1. Introduction

Automation and mechanization of industrial technological processes usually leads to an increase of the power of technological equipment. This is due to the increase in labor productivity of the staff person who manages the mechanized equipment. At that time the increase in power of technological equipment usually leads to an increase in its metal construction and energy intensity. Using mathematical modeling methods and modern program logic controllers allows changing the approach to the choice of parameters of agricultural process equipment. For example, the distribution of liquid feed many times a day will significantly reduce energy consumption by reducing the performance of equipment due to its round-the-clock operation in discontinuous mode.

In the Republic of Belarus are more than 100 industrial pigsty farms. Feeding of pigs by liquid concentrated feeds is a widespread feeding technology providing high efficient use of expensive resources. Usually it is used a double distribution of feed in accordance with zoo technical standards. Feed distribution is an energy and labor intensive process. Reducing the amount of consumed electrical energy can be achieved through the use of modern automated methods of process control. Moreover it allows shifting the operator’s intellectual control functions to the computer device. Eliminating the need for the presence of the operator in the process control allows you to increase the operating time of the equipment and significantly reduce its performance and power.

Liquid feeding is a fully mechanized process and ensures high efficiency in feeding pigs [1, 2]. Therefore, the energy estimation of the effectivenesst of multi-times per day feed distribution compared to traditional technology of feeding pigs twice per day is actually important.

2. Mathematical model of energy consumption for feed distribution

The main functions of feeding process management are the following ones [3]:
1. determining of feeding time;
2. calculation of feeding doses in accordance with the animals number and age;
3. preparation of the required amount of feed;
4. distribution of feed for feeders in accordance with the planned doses;
5. control of food consumption.

In the past, functions (1, 2 and 4) have been completed by staff [3]. The need for staff in determining doses of feeding and control of feed consumption caused double feeding of pigs during the working day. Accordingly, the process equipment had to ensure the preparation and distribution of a daily dose of feed in 2-4 hours. The development of modern programmable logic controllers (PLC) and the use of mathematical models for pig growth process [1, 4] allow to implement the function (1) by PLC without the presence of personnel.

The algorithm for feeding dose calculation is based on the mathematical model of the weight gain for fattening pigs [1, 4]:

$$ P(m) = \mu \cdot m^k \cdot \frac{D - D_{maint}}{D + D_{maint}}, \quad (1) $$

where $m$ [kg] is the animal body weight; $P$ [kg per day] is a weight gain per day; $\mu$, $a$ are empirical constant values determined by pig breed and environmental and feeding conditions at the farm; $D$ [feed unit] is a day feeding dose; $D_{maint}$ [feed unit] is the maintenance daily dose of feeding.

The maintenance daily dose of feeding provides 420 kJ/kg$^{3/4}$. It is determined by the formulæ:

$$ D_{maint} = k \cdot m^{3/4} \quad (2) $$

where $k$ [feed unit/kg$^{3/4}$] is a constant value depending on the energy content in 1 kg of the feed.

Model (1) is valid for various zoo technical experiments when being adjusted by selecting coefficients: the values of $\mu$ and $a$ depend by the animal breed and the farming conditions and the value of $k$ depends on the quality of feeds used. By analyzing a large amount of experimental data there was made an estimation of the adequacy of the proposed mathematical model (1). As an example, some experimental data and the results of calculations according to formulæ (1) are presented at Table 1.

<table>
<thead>
<tr>
<th>$m$ [kg]</th>
<th>$D$ [feed unit]</th>
<th>$D_{maint}$ [feed unit]</th>
<th>$P$ [kg]</th>
<th>Error [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>36.3</td>
<td>2.1</td>
<td>0.444</td>
<td>0.75</td>
<td>0.78</td>
</tr>
<tr>
<td>45.4</td>
<td>2.542</td>
<td>0.525</td>
<td>0.82</td>
<td>0.83</td>
</tr>
<tr>
<td>54.5</td>
<td>2.838</td>
<td>0.602</td>
<td>0.86</td>
<td>0.86</td>
</tr>
<tr>
<td>72.6</td>
<td>3.185</td>
<td>0.746</td>
<td>0.91</td>
<td>0.88</td>
</tr>
<tr>
<td>90.8</td>
<td>3.895</td>
<td>0.882</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>100</td>
<td>4.312</td>
<td>0.949</td>
<td>0.98</td>
<td>0.99</td>
</tr>
</tbody>
</table>

Obviously, formulæ (1) adequately describes the required dependence, since the error does not exceed the possible for these data (2-3%).

