599. Vibration and noise measurements during silage thickening with inertia directional vibrator

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Abstract. Literature review and performed theoretical investigation indicates that it is environmentally and economically feasible for small and average size farms to use vibrational thickening method for silage preparation. However, the results need to be verified with experiments.

This research work provides analysis and evaluation of flat surface inertia type vibrator, in which the excitation force is induced by turning the unbalanced mass. Directed action vibrator was manufactured and tested. Results indicate that application of inertia directional vibrator for thickening of finely chopped corn and Jerusalem artichoke stalk mixture, after 40 minutes thickening, allows to obtain a 114.6 kg m^{-3} density for both layers, while thickening the first 65 kg mass mixture layer after 10 minutes - a 197.9 kg m^{-3} density. Dry material densities correspond to 61.5 and 106.3 kg m^{-3} respectively. After examination of fodder quality it was determined that corn mixture silage, thickened by the inertia directional vibrator, satisfies high-grade silage requirements.

Performed tests demonstrated that the effect of vibrations on whole body and the measured noise levels do not have detrimental effect on human health and the established acceptable limits are not exceeded while operating the inertia directional vibrator. The vibrator is suitable for silage preparation since it does not contaminate the fodder with dirt and gasoline products during operation. The proposed silage preparation method provides opportunities to use ecologically safe containers as well as sectional and other types of enclosures.

Keywords: silage, container, inertia directional vibrator, thickening, density, vibration, noise.

Nomenclature

t_g – time required for a production cycle starting with plant stems chopping, min;
t_{sm} – duration of plant stems chopping, min;
t_p – duration of plant stems chaff loading into container, min;
t_u – duration of lifting up of vibrator, min;
t_t – duration of plant stems chaff thickening, min;
t_s – duration of sealing and pressing grass in a container, min;
t_i – duration of technological operation, min;
N_i – efficiency of technological operation, t h^{-1};
a_i – measured standard deviation of acceleration value (m s^{-2}) in i-th frequency band;
$K_{a,i}$ – weighing coefficient in i-th frequency band;
n – number of frequency band;
KVV – acceleration value for i-th work period;
T_0 – foundation work period length, equal to 28800 sec.

Introduction

Feeding of cattle with silage is widespread all over the world. More and more grasses are used for silage production in Western Europe states. This is confirmed by data on the percentage of usage of harvested grasses for silage production: in Holland – 99 %, in Denmark – 93 %, in Northern Ireland – 90 %, in Norway – 75 %, etc. [1]. In the process of energy deficit ensiling of grass forages has been and will continue to be the main way of their preservation. It is predicted that the production of chopped grass silage in trenches, heaps, containers and bales would remain in the nearest future. In preparation of silage its quality depends on the time of filling trenches and containers and mass pressing. Only caterpillar tractors were used for silage pressing in Lithuania up to 1990. Later heavy wheeled tractors K-701, T-150K, average draught class MTZ and other tractors were started to be used for this purpose. In 2001 research on using low capacity tractors (T-25A, etc.) in pressing chopped grass was carried out [2].

In Lithuanian climatic conditions the production of hay should be decreased and the production of silage should be increased [1]. In order to produce good quality silage a necessary condition is an adequate pressing of plant mass. Taking into account the fact that grass mass surface is unstable, a tractor driver can be injured or killed if a tractor turns over while pressing the mass [3].

Density is one of the indicators characterizing the pressing of fiber-plant mass. In analyzing the process of fiber-plant mass thickening the majority of authors follow this assumption: pressure fluxion by mass density is a function of added pressure [4, 5]. This assumption is used in describing simplified models of grass mass pressing [1]. Individual grass features are described mathematically by applying idealized strain components of real materials and their different combinations. Deformation and relaxation of elements forming a model are described by differential equations [2, 6, 7].

Recently the Institute of Agricultural Engineering at Lithuanian University of Agriculture (IAE LUA) has been carrying out investigations related to application of vibratory grass mass pressing method as an alternative approach to mass pressing by tractors. So far Lithuanian farmers have not used this vibratory grass mass pressing method in practice. However, the obtained research results will be used to prepare recommendations for application of these vibrators for silage pressing in the farms [8-10]. In order to evaluate the proposed vibratory method a detailed analysis of physical characteristics of the pressed mass has to be performed as the types of used vibrators and their operational parameters depend on them. Thus, the research goal is silage production technology while pressing mass by a vibratory thickener.

It is very important to reduce vibrations and noise while pressing mass by a vibratory thickener. The vibrations that are transmitted by mechanical oscillations are harmful to worker's health and safety, especially elevating the lower back pain and spine traumas [11]. The damaging vibrations transmitted to the whole body mainly propagate from support surfaces (floor, seat, etc.) in the frequency range from 0.5 Hz to 80 Hz, have certain amplitude and are usually characterized by acceleration. Operators of industrial machinery mainly suffer from the whole body vibrations (tractors, excavators**,** trucks, press and stamp equipment; it should be noted that many operators are subjected to harmful vibrations through hands or arms from various vibration sources) [12]. Vibrations are also transmitted to persons working in the near vicinity of vibrating or compacting machinery.

Hearing degradation or even its loss from excessive exposure to noise is one of the most prevalent industrial health issues in Europe. Agricultural industry is attached to EU sectors, where the highest risk to noise exposure was established. Thus, measurements have to be obtained not only for vibrations, but also for noise, while thickening silage by inertia directional vibrator. According to European Parliament and Council Directive 2003/10/EB, the noise levels can be reduced at a work place by taking into consideration preventive means, work facilities, and by choosing work order and methods with specified goal to reduced risk at noise source [13].

The research objective of the current study is evaluation of silage preparation in a container storage technology by means of vibratory thickening approach as well as determination of thickening efficiency, vibration and noise level measurements during silage thickening by inertia directional vibrator.

Experimental methods

Corn and Jerusalem artichoke stalks chaff thickening and silage quality estimate method

The trial was carried out in a laboratory stand, which scheme is indicated in Fig. 1. Corn and Jerusalem artichoke stalks chaff was thickened in the container storage at the bottom of which an opening had been made and a sensitive pressure plate had been fitted. The centrifugal directed action vibrator with two masses rotating in counter-clockwise directions was used for grass thickening. The vibrator was rotated by an asynchronous motor of 1.1 kW, 1500 min^{-1}. Weights of 7.0 kg mass were fitted to rollers in the vibrator, their mass centers were 40 mm away from the axis. The total mass of this vibrator was 125 kg.

The container was filled by chopped silage mass, the vibrator installed on the top and continuously operated for 20-40 minutes. While the vibrator was working, every 5 minutes the thickness *h* of the mixture was recorded by measuring instruments. The tests indicated a very intensive thickening of the mixture sample in the first 10 minutes. Then, in later tests the thickening period was fixed to 10 minutes and the height of the mixture layer was measured every 5 minutes.

The efficiency of mass thickening experiments was graded according to the change in density ρ. Also the amount of dry materials (DM) in the thickened plant mass was determined and the density of dry materials calculated. The amount of dry materials indicates in grams how much of dry material is in a kilogram of mixture (g kg^{-1}) or (kg t^{-1}). The wet mass or DM density is determined from mass and volume ratio. The plant mass volume in the container was calculated using measurements by a ruler (accuracy ± 0.001 m) at four selected points. The plant mass in the container was determined by scales, having the range of 0-100 kg, and accuracy of ± 0.1 kg. After two layers of silage mixture was poured into the container (each layer was of 65 kg corn and Jerusalem artichoke stalks mixture) and both layers compressed, the silage was covered with a plastic film and further compressed using the force of the inertia directional vibrator. After two months, the silage samples were taken and the quality of the fodder was determined using standard methods [8].

The average densities of the mixture that were obtained during silage preparation in the trench are given in Table 1. During testing we used industrially established results since in silage preparation from green vegetal standards only the qualitative silage parameters are specified and to achieve the required mass density is not determined [1].

Each experiment was repeated at least 3 times, the test results were analyzed by statistical methods, the arithmetic mean and the standard deviation were calculated and the error was estimated by selecting Student distribution coefficient with a probability of 0.95.

To determine silage quality, the samples (3 each 1 kg) were selected from a mixture that was prepared 2 months in advance. Samples selected for the silage container that were made from corn and Jerusalem artichoke stalks were taken after the grass mass was thickened by two 0.65 m layers. During the tests, the pH contents amount of ammonia, acid-milk, vinegar as well as butter amount and their ratio were determined using the established standard methods [8].

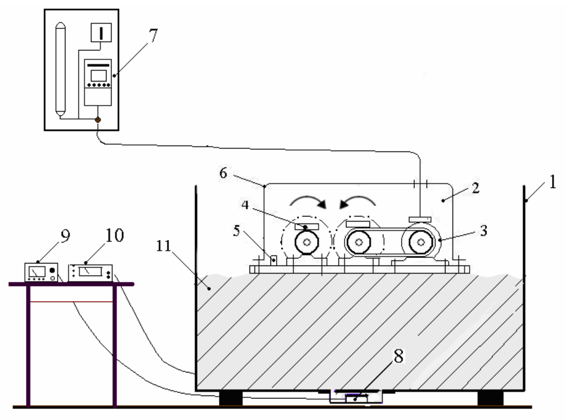

Fig. 1. Scheme of grass thickening in container storage using centrifugal directed action vibrator: 1 – container storage; 2 – centrifugal directed action vibrator; 3 – electrical engine; 4 – weights; 5 – vibration sensor; 6 – vibrator cover; 7 – electric current frequency converter; 8 – tensometer sensor; 9 – pressure measurement device; 10 – vibration measurement device; 11 – mass of thickened plants

Table 1. Silage preparation in the trench [1]

The sort of silage	Moisture content, %	Average density (kg m^{-3}), when silage layer thickness in the trench is 2 m	Average density on dry materials (kg m^{-3}), when silage layer thickness in the trench is 2 m
Corn silage	82	840	151
Meadow grass silage	78	845	186
Wilted meadow grass silage	50-60	480-810	240-340

Method for estimation of vibration effects at working place

The objective of this study is to measure and quantify effects of vibration on human body at a work place. While working in a standing position, vibrations are transmitted to the entire body through the legs, and while in sitting position – through the pelvis and spine (acting through x, y, z axis as illustrated in Fig. 2). When a person suffers from vibration-induced health problems, the main effects are usually not due to local ailments of peripheral nervous, vascular, muscular and articular, but from damage to the whole body organism, in particular, to the central nervous system [12].

The whole body vibration measurement and analysis schemes are provided in Fig. 2.

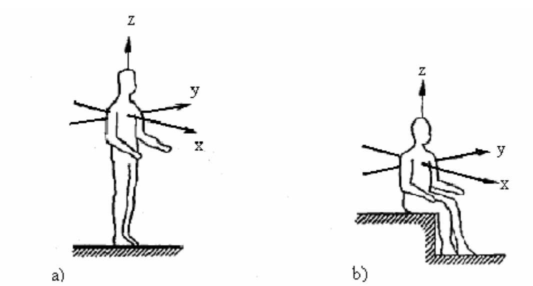

Fig. 2. The directions of acting vibrations on the whole body: standing (a), sitting (b)

Method for measurement of noise effects at work place

The presented noise study aims at determination of noise propagation in the silage preparation room. For the silage thickening, a compacting vibratory device is used, where the operating motor radiates impulse noise and induces impact-type vibrations.

The impulse noise was evaluated by comparing the measured results to the permissible noise levels that are specified in Lithuanian hygiene norm HN 33-1:2003 [13].

