St. ISTVÁN UNIVERSITY

GRINDING KINETIC AND ENERGETIC EXAMINATION OF HAMMER MILLS

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Péter Korzenszky

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Leader: Prof. Dr. István Farkas

Dr. of Technical Sciences

Faculty of Mechanical Engineering,
St. István University, Gödöllő, Hungary

Tutor theme leader: Dr. Endre Judák CSc

Associate Professor

Department of Process Engineering
Faculty of Mechanical Engineering,
St. István University, Gödöllő, Hungary

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Affirmation of program leader	Affirmation of tutor theme leader

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INTRODUCTION

Cultivation of plants and animal husbandry are inseparable categories. After procession animals or humans consume crops directly or indirectly. The products marked out for animal consumption are processed in fodder-processing plants where with the prescribed recipe the appropriate fodder is produced for the actual species.

Comminution is one of the most important steps of fodder production preparation.

There are different methods for comminution. The most spread method is the process of grinding in small works.

In general, grinding is a method of comminution of grain crops (occasionally pressed forage or pellets, cakes, cobs) for easier utilization of nutrients and for easier digestion. Experiments with poultry and pigs resulted in optimal 0.7-0.8-mm grain diameter. Hence grits fineness is a very important characteristic parameter.

Grinding machines based on the principles of free impacts or collisions are the most spread mills in the agriculture. The principles of their operation is that the grain is broken by fast-moving swing hammers with repeated beats – the impelled particles hit against the faces, and re-enter the grinding space until falls out of the screen) This method is applicable for comminute most grain crops and forage. Their structure is simple, they are easy to handle and their work is reliable.

The wanted grain size at the former traditional grinding machines depends on the commutable screen's aperture.

Turbulence caused by fast moving hammers blows grits out of the machine. Grain size depends on how long the material is retained in the grinding space as well. The work of hammer mills also depends on the uniformity of dosage. The biggest grain size is defined by the hole size of the screen. To reach an actual grits fineness, the screens have to be exchanged while the mill is stopped. These pauses are not economically profitable; they consume time and human resources.

Grinding depends on a lot of parameters which influence the productivity of process and the quality of fodder as well.

By changing machine adjustments (and rotary speed), the quality and productivity of process can be increased. A against the former constant-speed step adjustment, using the frequency converter in the system provides the opportunity for the control system to vary infinitely the hammer speed.

The aim of my research is the adjustment of grinding hammer's infinitely variable peripheral speed. With this research I aim to do the following:

- examine the processes of grinding machines in model experiments, with using frequency converter in the system (contrary to usual systems) and a high-speed measurement system for data sampling,
- do impact studies of parameter changes which affect the grinding process and end-product quality, grinding kinetic and energetic analysis
- study relations between increasing speed levels and grits surface growth,
- explore the formation of particle size distribution with application of different adjustments,
- examine the changes of mechanical power requirement in different stages of grinding,
- analyze relations between specific surface area of grits and mean particle size, explore the limits of specific surface area growth,
- explore connections between significant particle size values, conversion opportunities, functions, empirical formula
- examination of energy need for creating new surface units,
- analysis of load and mechanical performance formation in non-constant phases of grinding process,
- examination of connections between mass flow and power input in the transient phase of grinding

My research is aided by a measurement system which can be applicable for changing of operating parameters, for on-line data recording and storage. Application of modern data recording and modern software helps the computer data processing and evaluation.
By the explored relationships, optimization of grinding process and end-product quality can be improved in the aspects of powerdemand.

1. EXAMINATION METHODS OF HAMMER MILLS AND EXAMINATION CIRCUMSTANCES

1.1. Research antecedents

Before the theoretical grinding investigations, I looked over the earlier researches carried out at St. István University in connection with my topic. After this phase I made research about papers on this field written by leading scientists. Then I collected the published articles. I found references in Hungarian works and I examined results mentioned in foreign specialized literature. I formulated results about those areas that had not been examined yet, or need specification after examination of international and Hungarian specialized literature.

My investigation field is based on the infinitely speed adjustment of hammer mill. Rotary speed changes were solved before in the step way which needed a repeated stoppage and dismantling-reassembling process. This method was not economically profitable and consumed time.

1.2. Test conditions

Experiments were carried out with a Zenit Junior hammer mill which is similar to those machines which are widely used (and it is convenient for measurement purposes due to analogy theory). I made a measurement diary in which I put down the date, the name and value of modified parameters, the actual options of data recorders and adjustment settings. I noted differences from basic adjustments and at data saving I marked it in the name of the file.

I made most of experiments in the laboratories of the Process Engineering Department of St. István University, Faculty of Mechanical Engineering. For decreasing complicated factors (and for further corrections) I recorded the outside temperature. I purchased examined materials always from the same sources with knowledge of parameters (basic parameters, species, and moisture content). True to variety materials were used for examination.

The preparation of materials was made on outside locations. I examined the purity of materials by organoleptic inspection. Sample quantity was determined in *10 kilograms* (after previous grinding and experimental adjustments).

1.3. New measurement assembly

I made a new measurement system by modifying the Zenit Junior hammer mill assembly. For precision and traceability I built a modern and high-speed sampling system. There are two important examination fields in connection with my studies. The first is the examination of constant peripheral speed in steady state (this had been studied previously by researchers). The second is the examination of unsteady state (this hadn't been examined by researchers). In the unsteady grinding phase dynamic changes happen in relatively short time periods. In fast transient processes – which are transitions between two stationary states –, some measured variables may multiply their initial value and the measurement system should be able to make high resolution and precise measurements. For experiments, I had to build sensors in the instrumentation. Data of these sensors had to be registered in every moment.

A comparison of the unsteady state functions and the derived kinetic functions with steady state were the important aims of the research. This method is the basis of producing general and generalized characteristics. The diagram of the new experimental apparatus (Figure 1.1) shows the new measurement system with indication of input and output parameters.

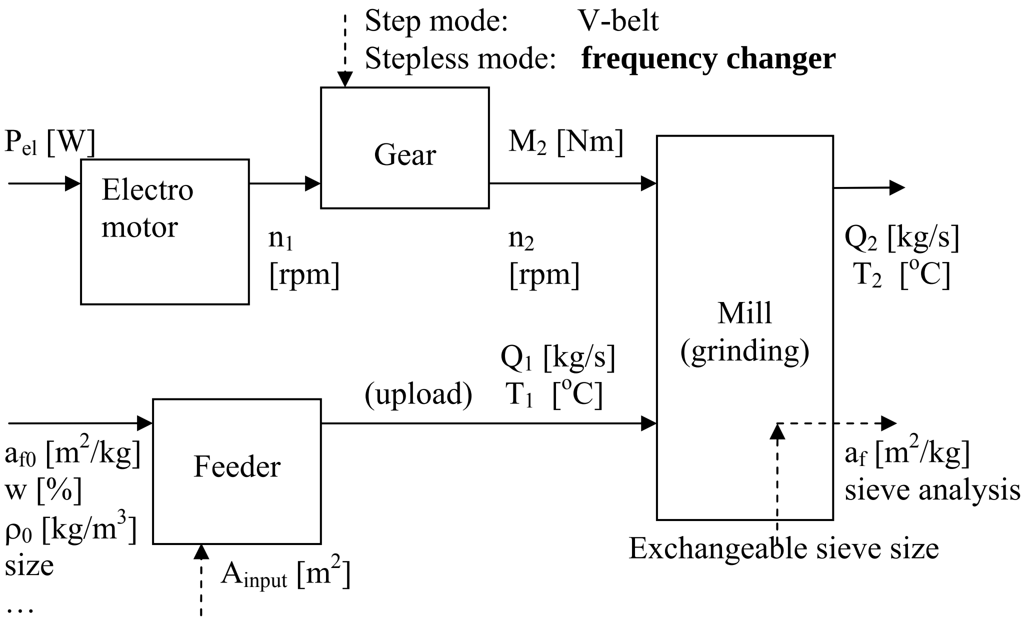

Figure 1.1 The scheme of the experimental apparatus, input, output variables, parameters

A frequency converter which is fitted in performance and loading to the Leroy Somer (LS132ST) type asynchronous motor was chosen (with parameters of *5.5kW* power and one pair of poles). With the help of the frequency converter we could adjust without stages the nominal 2900-rpm rotary speed between the theoretical *0 and 24,000* rpm interval (according to the manual of device: *0 to 400 Hz*). Due to the engine construction and some rational parameters, we limited the rotary speed value to a certain extent larger value than the nominal rotary speed (*3600* rpm at *60Hz*). The engine drives the shaft of the grinding machine through the V-belt transmission so 6500 rpm (99 m/s) can be reached in the grinding space.

The data gained from the sensors and transmitters were recorded with a SPIDER 8 data logger. The data logger's basic construction is applicable for simultaneous sampling of 8 separated parameters. The first two channels (0 and 1) are applicable for receiving impulse-like quantities, the 6th and 7th channels are applicable for receiving transmitter universal output signals (*0-10 V, 4-20 mA).* Bridges, half bridges and quarter bridges can be attached to the other channels. Graph 1.2 shows the equipped grinding machine with frequency converter, 8-channel data logger and a data recorder computer.

Figure 1.2 Zenit Junior hammer mill – measurement system
SPIDER 8 data recorder, Measurement Computer, Frequency converter

1. 3.1. Calibration and monitoring during the tests

The preparation of experiments included a gauge calibration. Calibrations were made due to the actual (several times modified) Hungarian and international measurement standards. I had to calibrate those gauges which won't measure original settings. The flat balance equipped with a load cell and the torque meter unit made of strain gauges needed calibration. Those measuring equipments which I used without disassembly needed also monitoring. I checked these in every six months and after the longer periods without usage (2 weeks) I checked them also.

Controlling meant in all cases that I provided reference adequate signals for measured quantities and I watched differences between reference signals.

The gauges which needed calibration were the following:

- Reflection optogates for rotary speed measurement,
- thermometer (K-type thermocouple),
- frequency converter's transmitter output,
- slide-position inductive transducer.

1.4. Course of examination

At planning the measurements, I reviewed the measurement adjustments and results I had known previously.

I constructed different measurement assemblies for examination of the following important parameters: rotary speed (n), torque (M), temperature (T), input-output quantity of materials (m), throat size, input electric current (I), electric and mechanical power (P), screen hole diameter.

With the new measurement assembly, I managed to reproduce the results of former researchers gained by similar measurement systems. This had an importance in making comparisons.

In all cases, I determined the subject of examination, parameters, gauges needed, circumstances, conditions and schedule.

1. 5. Examination methods

I differentiated the methods used at measurements, data recording and evaluating.

1.5.1. Measurement methods

In the measurements, I used the advantages of the Wheatstone resistance bridges, tensometers and rotary speed description processes. I carried out the following measurements: rotary speed measurements, torque measurements, power measurements, weight measurements, mass flow measurements, temperature measurements, humidity measurements.

I aimed to use simple, standardized, fast and precise algorithms as measurement methods.

In parallel with the grinding experiments, I made screen analysis to characterize masses of grits.

1.5.2. Data collection methods

I used a SPIDER 8 data logger and the Catman v4.5 measurement software for data recording. The basic assembly system makes possible recording of several parameters through 8 separated channels. It is applicable for processing signals of strain gauges, inductive bridges, half bridges, impulse markers, voltage, and electricity sources.

Tasks in connection with measured signals can be done inside: drive of passive sensors, receiving signals, amplification, calibrated signal condition, digitalization, assemblage to computers.

Figure 1.1 contains the specification of data recorder channels and measured factors.

Figure 1.1 Specification of applied 8 channels

Channel number	**CH 4**	**CH 5**	**CH 6**	**CH 7**
Specification	Electro-tensometric load cell	Electro-tensometric load cell	Frequency changer	Thermometer
Channel number	**CH 0**	**CH 1**	**CH 2**	**CH 3**
Specification	Rotary speed	Rotary speed	Strain gauge	Inductive path

During data recording I used a 50-Hz sampling mode. This means that I sampled data in every 20 ms from the variable quantities. One measurement adjustment means approximately 5000 recorded signals per channels. 45.000 data are altogether recorded and evaluated in one measurement assembly. I repeated each measurement at least three times. By description of signal series, I obtained the data quantity for evaluation.

1.5.3. Data evaluation methods

I had to evaluate different basic parameters. I determined derived characteristics from the basic data (specific surface, load, mass flow, hammer peripheral speed). During evaluation I processed 45.000 data per measurement with a pre-defined algorithm. I had to choose non-relevant data from the data base – these are originated from measurement errors. I had to find relation between the following values. After data display I described tendencies, phenomenon and possible function relations. I evaluated all measurement data with the preceding algorithm. After this I searched for connections between the adjustments and the results.

I represented the selected, ranked, evaluated similar quantities. Then I ranked results due to hammer peripheral speed and I described tendencies and function relations. I used conventional processes, calculation methods and markings for screen analysis. (Rittinger's model, RRB-distribution, X_o, X_{50}, X_{80}, X_{mean})

2. RESULTS OF HAMMER PERIPHERAL SPEED CHANGES ON THE HAMMER MILL

In Hungary hammer mills are the most spread. Their structural simplicity and reliability is outstanding.
The feeding of the applied Zenit Junior hammer mill is tangential and the outfall – in connection with the mass flow – is gravitational. The number of hammers is 12. On one bolt pin there are *3x4 hammers with 0.18 kg/piece* weight. The diameter of hammer circle is *290 mm*, the screen's angle of wrap is 210^o, the complete screen surface is near $470cm^2$, the slot between screen and hammers varies between 3 and 11 mm and the width of grinding space is *80 mm*.

The hammers in the workspace are situated radial at operation. The incoming and inside materials in the grinding space are comminuted by the hammers due to force caused by the impetus. The situation of hammers in working space can be seen in Figure 2.2.

Figure 2.1. Arrangement of hammers in the grinding space

Figure 2.2. It is hard to distinguish the different loads during grinding

2.1. Preparation of original measurement method

On the basis of data found in specialized literature and with the help of previous measurement results, I developed a new measurement assembly. The developed measurement system is applicable for high-speed sampling analysis of fast changing processes.

For previous measurements and experiments, the Zenit Junior hammer mill was mounted with a 3 grade V-belt drive. I reconstructed the drive so the continuous change of peripheral speed of hammer became possible. The construction of test bench and markings of measurement points can be seen on Figure 2.3.

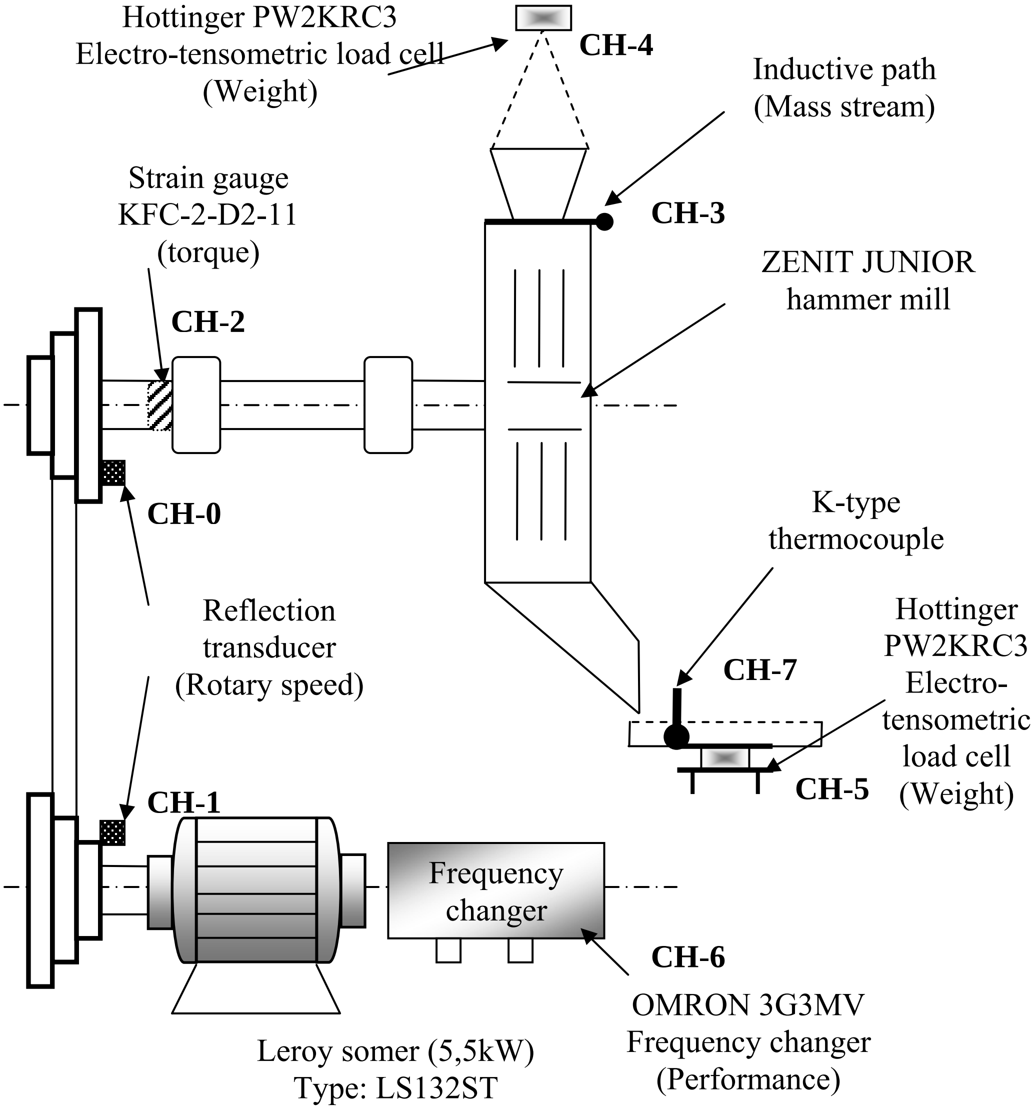

Figure 2.3. The structure of test bench mounted with frequency converter (with measurement point markings)

2.1.1. Application opportunities of frequency changers

For producing different hammer peripheral speed, I used an electromotor equipped with a frequency changer. I programmed the apparatus so that I could get direct performance proportional signals. I fitted the transmitter output to the appropriate module of data logger and I recorded the data. According to the instruction manual, I limited the output frequency interval to *0-60 Hz*, because the utilized engine's synchronous rotary speed is *3000 rpm* (which is equal to *50-Hz* frequency.) The electromotor cannot be driven at higher power than nominal load without any damage. Because of this, I increased the rotary speed interval to the value of *3600 rpm* (*60Hz*).

With the application of frequency converter, rotary speed changes could be made without stoppage and mounting. The rotary speed regulation is provided by the frequency changer with Pulse-width-modulation (*PWM*).

The plot and picture of OMRON 3G3MV-A4055 frequency converter can be seen Figure 2.4.

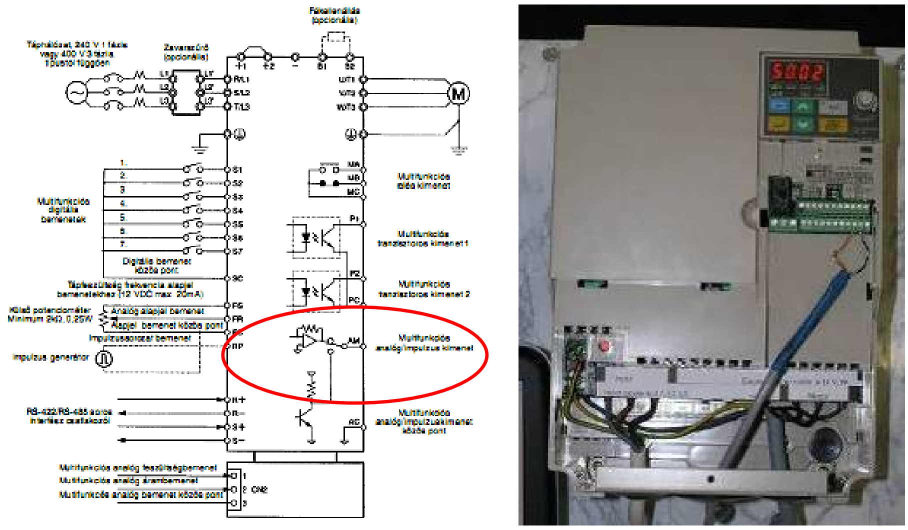

Figure 2.4. OMRON frequency converter and its connection plot

Electric performance is proportional to input current. The frequency changer determines the input electric power on the basis of input current and voltage. With the usage of the frequency converter's power output, I measured the input current and performance with a TRUE RMS tong-test current meter. The special tong-test current meter had to be used, because the values can not be measured by traditional gauges in this case, considering the usage of high-frequency controlling of the frequency converter.

2.2. Mechanical power and specific surface area growth

Value of time unit surface growth determines the given grinding process and can be used for comparisons.

Determination of specific surface in the case of actual particles (with the usage of cube model, and disregarding the density:

$$a_f = \frac{6}{x_i} \cdot f_i \qquad [\mathrm{m^2/m^3}] \tag{2.1.}$$

Thus, following from the above, the unit of specific surface area (a_f) is m^2/m^3.
This can be easily recalculated to the form m^2/kg with the knowledge of solid density ρ $[kg/m^3]$. I use the concept of specific surface a_f $[m^2/kg]$ this way in the following.

I determined the specific surface growth intensity as the product of mass flow Q $[kg/s]$ and specific surface growth Δa_f $[m^2/kg]$. I recorded measurement results on different hammer peripheral speed, with known humidity and screen diameter values. Different mechanical power (P_{2mech}) and mass flow (Q) values belong to the different hammer peripheral speeds and different surface growth intensities belong to different mass flows.

In steady state of grinding, the surface growth intensity (dA/dt) – with increasing hammer peripheral speed – can be defined as a function of mechanical power (P_{2mech}) measured on the shaft with an equation of the second degree in the case of grinding corn. This can be seen on Figure 2.5.

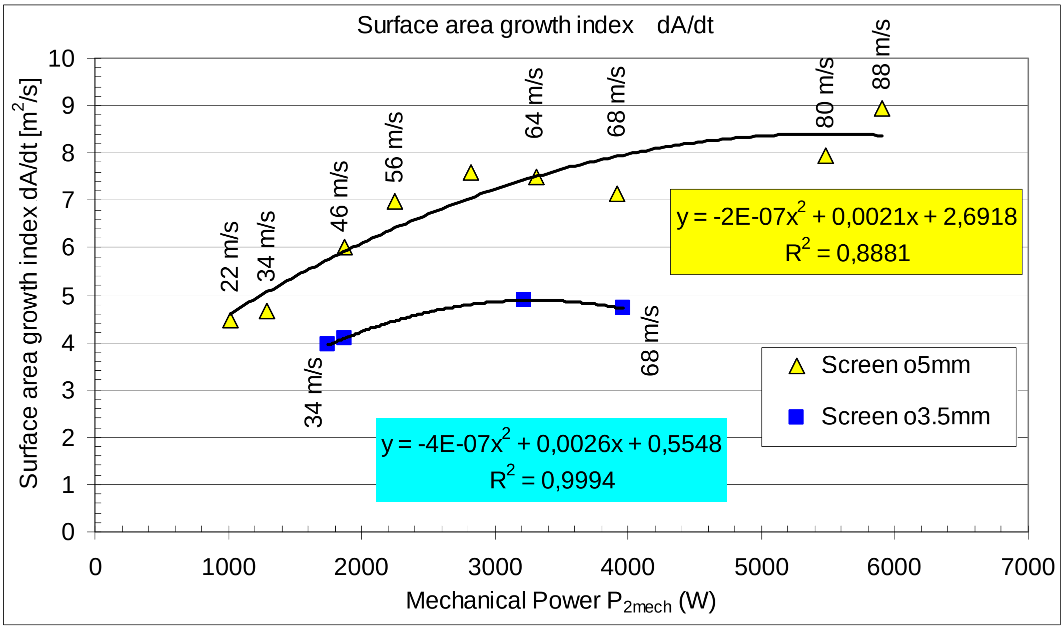

Figure 2.5. Surface growth intensity with increasing hammer peripheral speed is on the second degree in function of performance on shaft

Local maximum points can be seen on the graph. This concludes that it is not worth increasing the hammer peripheral speed and performance above a given value because it is not combined with bigger surface growth intensity.