To calculate the feed dose, it is necessary to justify the optimum criteria. For example, when using as an optimum criteria minimum cost of the feed unit, the required feed dose is determined by the ratio:

$$ D_{opt} = \left(1 + \sqrt{2}\right) D_{maint} \approx 2.4 \cdot D_{maint}. \quad (3) $$

That is, knowing the initial weight of the pig on the first day we can determine the maintenance dose by the formulæ (2) and then calculate the optimal feeding dose by the formulæ (3). And then a daily weight gain is calculated by the formulæ (1). On the next day one should repeat the calculations.
Then the animal live mass at the day number \( n \) since the starting of feeding will be calculated as follows:

\[
m(n) = m(1) + \sum_{i=1}^{n} P(i),
\]

(4)

where \( n \) is the number of day elapsed since the start of feeding; \( m(1) \) [kg] is the animal’s live mass at the start of feeding; \( P(i) \) [kg per day] is the daily weight gain at the day \( n \).

Fattening pigs are contained in group boxes, so a group feed dose for the box number \( l \) is the following:

\[
D[l] = N[l] \cdot 2.4 \cdot D_{\text{maint}}.
\]

(5)

And the total amount of feed required for all group boxes is:

\[
V = \sum_{i=1}^{n} D[i].
\]

(6)

The performance of the liquid feed distribution line \( Q \) should ensure the distribution of feed for the whole number of animals in the farm according to technological requirements [3]:

\[
Q = V/(n \cdot t).
\]

(7)

where \( V \) [L] is a required day amount of the feed of the desired moisture value; \( n \) is the number of feedings per day; \( t \) [sec.] is the duration time of the feed distribution process.

Earlier in [5] the correlation between the power of the liquid feed pump and its performance was empirically determined

\[
P = l \cdot K_0 \cdot Q^\gamma.
\]

(8)

where \( Q \) [m³/sec] is the current flow rate of the liquid feed; \( l \) [m] is the feed line length; \( K_0 \) and \( \gamma \) are approximation coefficients depending on the feed moisture \( W \) [%] and geometrical characteristics of the feed distributing line. According to experimental data there in Table 2 are shown the following results.

### Table 2: Experimental correlation data between the power of the food pump \( P \) and its performance \( Q \) and feed moisture \( W \).

<table>
<thead>
<tr>
<th>Feed moisture ( W, % )</th>
<th>( Q, \text{L/sec} )</th>
<th>( P, \text{kW} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>85.9</td>
<td>1.28</td>
<td>0.8</td>
</tr>
<tr>
<td>84</td>
<td>1.72</td>
<td>1.2</td>
</tr>
<tr>
<td>82.5</td>
<td>2.25</td>
<td>1.5</td>
</tr>
<tr>
<td>80</td>
<td>2.98</td>
<td>3.4</td>
</tr>
<tr>
<td>78.6</td>
<td>3.63</td>
<td>4.2</td>
</tr>
<tr>
<td>77</td>
<td>4.3</td>
<td>4.7</td>
</tr>
</tbody>
</table>

Daily energy consumption for distribution of feed will be determined by the formulae:

\[
E = P \cdot t \cdot n.
\]

(9)

Substituting (7) and (8) in (9) we get:

\[
E = \left( l \cdot K_0 \cdot Q^\gamma \cdot t \cdot l \cdot \gamma \right) n^{-\gamma}.
\]

(10)

Using typical equipment at pigsty farms requires staff presence. Therefore a technology of feeding pigs twice a day is accepted. The implementation of automatic intelligent control will eliminate the presence of the staff and apply multiple feeds in smaller doses. As a result, this will reduce energy consumption for the distribution of liquid feed in 2 or more times compared with 2-time feeding (see Fig. 1).

### 3. Conclusion

PLC of the automatic feed distribution control system can take over the functions previously performed by personnel, including:

- mathematical calculation of feeding doses, including their optimization;
- control of food consumption;
- warning the farm staff about the need to diagnose the state of animals;
- logging the data parameters of the process of feed distribution.

In the mechanization era of the agro technical production, an increase in labor productivity was associated with an increase in equipment power and performance. The exclusion of the staff personnel from the management of feeding pigs allows increasing the time duration of feed distribution and therefore to reduce the equipment performance and power and metal consumption. For example, when feeding several times a day (up to 20 times), a reduction in a single dose of feed distributed can significantly (up to 5 times) reduce the amount of metal required for the mixing baths and group feeders. If the feed distributed to feeders is not eaten in 30 – 40 minutes then the next feed dose can be adjusted or a warning signal for diagnosing the condition of the animals in this group box can be generated.

### 4. References