Steady noise – noise where levels variations are no more then 5 dBA in duration of 25 – 30 minutes, estimated by noise level, or it could be estimated by noise pressure. Non-steady noise – noise, where levels variations are more than 5 dBA and are constantly changing, abruptly discontinue or pulsate. In the residential territory, it is estimated by equivalent and maximum sound level.

Non-steady noise equivalent sound level is steady wide bandwidth noise that has he some average quadratic pressure as the investigated non-steady noise in a certain time interval.

Noise level was measured by Brüel&Kjær sound meter 2260 [9]. The relational measurement error is ±1.5 %. The noise frequency spectra were measured in the frequency range of 31.5 – 8000 Hz.

Noise measurements were performed during day time with the doors of the silage facility closed. Eight measurement locations were selected. These locations were selected to most effectively capture noise propagation in the facility (1 m, 2 m, 3 m, 4 m, 5 m, 6 m and 7 m distance from the container and at 1.5 m distance from the floor). Noise level was fixed inside the facility for the purpose to estimate noise propagation at distances from the container.

Results

Results from corn and Jerusalem artichoke mass thickening experiments

Plant mixture thickening changes due to different thickening time periods whilst using the inertia directional vibrator are presented in Table 2.

The first 65 kg mixture layer corresponds to 10 minutes thickening period and the second additional 65 kg layer corresponds to a repeated 30 minutes thickening. After 40 minutes thickening, a 114.6 kg m^{-3} density was obtained for both layers, while thickening the first 65 kg mass mixture layer after 10 minutes a 197.9 kg m^{-3} density was achieved. Dry material densities correspond to 61.5 and 106.3 kg m^{-3} respectively.

For this test, the resulting silage density was high. It was influenced by a thin layer of compacted mass, low moisture content of plants (corn stems – 58.8 %, Jerusalem artichoke stems – 50.4 %), and plant stems chaff was not very small (chopped stems length 15-25 mm).

Although this testing revealed a relatively low mass density, the chopping quality of corn and Jerusalem artichoke was high, as well as corn that includes well-ensilaging plant species, sufficiently high quality feed was obtained.

While assessing the experimental technology of preparation of corn and Jerusalem artichoke silage in a container storage using vibratory thickening approach, the attention was focused on plant stems chopping, loading into the container and thickening with the vibratory mechanism (harvesting and transporting operations were not analyzed). This technology was assessed in terms of three parameters: time required to perform each operation and the complete production cycle, production efficiency, and the feed quality.

Time t_g required for a production cycle starting with plant stems chopping is equal to:

$$t_g = t_{sm} + t_p + t_u + t_t + t_s, \tag{1}$$

where: t_{sm} – duration of plant stems chopping, min;
t_p – duration of plant stems chaff loading into container, min;
t_u – duration of lifting up of the vibrator, min;
t_t – duration of plant stems chaff thickening, min;
t_s – duration of sealing and pressing grass in a container, min.

Table 2. Test data of corn and Jerusalem artichoke stalks mixture thickening in a container store with the inertia directional vibrator

Test №	Thickening time periods, min.	Thickness of plant mass layer in a container, mm (container measurements: 0.75×1.22×0.95 m)	Plant mixture density, kg m^{-3}	
			Wet mass	Dry materials
First plant layer mass (65 kg)				
1.	Bulk plant mass	507 ± 8	125.3	67.3
2.	Plant mass after placing the vibrator	397 ± 11	155.4	83.5
3.	After 5 min. vibrator work	312 ± 29	191.0	102.5
4.	After 10 min. vibrator work	299 ± 30	197.9	106.3
Second plant layer mass (65 kg); Common plant layer mass (130 kg)				
5.	Bulk plant mass	801 ± 14	82.5	44.3
6.	Plant mass after placing the vibrator	695 ± 21	94.1	50.5
7.	After 5 min. vibrator work	615 ± 25	105.2	56.5
8.	After 10 min. vibrator work	595 ± 29	108.5	58.2
9.	After 15 min. vibrator work	582 ± 38	110.6	59.4
10.	After 20 min. vibrator work	574 ± 40	112.0	60.2
11	After 25 min. vibrator work	569 ± 41	112.9	60.6
12.	After 30 min. vibrator work	560 ± 44	114.6	61.5

Technological indicators of plant stems chaff thickening are given in Table 3. Depending on consistency and parallelism of technological operations 19-40 min are needed to perform a production cycle with a full container (150 kg of chaff). At adequate planning and distribution of operations a silage production cycle (without plant harvesting and transporting operations) can be shortened down to 9-26 min, i.e., down to the total time of carrying out vibrator, lifting it up and lowering down, and chaff thickening operations.

The efficiency of a production cycle was limited by a technological operation of the lowest efficiency. In this case it was grass thickening – 0.4-0.9 t h^{-1} (Table 3).

Table 3. Technological indicators of thickening of chaff of vibratory plant stems

Technological indicators	Technological operations					
	Plant stems chopping	Chaff loading into container	Vibrator lifting up and down	Chaff thickening	Chaff sealing and pressing	Complete production cycle
Duration of technological operation t_i, min	7-10	3-5	4-5	5-20	5-10	19-40
Efficiency of technological operation N_i, t h^{-1}	1-1.5	2-3	0.4-0.9		-	-

Note: in the column of *Duration of technological operation* (line two) the time was registered when the operation was carried out with 150 kg of chaff

Vibration measurement results at the work place

Experiments were performed in order to determine accurately the effects of vibrations on workers from the inertia directional vibrator while thickening silage. One set of vibrations were measured at work place at 1 meter from the operating equipment. Two sets of experiments were performed to measure noise at work place: (1) vibrator without cover, (2) vibrator with a cover; the measurements were taken in a facility with all doors closed and at distances: 1–8 m.

The results of measured vibrations in our experiment are given in Table 4.

Table 4. The protocol of whole body vibration action

Rated direction (X, Y, Z)	Vibration acceleration values of 1/3 octave bands, m s^{-2}																			
	1,0	1,25	1,6	2,0	2,5	3,15	4,0	5,0	6,3	8,0	10	12,5	16	20	25	31,5	40	50	63	80
The measured vibration acceleration values of 1/3 octave bands $a_i^{'}$, m s^{-2}																				
	3	3	4	6	7	9	14	18	30	6	5	5	9	4	13	11	11	9	7	6
Weighing coefficients of the frequency bands (K_{ai}) and axes																				
Z	0,5	0,56	0,63	0,71	0,8	0,9	1,0	1,0	1,0	1,0	0,8	0,63	0,5	0,4	0,32	0,25	0,2	0,16	0,125	0,1
X Y	1,0	1,0	0,8	0,6	0,5	0,4	0,315	0,25	0,16	0,25	0,2	0,16	0,125	0,1	0,08	0,063	0,05	0,04	0,032	0,025
Calculated vibration accelerations of the frequency bands ($a_i = a_i^{'} K_{ai}$)																				
	1,5	1,68	2,52	4,26	5,6	8,1	14,0	18,0	30,0	6,0	4,0	3,15	4,5	1,6	4,095	2,75	2,2	1,44	0,875	0,6
	3,0	3,0	3,2	3,78	3,5	3,6	4,41	4,5	4,8	1,5	1,0	0,8	1,125	0,4	1,04	0,693	0,55	0,36	0,221	0,15

According to obtained results we calculated that:

$$a_{wi} = \sqrt{\sum_{i=1}^{n} \left(a_i^{'} \cdot K_{a,i}\right)^2} = 32 \cdot 10^{-3} \quad m\ s^{-2}, \tag{2}$$

where: $a_i^{'}$ – measured standard deviation of acceleration value (m s^{-2}) in i-th frequency band;
$K_{a,i}$ – weighing coefficient in i-th frequency band;
n – number of frequency band.

