The research of one-stage particle size-reduction process of blocked frozen meat with multiple cutting tools with milling operation method

B R Kapovsky¹, P I Plyasheshnik², T G Kuznetsova¹ and A A Lazarev¹

¹ V.M. Gorbatov Federal Research Center for Food Systems of Russian Academy of Sciences, 26, Talalihina Str., Moscow, 109316, Russia
² Moscow State University of Food Production, 11, Volokolamskoe highway, Moscow, 125080, Russia

E-mail: b.kapovski@fncps.ru

Abstract. This article shows experimental data about energy demands of innovative one-stage particle size-reduction process of frozen meat, formed in blocks, with milling operation method. We researched the particle size-reduction of meat blocks (beef and pork) by tools of different construction and shape of cutting edge: a slab mill with small edge and a fitted on shaving milling tool with a hard-faced knife. This study based on results of measuring three-phase active power, used by the cutting electric drive in working condition. The article presents the calculation of the measurements of numerical characteristics (mean value and mean square deviation) of statistical samples of power values with completing particle size-reduction tool with milling tools. The research shows that placing additional sustainer, that fixes a block of meat directly near the cutting zone, leads to decrease of energy demands for the cutting process up to 20% and to lower the dispersion of power values more than three times. The data obtained during the research let work out technical requirement specification for producing a commercial prototype of cutting particle size-reduction. The data allow creating the calculate method of numerical characteristics of a random process for a load of multiple razor tool in working condition. That model is used for designing an intellectual system of management of technological process on the transfer line for meat product producing with using one-stage particle size-reduction of raw materials with the milling method.

1. Introduction

Industrial usage of innovative one-stage particle size-reduction of frozen meat materials with milling method, being an object of authors, defines the tasks of experimental research of the process in laboratory conditions:

- the definition of power demands on the process of multiple razor cutting that let us calculate installed power of electric drive mechanism of cutting particle size-reduction, meant for size-reduction of meat blocks of typical industrial sizes;
- the definition of requirements for the construction of particle size-reduction, that provide the decrease of mentioned power demands and guarantee the quality of size-reduction;
• the research of specifics of the behaviour of transition process in the electromechanical system of the mechanism of cutting of particle size-reduction for calculating the characteristics of intelligent system management of the technological process of producing meat products with the usage of energy-saving one stage particle size-reduction [1, 2].

2. Materials and methods
As a raw material for size-reduction experimental frozen blocks of meat is used (Beef of the second class – later in the text as ‘beef’; greasy pork rib – later in the text as ‘rib’), formed in press-form construction by Gorbatov Research Center for Food Systems. The sizes of experimental blocks are height 0.070 m, width 0.075 m, length 0.300 m. The experimental blocks before size-reduction are put into the freezer with temperature -12°C – (-14°C). Then frozen experimental blocks one by one are taken out from the freezer and put into operation section of the size-reduction machine milling modification 1 (IBF – 1). The size-reduction is completed with a slab mill with small edge according to GOST 29092-91 and a fitted on shaving milling tool with hard-faced knife TM21M EEC (company Freud, Italy). During the process of size-reduction of experimental frozen blocks of meat with industrial analyser-registrar ACM-3192, we measured and registered active three-phase power, consumed by electric engine of the driver of cutting machine IBF – 1 in working condition. The sampling period (time between two consequent measurings) is considered as minimally possible for a mentioned device and is 2 s. The measuring of electromagnetic torque of engine of the driver of cutting machine with a fewer sampling period is carried out with a multi-channel digital recorder Flash-Recorder-2-16RTC-SD. Figure 1 shows the connection of recorder and analyser-registrar ACM-3192 to the output of the control cabinet, setting IBF – 1. Figure 2 shows the computer, where the recorder Flash-Recorder-2-16RTC-SD is connected. Transient values of fixated measurement are recorded into HD of a mentioned computer with special software.