Function relations can be determined with the following equations in the case of grinding corn:

In the case of Ø 3.5mm screen:

$$\frac{dA}{dt} = -4 \cdot 10^{-7} P_{2mech}{}^{2} + 0.0026 P_{2mech} + 0.5548 \qquad (2.2.)$$

In the case of Ø 5mm screen:

$$\frac{dA}{dt} = -2 \cdot 10^{-7} P_{2mech}{}^2 + 0.0021 P_{2mech} + 2.6918 \qquad (2.3.)$$

2.3. Mean grain size and density function

During the grinding process I took samples from the grinded material at different adjustments. After separation of fractions, the proportion of remained fraction weight (m_i) and the controlled fraction's total weight (m_{tot}) gives the frequency of size class. With this, the R-curve (Sieve-retention curve) can be constructed. X_{mean} grain size is the ratio of material quantity remained on the screen – between two sieving processes – and the total quantity of sieved material.

$$X_{mean} = \frac{\sum \left(\frac{X_i + X_{i+1}}{2} \right) \cdot m_i}{\sum m_i} \qquad [\mu m] \qquad (2.4.)$$

where,

X_i és X_{i+1} – the size of sieve i and the size of sieve i+1 [μm]
m_i – the quantity of material left on the sieve i [g]

From the retained material quantities on the following sieves, the percentage out of total grits can be defined. Figure 2.6 shows the measurement results at different hammer peripheral speeds.

It can be seen on the picture that, at grinding actual species of corn grains with an actual moisture content (w=constant), constant mass flow (Q=constant) and screen diameter, the changes of hammer peripheral speed (v_{per}) shift the maximum point of grain size density function and mean grain size values. With increasing peripheral speed the values of mean grain size decrease, so the grits fineness grows.

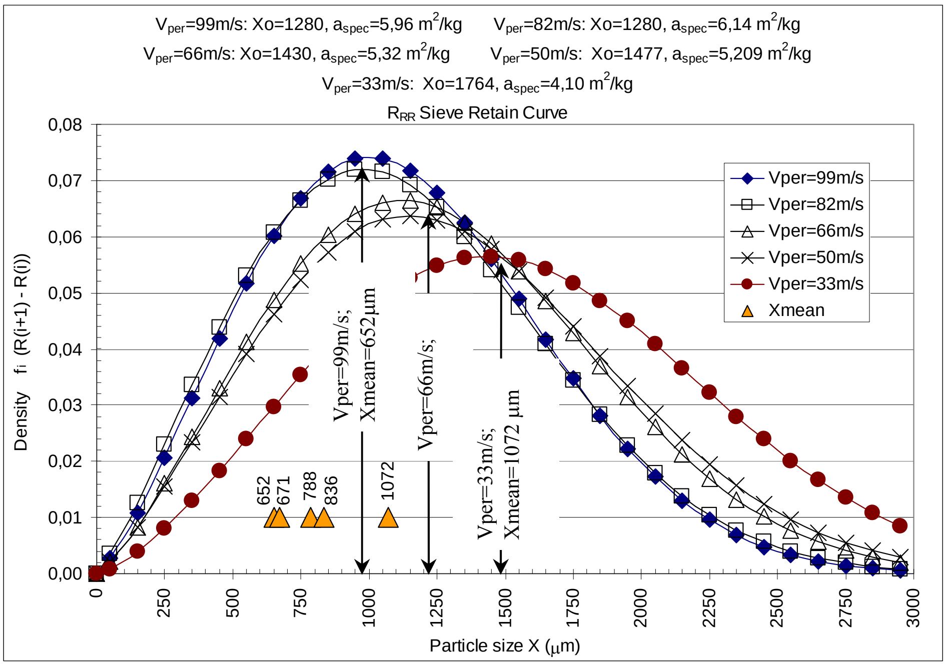

Figure 2.6. Particle size distribution density curve
Different mean particle sizes (X_{mean}) belong to different hammer peripheral speed (v_{per}) in the case of Ø 3.5mm screen

Decrease of mean particle size (X_{mean}) can be reached by increasing the peripheral speed (v_{per}) and the power (P_{2mech}). The quadratic character of the required power level can be seen on Figure 2.7.

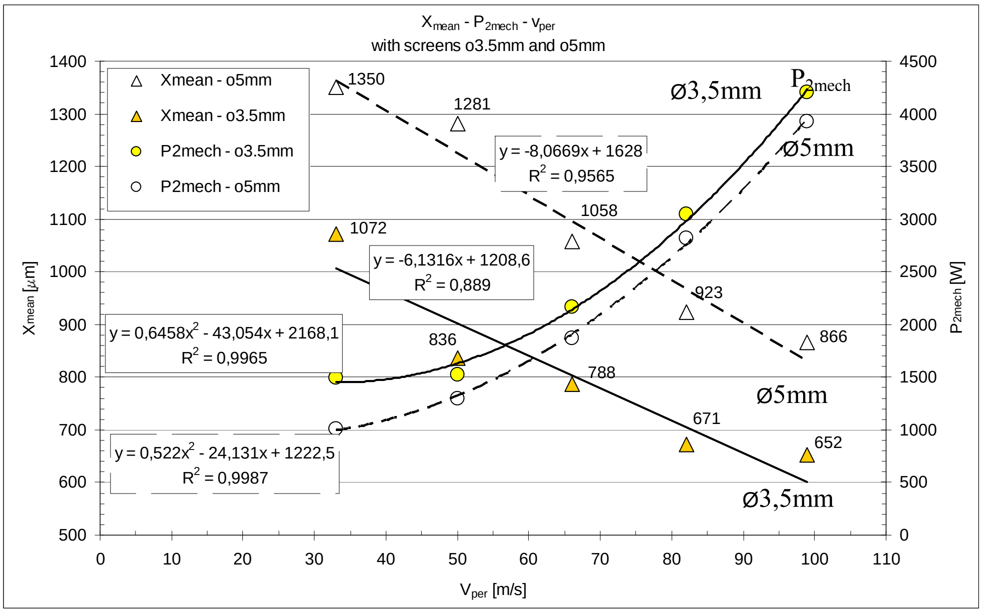

Figure 2.7. The result of increasing hammer peripheral speed on mean particle size X_{mean} and performance P_{2mech}

With the knowledge of mean particle size required by the feeding technology, the appropriate hammer peripheral speed fitted to the optimal performance level can be chosen.

2.4. Mean particle size and specific surface area

The definition of particle surface area is relatively simple even after grinding. The hyperbola which is produced at the definition of specific surface is added in the case of grinding more grains. The relation between the added surface areas and the mean particle size is not unambiguous.

According to my measured data the formation of specific surface as the function of mean particle (X_{mean}) size shows a hyperbolic relation. (Figure 2.8)

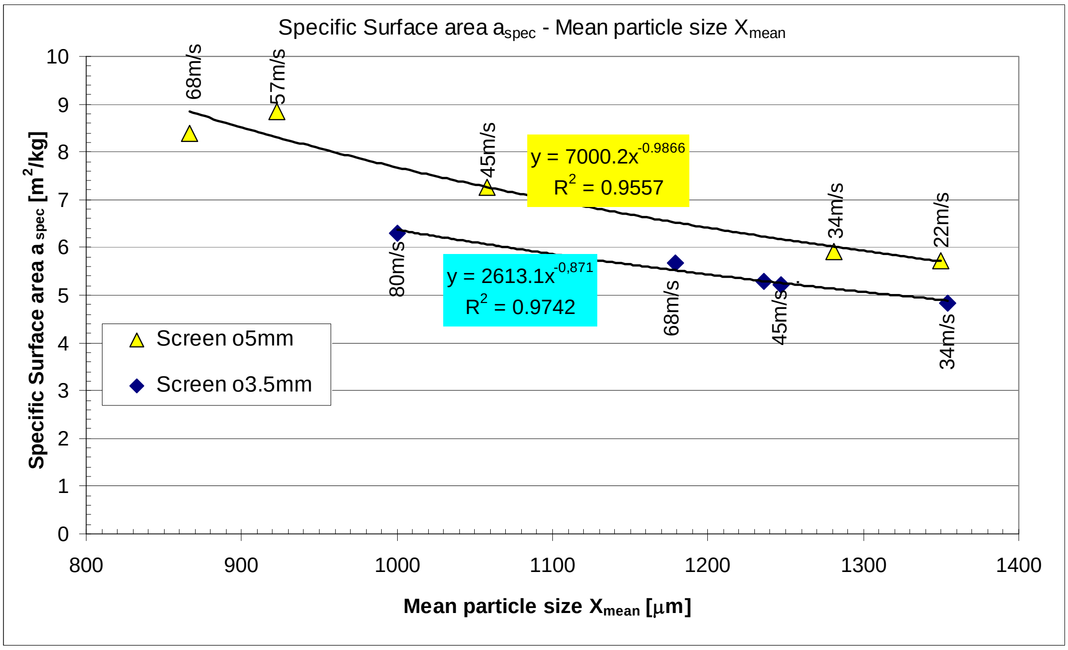

Figure 2.8. Relation between mean grain size (X_{mean}) and specific surface, with changing hammer peripheral speed hyperbola

With increasing hammer peripheral speed, the grits fineness also increases, but the value of new produced specific surface area grows in accordance with the hyperbola function. Mean particle size is an accepted and used, easily calculated and characteristic parameter of the grits bulk. The new produced surface area of grits is hard to measure. The mathematic relationship between the two parameters gives possibility to make our knowledge precise which can be useful in fodder utilization experiments.

2.5. Specific surface area and mass flow

The formation of specific surface is influenced by several parameters. In practice we can measure only indirectly the produced new surface areas after the grinding process. If we can predict the expected specific surface area, we can influence the growth of livestock.

According to experimental measurement results, it can be declared that, in the steady phase of grinding with increasing hammer peripheral speed, the value of mass flow (Q) can be increased. The specific surface area (a_f) can be defined with an equation of the second degree as the function of mass flow.

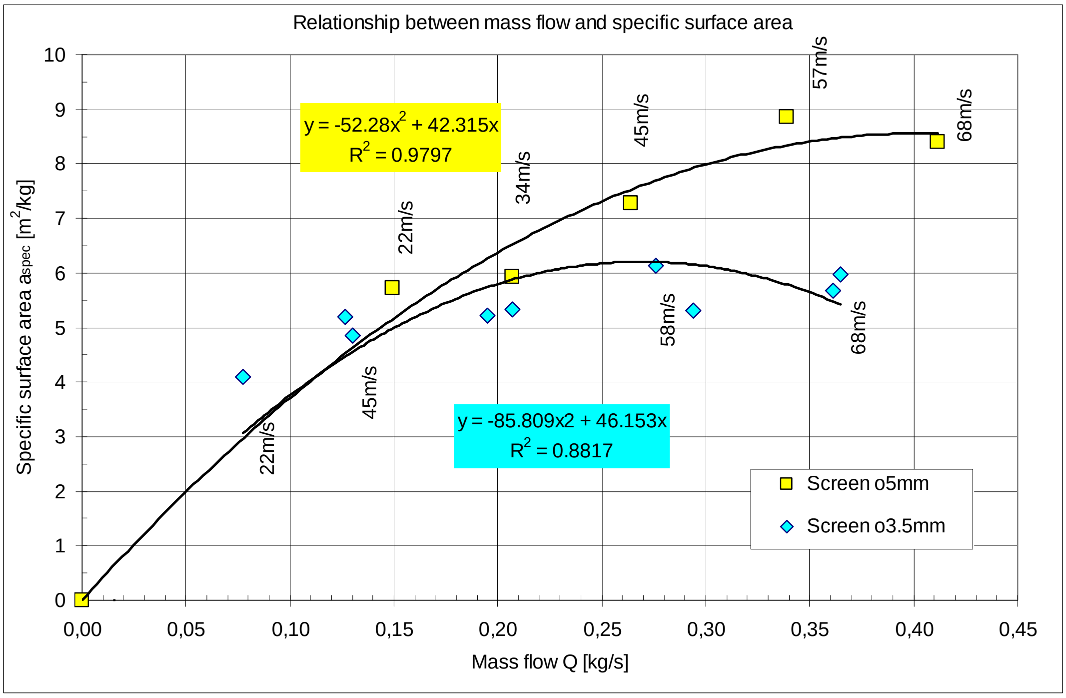

Figure 2.9. The increasing of mass flow with hammer peripheral speed and the formation of specific surface area results in an equation of the second degree

In Figure 2.9, the mass flow values required of producing the maximum specific surface area can be reed off. With usage of Ø5mm screen the maximum specific surface area (a_f=*8.5m²/kg*) belongs to the value of Q=*0.42kg/s* mass flow. The increasing of mass flow doesn't mean unlimited specific surface area growth. The maximum specific surface is defined by an optimal value of mass flow which can be precisely adjusted by changing the hammer peripheral speed.

2.6. Relation of the mean particle size and other significant values

The equation of mean particle size is in relation with X_o, X_{50} and X_{80} screen sizes derived from the Sieve-retention curve *R(x).* The relationship was not *unambiguous* up to the present.

The definition of mean particle size can be done with relatively simple mathematical operations after a screen analysis.

But if we want to produce for example X_0 significant grain size, we have to solve some equations and regression for comparison. On the basis of graphically solved equations, one can conclude the value of X_0.

If we have the graphs about measurement data, it is an easier solution. With the help of these graphs, a known particle size can be easily converted to another significant particle sizes.

After numerical evaluating measurements data, I had a mass of facts with which tendencies and trends could be defined in the case grinding corn with the actual moisture content (w=10.5%). On the basis of the mentioned relation between significant particle size values (X_o, X_{50}, X_{80}) and mean particle size (X_{mean}), the relationship can be defined with lines which start from the origin. Figure 2.10 contains the equations of lines.