Estimating at the work place the whole body vibration time T_i = 1200, the KVV quality was calculated:

$$KVV = a_{wi}\sqrt{\frac{T_i}{T_0}} = 32 \cdot 10^{-3}\sqrt{\frac{1200}{28800}} = 64 \cdot 10^{-4}, \tag{3}$$

where: KVV – acceleration value for i-th work period;
T_0 – foundation work period length, equal to 28800 sec.

Vibration norms according to requirements [12]:

1. The whole body daily vibration exposure limit value calculated for eight hour work period should not exceed 1.15 m s^{-2} or active vibration doze value should not exceed 21 m $s^{-1.75}$;
2. The whole body daily vibration exposure value to start activities based on eight hour work period should not exceed 0.5 m s^{-2} or active vibration doze value should not exceed 9.1 m $s^{-1.75}$.

Since the obtained KVV value is significantly lower than the required limit, we conclude that usage of this type of vibration equipment do not pose any problems to the operator.

Noise measurements results at the work place

We measured noise levels for equipment operating with a cover and without cover. Before the measurements were taken, the characteristics of noise were determined according to the methodology described above.

The equivalent noise level dependence on frequency is given. The measured results are presented in octave bands at different frequencies. Following the hygiene norm HN 33-1:2003, the acceptable equivalent noise should be 85 dBA [13]. The results presented in Fig. 3 indicate that at work place the equivalent noise level does not exceed the acceptable levels provided in hygiene norm HN 33-1:2003, except near the 2000 Hz average geometrical frequency.

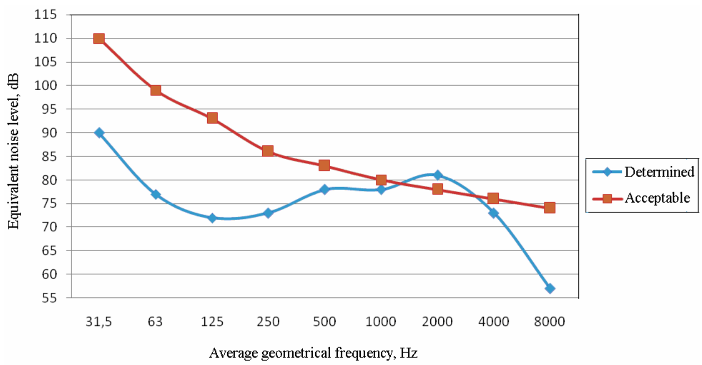

Fig. 3. Equivalent noise level propagation frequency characteristics at work place when the vibrator is without cover

After measuring the noise levels at different locations in the work area (at the same distances as before), it was decided to take the average of spectra A that is equal at 80 Hz. This type of measurements was obtain second time, except that at this time the noise level was measured for vibrating equipment covered with a special safety cover (Fig. 4).

After completion of the experiment it became clear that the noise levels at this facility do not exceed the acceptable limit and do not cause any health problems to the workers.

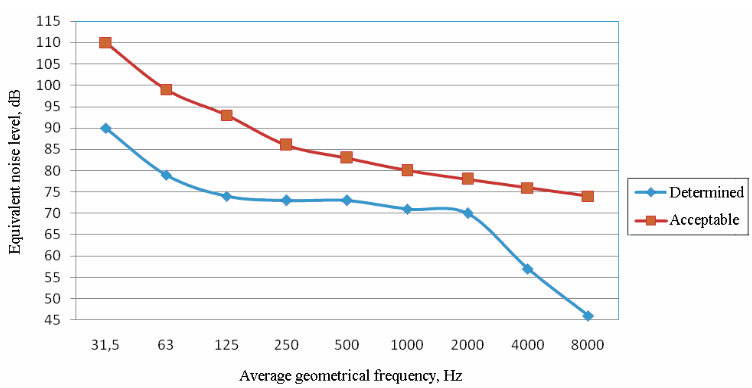

Fig. 4. Equivalent noise level propagation frequency characteristics at work place when the vibrator is with a cover

Evaluation of silage preparation technology from viewpoint of community safety

Our tests demonstrated that application of inertia directional vibrator is appropriate for silage thickening in a container. This thickening approach eliminates the need use traditional thickening with a tractor that contaminates the grass with dirt and gasoline products. The proposed silage preparation method provides on opportunity to use environmentally safe containers as well as sectional and other types of enclosures. In addition, working with the inertia directional vibrator does not have a negative effect on person's health. The experiments confirmed that vibration and noise levels do not exceed the permissible limits.