The measuring of electromagnetic torque of electric engine of a driver of cutting machine IBF – 1 is carried out according to requirements of Kotelnikov-Shannon theory about sampling time (sampling period) of continuous signal for interpolatory representation it as a discrete signal.
3. Discussion of the results
The sampling period of the recording of transient values of electromagnetic torque of engine of the driver of cutting machine in working condition is set 0.00016 s. Figure 3 shows a recording of electromagnetic torque at the size-reduction of a frozen block of beef from the beginning of size-reduction to its end. Figure 4 shows the same process of size-reduction of a frozen block of rib (shaving milling tool with a hard-faced knife). Abscissa axis (X-axis) fixed time (hours, minutes, seconds, milliseconds), ordinate axis (Y-axis) fixed measured quantity.

![Figure 3](image)

**Figure 3.** Recording of transient values of electromagnetic torque of engine of the driver of cutting machine in working condition (beef size-reduction).

As the changing of electromagnetic torque of driver engine in the present situation is a random process in time [1], thus we are going to consider data collection, registered in every separate experiment, as general data collection. At the sampling period (quantization) of measuring of electromagnetic torque 0.00016 s, in recording time interval 0.5 s there are more than 3000 measurements of value. The calculation of numerical characteristics of random process $M = f(t)$, where $M$ – electromagnetic torque of engine driver of cutting machine IBF – 1, $t$ – present time, is carried out by statistical samples from general data collection. The data is gathered with time interval 0.0096 s, not superior to limit value of sampling period (0.01 s) [3].

![Figure 4](image)

**Figure 4.** Recording of transient values of electromagnetic torque of engine of the driver of cutting machine IBF – 1 in working condition (pork rib).
The results of statistic values calculation of the spectral density of process $M(t)$ according to experimental data for five calculated points at size-reduction of two types of raw material are shown in Tables 1 and 2. Here: $S_1$ – the statistical value of spectral density of process $M(t)$, smoothed by applying Hamming window; $q$ – number of steps bias at frequency axis at representing process $M(t)$ in the frequency domain; $\Delta w$ – frequency bias between the assessed value of spectral density at one step of the calculation. Frequency bias $\Delta w$ correlates to time bias at evaluating correlation function at representing the process $M(t)$ in the time domain.

The results of measurement of active power at size-reduction of beef and pork rib are analyzed as a whole statistical sample of data for milling tool of one type, forming IBF – 1.

### Table 1. Statistical values of the spectral density of process $M(t)$ (beef size-reduction)

| $q$ | 0   | 1   | 2   | 3   | 4   |
|-----|-----|-----|-----|-----|-----|
| $S_1(q\Delta w)$, (Nm$^2$s/rad) | 1.52744 | 0.66205 | 0.01277 | 0.01019 | 0.00834 |

### Table 2. Statistical values of the spectral density of process $M(t)$ (pork rib size-reduction)

| $q$ | 0   | 1   | 2   | 3   | 4   |
|-----|-----|-----|-----|-----|-----|
| $S_1(q\Delta w)$, (Nm$^2$s/rad) | 1.45439 | 0.62310 | 0.00259 | 0.00290 | 0.00774 |

For mechanism with milling tool with the small edge expectation value of the statistical sample is 3.07 kW at sigma 0.789 kW; with installing additional sustainer in the cutting zone of an operating camera, these characteristics are 2.44 kW and 0.195 kW. For mechanism with hard-faced knives, the value of mentioned characteristics is 1.29 kW and 0.195 kW relatively.

### 4. Discussion of the results

The data of measure of active power at size-reduction of beef and pork rib is analyzed. As whole statistic sample as aim to calculate specific energy demands of installed power of the electric engine of the cutting mechanism of milling size-reduction, constructed for size-reduction of frozen blocks of meat (beef and pork rib) of industrial sizes. The installing of additional sustainer (Figure 5) that fixes a block of meat in exactly near the zone of cutting leads to decreasing energy demands for cutting meat.
process up to 20% and decreasing the dispersion of power values more than three times, that improves the quality of size-reductor (its homogeneity). Additional sustainer shortens the length of the console, decreasing the deformation of bottom rail surface of operating camera of size-reductor.

The decreasing of deformation in springing technological system (size-reductor – operating camera – multiple-razor tool) leads to decreasing of transient load on the electric engine of the cutting mechanism. This process is caused by periodical change of cutting power as teeth of milling tool go in (out) raw material and because of twisted and torsional deformation of system. That makes the process of milling frozen blocked meat less energy demand.

For engineering calculation, it is possible to carry out an approximation of the correlative function of process M(t) by the sum of sampling of indiscrete time function in separate time moments. If samplings of any realization m(t) accidental process M(t) correlates to time moments and if the values m(t) are then the discrete equivalent of the indiscrete correlation function is demonstrated in formula 1:

\[ R(n\Delta t) = \left[\frac{1}{N - n + 1}\right] \sum_{k=0}^{N-n} x_k x_{k+n} \]  
\[ R(n\Delta t) = \left[\frac{1}{N - n + 1}\right] \sum_{k=0}^{N-n} x_k x_{k+n} \]  

with \( n = 0,1,2, \ldots, Q \) and \( Q \ll N \).

Approximate (estimate) function (1) is a random function, depending on all variety of possible sampling. But expectation function of approximating (1) is in agreement with the exact value of autocorrelation function and is its unbiased estimator [4, 5]. Spectral density of stationary in the broad meaning random process is Fourier transformation of correlation function (formula Vinner–Hitchin). Mathematically it is characterized by formula 2:

\[ S(w) = \int_{-\infty}^{\infty} R(\tau) \exp(-j\omega \tau) \, d\tau = F[R(\tau)] \]  
\[ S(w) = \int_{-\infty}^{\infty} R(\tau) \exp(-j\omega \tau) \, d\tau = F[R(\tau)] \]  

Transformation (2) can be written through cosine component, formula 3:

\[ S(w) = 2 \int_{0}^{\infty} R(\tau) \cos \omega \tau \, d\tau \]  
\[ S(w) = 2 \int_{0}^{\infty} R(\tau) \cos \omega \tau \, d\tau \]  

Then discrete approximation of spectral density of process M(t), represented as cosine component, can be written as formula 4:

\[ S(q\Delta w) = \Delta t \left[ R(0) + \sum_{n=1}^{Q-1} R(n\Delta t) \cos \left( \frac{q\pi n \Delta t}{M} \right) + R(Q\Delta t) \cos q\pi \right] \]  
\[ S(q\Delta w) = \Delta t \left[ R(0) + \sum_{n=1}^{Q-1} R(n\Delta t) \cos \left( \frac{q\pi n \Delta t}{M} \right) + R(Q\Delta t) \cos q\pi \right] \]  

where \( q = 0,1,2, \ldots, Q; \Delta w = \pi/(Q\Delta t) \) – frequent bias between estimated values of spectral density.

The present estimate can be smoothed by multiplication (4) on even function of a special type (spectral window Hamming). The smoothed estimate of the spectral density of process M(t) has formula 5:

\[ S_1(q\Delta w) = 0.54 S(q\Delta w) + 0.23 \{ S[(q+1)\Delta w] + S[(q-1)\Delta w] \} \]  
\[ S_1(q\Delta w) = 0.54 S(q\Delta w) + 0.23 \{ S[(q+1)\Delta w] + S[(q-1)\Delta w] \} \]  

The present values of the spectral density of random process M(t) (tables 1 and 2) are used at computer modelling of one-stage size-reduction of frozen blocked meat [1].

5. Conclusion
According to the results of experimental research of one-stage process of size-reduction, technical requirement specification for designing industrial-experimental example of milling size-reductor is
created and sent to machinery fabric. In technical requirement specification, there is hard fitting of a
block of meat in the zone, situated exactly in front of milling tool, including its total size-reduction.
Counting quick-changing transfer processes in the electromechanical system of the engine of cutting
machine (Figures 2 and 3), there is chosen frequent vector regulation of cutting meat speed for its
stabilization for achieving required quality of size-reduction. The method of calculating of number
characteristics of a random process of load multiple-razor tool in working condition is used for
designing intelligent system management of the technological process in autotomized line for
producing meat product with applying one-stage size-reduction with milling method.

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