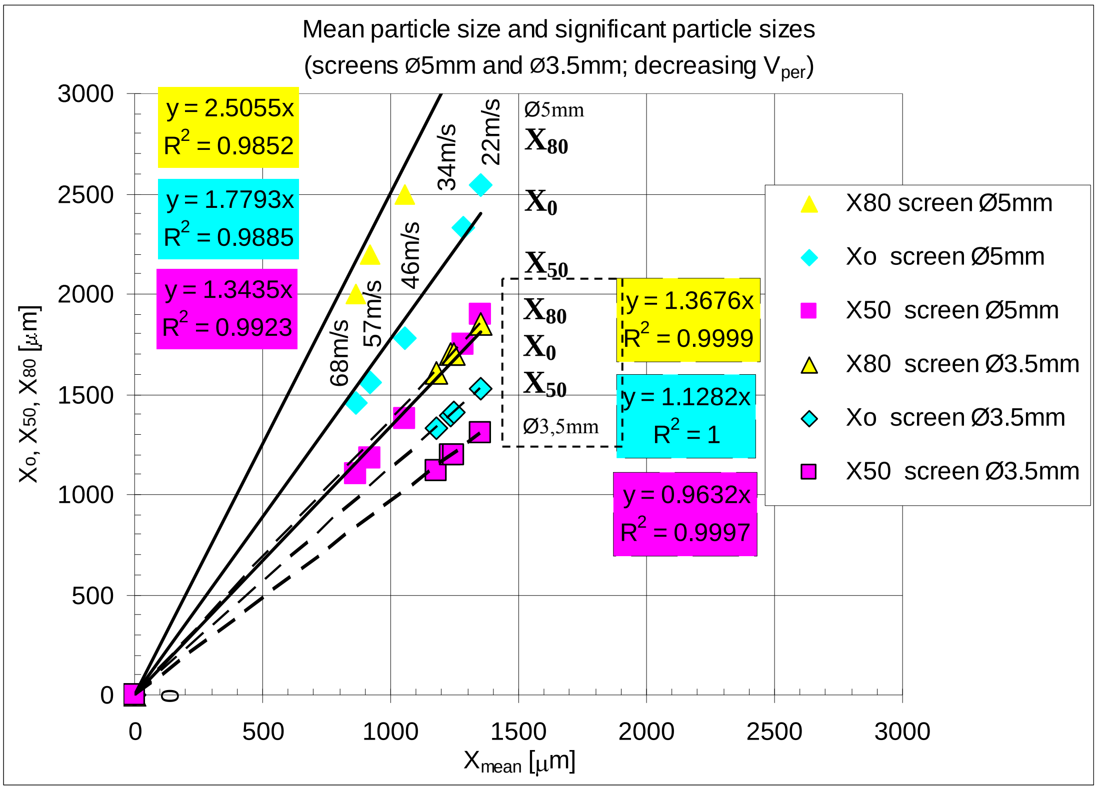

Figure 2.10. X_o, X_{50} , X_{80} particle sizes in the function of mean particle size with knowledge of different hammer peripheral speeds

Larger mean particle sizes – rougher, coarser grits – belong to lower hammer peripheral speed. This means that the other significant particle sizes are going to grow too. The lines which start from the origin define the ratio between X_{mean} and significant particle sizes.

2.7. Relation of specific energy need and peripheral speed

The mechanical power (P_{mech}) and the peripheral speed (v_{per}) show a linear relation. Theoretically this means that, with increasing rotary speed, the power increases linearly. On the basis of measurement data, the conclusion is that there is a second degree connection between the hammer peripheral speed (v_{per}) and the power on the shaft of the grinding machine (P_{2mech}). X_{mean} particle size decreases proportionally with the rotary speed growth. In Figure 2.11, the specific energy requirement (E_f), power (P_{2mech}) and mean particle size (X_{mean}) can be seen as the function of hammer peripheral speed.

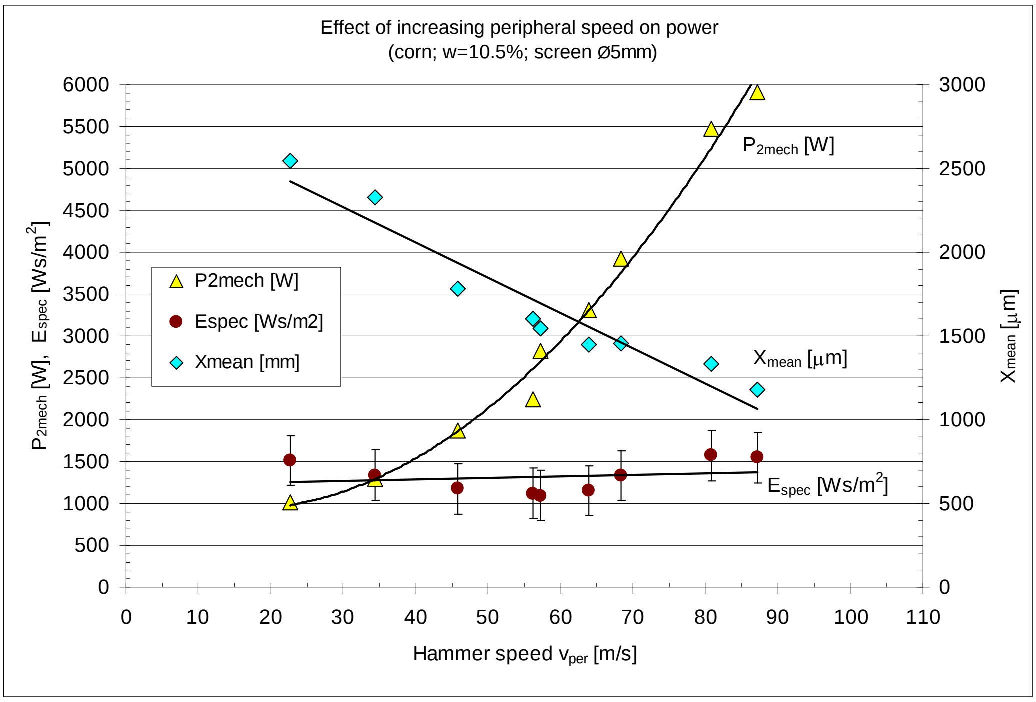

Figure 2.11. Mechanical power (P_{2mech}), specific energy requirement (E_f) and mean particle size ($X_{átlag}$) as a function of hammer peripheral speed

2.8. Examination of unsteady state

The previous traditional examinations were dealing with the stationary steady state of grinding, because the important phases of grinding happen in these stages. The unsteady state is the phase of filling-up and discharge of the grinder happens. This transient phenomenon did not take part before in traditional grinding practice, because constant hammer peripheral state was assumed. Unsteady state was avoided intentionally. In today's practice, we can define the adequate state of grits after finishing the grinding process, sampling and screen analysis for agro-technical requirements. If they are not adequate, they get back to the grinding process. This means that we work is repeated for our aim. Extension of constant interval with hammer peripheral speed changes and the examination of unsteady phase give us an opportunity to predict what will happen. With the usage of frequency converter the transient phase can be lengthened if the technology needs so.

2.8.1. Relation of power and charge in the unsteady state of grinding

In the unsteady phase at the beginning of charge formation, the speed of changes is the machine's own feature. The amount of charge depends on the hammer peripheral speed because a part of the grinding energy is produced by the hammer's beating. Increasing hammer peripheral speed needs more electric energy so higher power can be gained on the grinding machine's shaft. Different mechanical powers are connected to different hammer peripheral speeds. With changing peripheral speed, the charge and the mechanical power show a linear connection. The lines start from the origin, because the known no-load power levels were subtracted – offset compensation – from the measured performance values. On the basis of the graph, it can be seen that the slope of the lines varies as a function of peripheral speed. Figure 2.12 shows the change of mechanical power in function of charge growth in the case of different hammer peripheral speeds.

