Justification of a method for determining the moment for switching on the level one signaling of filled grain harvester hoppers

Article · September 2017

DOI: 10.15547/ast.2017.03.040

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ISSN 1313 - 8820 (print)
ISSN 1314 - 412X (online)
Volume 9, Number 3
September 2017

AGRICULTURAL SCIENCE AND TECHNOLOGY

2017

An International Journal Published by Faculty of Agriculture,
Trakia University, Stara Zagora, Bulgaria

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The journal is accepted to be indexed with the support of a project № BG051PO001-3.3.05-0001 “Science and business” financed by Operational Programme “Human Resources Development” of EU.

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This issue is printed with the financial support by Contract No DNP 05-21/20.12.2016, financed from Fund 'