stator. In this phase the seeds continue in a straight line until they reach any obstacle, in this case until they hit the stator construction. In the case of stator construction according to Fig. 4 and considering that seeds are throwing equally all around the stator circumference, the bounced seeds will leave a footprint on the stator blade in affected green zone.

The angle β_{out} can be measured by optical methods from stator blades considering the real stator and rotor construction dimensions.



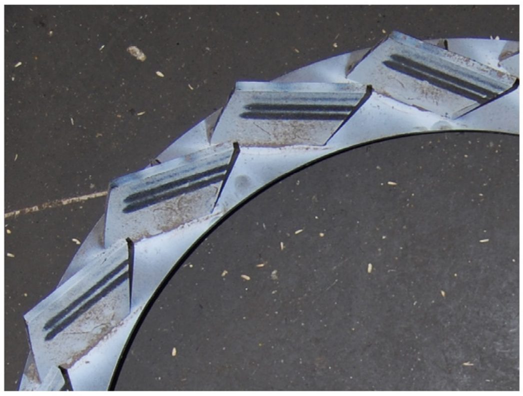


Fig. 4: Experimental determining of the friction coefficient by measuring the angle β_{out}

There was done one testing measurement of a specimen of sunflower seed with a moisture content of 5%. The material of rotor blade was hardened steel. Measured angle β_{out} was 59.5° what equals to friction coefficient of 0.55. This result is corresponding to range of expected values. The friction coefficient was measured by described method, however, there should be used another method in the next work to validate this result.

Conclusion

The description of displacement of the oilseed during the hulling process leads to stating a convenient method of determining friction coefficient between oilseed and rotor blade of hulling machine while. The advantage of this method is based on using directly industrial hulling machine for determining friction coefficient of certain specimen. In general, the coefficient of friction differs with a species of oil seed, but can also vary in many parameters, such a humidity or temperature of the specimen.

The knowledge of friction characteristics helps to construction designers or machine operators in local adjustments of hulling machine to reach maximal hulling rate since the parameters of seeds to hull are varying.

Acknowledgements

There is much appreciated sponsorship of grant TA04010992: Research and development of technologies for obtaining vegetable oils and cakes with an emphasis on quality of cakes as feed and the appropriateness of used of the construction materials. There is also much appreciated cooperation with Farmet a.s. where the experimental measurement was made.

References

[1] J. Hoidekr, J. Andrus, and V. Dynybyl, “The Mathematical Description of Sunflower Seed’s Hulling Process Using Impact Huller”, in The Latest Methods of Construction Design, 1st ed., Cham: Springer International Publishing, 2016, pp. 203-206.

[2] J. Hoidekr, “Analýza loupání slunečnicových semen”, in Studentská tvůrčí činnost 2014, 2014, 1st ed.