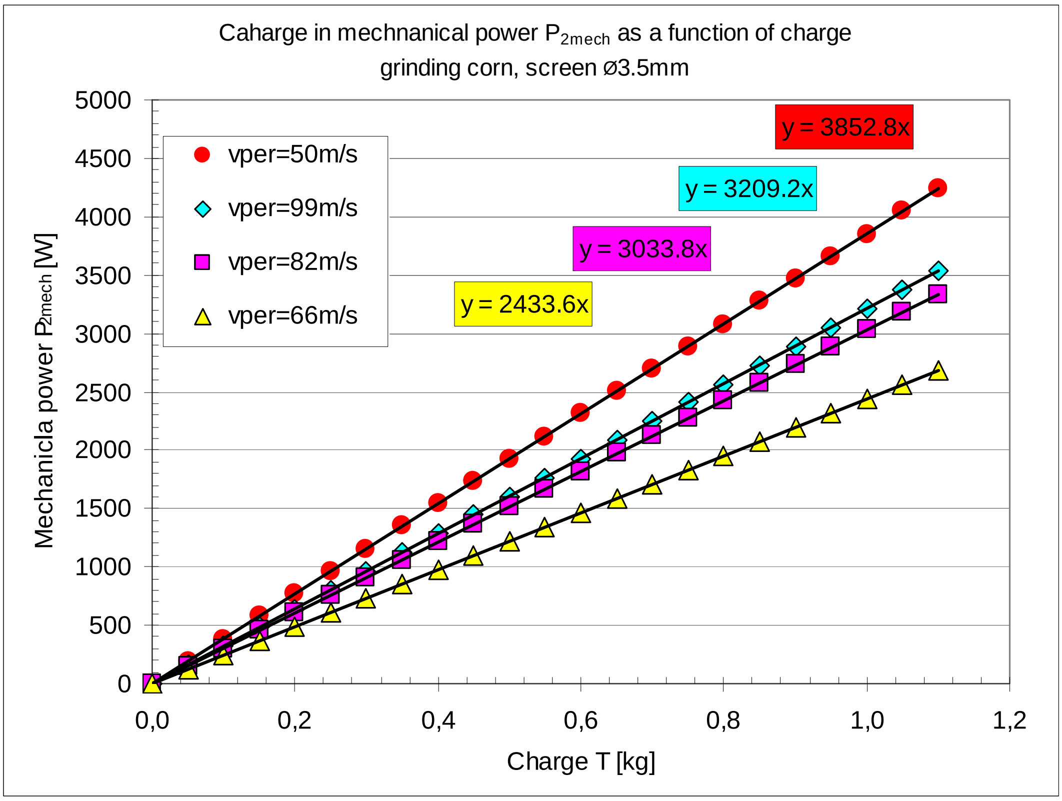

Figure 2.12. Mechanical power as a function of charge in the unsteady phase of grinding

In the figure, the angular co-efficient of the line connected to hammer peripheral speed v_{per}=*50 m/s* is the greatest. Although one may predict that this should be the least. The grinding process finished safely at this rotary speed, but operating with this rotary speed is not economical. On lower rotary speed in the transient phase operating the grinding machine is not worth.

It can be stated that, in the transient phase of grinding in cases of different hammer peripheral speeds, there is a linear connection – starting from the origin – between the charge (T) and the mechanical power need (P_{2mech}).

2.8.2. Relation of power and mass flow in the unsteady phase of grinding

Examination of unsteady grinding phases is important for recognition of dynamic relations. The characteristics which belong to charging and emtying are the first steps for discovery and formulating of control parameters.

The dynamics of starter and final stages of grinding are important in terms of adjustments – for size corrections or performance optimization – during running. If we know the mass flow growth which is connected to given power growth then the desired values can be adjusted precisely.

The initial charging phase and the final emptying phase are fast processes. The new measurement assembly is applicable for describing fast changing parameters with usage of adequate samples. At the examination of initial charging phase, I adjusted different hammer peripheral speeds, throat size and screen adjustments. With these settings, I recorded the changes of mass-flow and power.

In the transient phase, the formation of power as the function of mass flow is an equation of second degree also in the case of different hammer peripheral speeds. This can be seen in Figure 2.13.

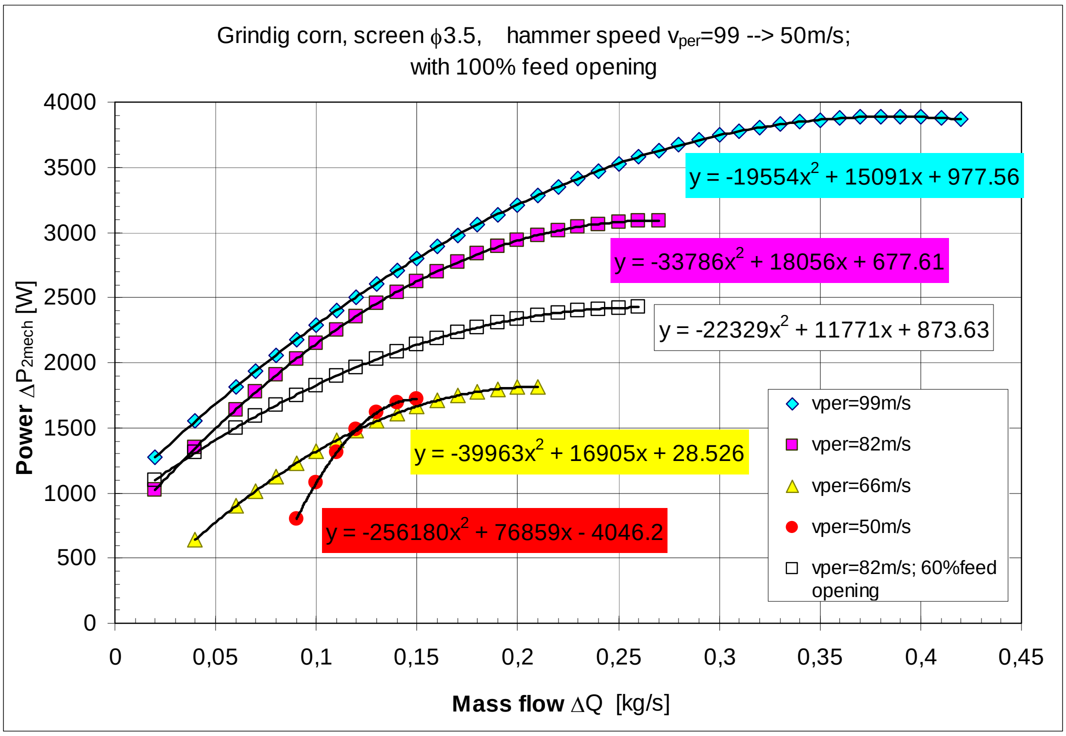

Figure 2.13. Relation of momentary mass flow and power change on shaft to different hammer peripheral speeds in the unsteady state of grinding

Formation of the power and mass flow shows the character of saturation curve. This means that the mass flow cannot be increased infinitely. The partial derivative of pure mechanical power according to mass-flow is linear in the unsteady grinding phase. The incline of lines is in inverse ratio with the growth of peripheral speed.

3. RESULTS

1 I declared that, in the case of grinding air-dry corn, the surface growth index (***dA/dt***) as the function of grinding power (**P_{2mech}**) can be defined with an equation of the second degree in the case of increasing hammer peripheral speed. (Figure 2.5)

In the case of Ø3.5mm screen:

$$\frac{dA}{dt} = -4 \cdot 10^{-7} P_{2mech}{}^{2} + 0{,}0026 P_{2mech} + 0.5548 \qquad R^2=0.9994 \qquad (3.1.)$$

In the case of Ø5mm screen:

$$\frac{dA}{dt} = -2 \cdot 10^{-7} P_{2mech}{}^{2} + 0.0021 P_{2mech} + 2.6918 \qquad R^2=0.8881 \qquad (3.2.)$$

2 I demonstrated that, in the case of grinding the actual type of air-dry corn, with a determined moisture content (*w=const.*), with given screen and with constant mass flow *(Q=const.)*, the changes of hammer peripheral speed (v_{per}) can change the partical size distribution function's maximum points. (Figure 2.6)

a) I proved that, with increasing hammer peripheral speed (**v_{per}**), the values of mean particle size (**X_{mean}**) decrease linearly. (Figure 2.7)

For example: In the case of Ø5mm screen: with $R^2 = 0.9565$ fit;

In the case of Ø3.5mm screen r: with $R^2 = 0.889$ fit.

b) I proved that, with increasing hammer peripheral speed (**v_{per}**), grits fineness grows, but the energy need for grinding grows in the quadratic proportion. (Figure 2.7)

3 I defined with measurement results that the hyperbola function formulated at determining a single grain's specific surface (***a_f***) can be extended to grits masses' mean particle size (***X_{mean}***).(Figure 2.8)

4 There is a second-degree relation between the mass flow (***Q***) and the specific surface area (***a_f***) at increasing hammer peripheral speed. Specific surface does not grow infinitely with increasing mass flow. The maximum specific surface defines an optimal mass flow value. (Figure 2.9)

a) With usage of Ø5mm screen at grinding air-dry corn, the maximum specific surface area (*a_f=8.5m^2/kg*) value belongs to the hammer peripheral speed v_{per}=68m/s and *Q=0.42kg/s* mass flow.

b) With usage of Ø3.5mm screen at grinding air-dry corn, the maximum specific surface area (*$a_f=6.2m^2/kg$*) value belongs to the hammer peripheral speed v_{per}=58m/s and *$Q=0.28kg/s$* mass flow.