Conclusions

1. After literature review and completion of theoretical investigation, it can be stated that it is environmentally and economically feasible for small and average size farms to use vibrational thickening method for silage preparation. However, the results need to be verified with experiments.
2. Results indicate that application of inertia directional vibrator for thickening of finely chopped corn and Jerusalem artichoke stalk mixture, after 40 minutes thickening, allows to obtain a 114.6 kg m^{-3} density for both layers, while thickening the first 65 kg mass mixture layer after 10 minutes - a 197.9 kg m^{-3} density. Dry material densities correspond respectively to 61.5 and 106.3 kg m^{-3}.
3. After examination of fodder quality it was determined that corn mixture silage, thickened by the inertia directional vibrator, satisfies high-grade silage requirements.
4. Performed tests demonstrated that the effect of vibrations on the whole body and the measured noise levels do not have detrimental effect on human health and the established acceptable limits are not exceeded while operating the inertia directional vibrator.
5. The vibrator is suitable for silage preparation since it does not contaminate the fodder with dirt and gasoline products during operation. The proposed silage preparation method provides opportunities to use ecologically safe containers as well as sectional and other types of enclosures.

References

[1] **Sirvydis J.** Production of herbaceous forage: monograph. Raudondvaris, 186 p., 2001 [in Lithuanian].

[2] **Spirgys A.** Safe use of low power tractors in chopped grass packing: doctor theses. Kaunas-Akademija, 141 p., 2001 [in Lithuanian].

[3] **Juraitis V., Kulpys J.** Forage production. Kaunas, 326 p., 2003 [in Lithuanian].

[4] **Langlen R. W.** Agricultural structures: wall leads. I Agr E Journal Landwards, 55 (4), pp 10-12, 2000.

[5] **Darby D. E., Jofriet J. C.** Density of silage in horizontal silos. Canadian Agricultural Engineering. 35 (4), pp 72-75, 1993.

[6] **Hegedűr A., Csizmadia B.** Vibration analysis of two-mass vibratory screen. International Conference on Mechanical Vibration. Timiscara, pp 23-24, 2002.

[7] **Csizmadia B., Hegedűr A.** Optimization the flexible elements of two-mass vibratory screen. Hungarian institute of agricultural engineering. 15, pp 44-46, 2002.

[8] **Sirvydis J.** Development of silage production. Agroengineering and energetics. 1, pp 74-82, 1999 [in Lithuanian].

[9] **Jasinskas A., Ferevičius D.** Research of silage thickening using vibrator of undirected action. Agricultural engineering: IAE LUA and LUA research papers. Raudondvaris, 36(2), pp 21-31, 2004 [in Lithuanian].

[10] **Jasinskas A., Rutkauskas G., Dravininkas A., Mieldažys A.** Vibratory thickening of grass mass. Agronomy Research. Engineering of Agricultural Technologies: Special Issue. Vol. **6**, pp 207-220, 2008.

[11] Protection of workers from the risks of vibration regulations. The State doc. Nr. 41-1350. 2004 [in Lithuanian].

[12] ISO 2631-1:1997. Mechanical vibration and shock. Evaluation of human exposure whole-body vibration. Part 1: General requirements. (Identical Lithuanian standard LST ISO 2631-1: 2004).

[13] Lithuanian Hygiene Standard HN 33-1:2003. Acoustic noise. Permitted levels of living and working environment. General requirements of measurement methods. The State doc. Nr. 87 – 3957, 2003 [in Lithuanian].