5 I quantified the relation between the mean particle size (**X_{mean}**) and significant particle sizes (**X_{80}, X_0, X_{50}**). These can be defined with lines which start from the origin. (Figure 2.10)

$$X_{80} = 1.3676 \cdot X_{mean} \qquad R^2 = 0.9999 \qquad (3.3.)$$

$$X_0 = 1.1282 \cdot X_{mean} \qquad R^2 = 1 \qquad (3.4.)$$

$$X_{50} = 0.9632 \cdot X_{mean} \qquad R^2 = 0.9997 \qquad (3.5.)$$

The equations are applicable for grinding air-dry corn with Ø3.5-mm size screen. On the basis of measurement data, I found a simple empirical relationship for this case.

6 I proved that the constant (**E_f=const.**) energy need E_f (Ws/m^2) for formulating a unit of new specific surface can be extended to different hammer peripheral speeds (Figure 2.11., grinding air-dry corn, ø5-mm screen)

7 I defined a new relation at transient phases of grinding. Mechanical power requirement (***P_{2mech}***) is linear as the function of charge (***T***).
(Figure 2.12.)

In the case of v_{per}=66m/s $$P_{2mech} = 2433.6 \cdot T_{load} \qquad (3.6.)$$

In the case of v_{per}=82m/s $$P_{2mech} = 3033.8 \cdot T_{load} \qquad (3.7.)$$

In the case of v_{per}=99m/s $$P_{2mech} = 3209.2 \cdot T_{load} \qquad (3.8.)$$

The relationships do not include the idle-running power requirement, and are true in the case of air-dry corn and Ø3.5-mm screen size.

8 a) I defined that, in the transient phase of grinding, the partial derivative of the pure mechanical power (***$\Delta P_{2mech}/\Delta Q$***) changes according to the mass flow is linear.

b) I declared that more mass flow (*Q*) values can be adjusted by the stepless control of hammer peripheral speed (v_{per}) in the transient phase of grinding, at a desired mechanical performance (*P_{2mech}*) values.

4. CONCLUSIONS AND SUGGESTIONS

The new measurement assembly constructed by me is not just applicable for reproducing traditional basic adjustments but it is also applicable for the detailed measurement of fast changing grinding processes.

This assembly can be adapted to all those systems where monitoring and controlling of hammer mills or similar machines are needed. The modular system structure is an advantage of the system. The system only measures and records the previously determined basic data. I suggest the instrumentation of the already installed grinding machines because, by usage of the model rules and with control measurements, a new controlling algorithm can be constructed for an actual plant.

During my experiments I defined the sampling frequency at 50Hz. This means that I recorded 50 data per channel per second. I simultaneously monitored all the 8 channels. If we want to use one adjusted technology, I suggest the decrease of sampling frequency, because a big unnecessary database will be produced, which doesn't contain any new information.

I also suggest the formation of the system into a feed back control circle. More so since the most applied frequency converters can work according to the PID control.

The problems which appear the unbalanced state of traditional hammer mills – constructed without frequency converter – are immeasurable but they still exist and load the system. As a further development and research aim, I recommend the analysis of dynamic relations with the application of the constructed measurement assembly – especially for avoiding working irregularities.

The electric motors constructed with frequency converters are applicable for the direct drive. With this, the transmission is simpler. Some machine parts such as V-belts, V-belt sheaves, tension roller can be left out of the traditional system. This may result in significant weight reduction in connection with actual machines. The weight reduction results in a decreasing loss and provides a bigger performance. With usage of frequency converters, a more effective operation can be achieved. With making correction in operation, there is no need for stoppage and screen change – which is a loss. In operation by changing rotary speed, the grain size can be influenced. I suggest the application of frequency converters on operating hammer mills.

It is a further advantage that the motor of the hammer mill is capable of starting at a load deviating from the nominal value so the particle size to be produced can be pre-defined. With usage of frequency converter, the current peaks can be avoided which occur because of the traditional star-delta starting processes.

I recommend the measurement assembly for practice, because, instead of traditional manual control, the processes are controlled on the basis of objective data. This new method is more economical, and spares time. Also the grits is better in quality.

From my experimental measurements and provided suggestions, it can be concluded that, with monitored simultaneous changes of parameters, the fodder grinding can be optimized – with the utilization of the results of the research in practice.

5. SUMMARY

Grinding is comminution of grain crops. The aim of the process is to ensure the most favourable fodder utilization for the actual species of animals.

Hammer mills are typical machines for fodder processing. The structure of these machines (hammer mills, impact mills) is simple and their reliability is outstanding.

The purpose of my research are the following: examination of processes in grinding space by changing parameters; more exact kinetic description of grinding on the base of model experiments; optimization of grinding process; increasing of end-product quality.

I have developed a measurement-sensor and data processor computer system for experimental purposes which can be considered as a pilot plant unit of an automatic controller system.

The experimental and measurement principles and the model functions (after correct adaptation) can be extended to any other grinding process and grinding machine (mill), according to the dynamic similitude.

The new system is suitable for infinitely variable adjustment of hammer peripheral speed (with the help of a frequency converter) unlike the former system with constant speed regulation. This new system makes dynamic change monitoring also possible (through the inserted computer) due to the high-speed data logger device.

The high-speed data recording makes the precision recording possible of changeable (non-stationary) working periods and it enables studying transient processes.

400 data per second are processed by the simultaneous monitoring of 8 channels and the 50 Hz sampling frequency.

40.000 data are available at each measurement setting with 100 seconds and 8 channels taken into consideration.

By the enlarged rotary speed range of the new measurement system, it became possible the recording of continual dynamic functions and the grinding kinetic analysis of the significant values and value pairs.

During my experiments I examined the grinding process with different settings and the effects of other parameters on the quality of end-products. The results lead to the more accurate cognition (energetic, kinetic) of grinding processes.

The numerous data gained at the experiments were processed after systematization and grouping. I made the data procession with the equations mentioned in specialized literature. I designed multivariate graphs for data evaluation. The most important consideration was the effect of the varied peripheral speed at summarizing the conclusion.

As results of the research carried out with coincidentally infinitely varying the peripheral speed of mill hammers, I draw the following conclusions:

- The coherence of mechanical power transmitted by the shaft of the grinding machine and the surface growing intensity
- The connection between the grits fineness and grinding energy need
- The connection between the mean particle size and the specific surface is hyperbolic.
- The specific surface growth has a maximum value.
- The connection between the mean (average) particle size and other known nominal particle size values
- The continuous energy need of a surface unit area can be extended also to the cases at using different peripheral speed of hammer.
- The relation between load and mechanical power in the non-stationary phase of grinding, and the connection between mass flow and performance

On the base of the analysis of the experiments carried out and the conclusions, a mechanically as well as energetically well-founded control circuit which is utilizable also for everyday usage in plants can be elaborated.

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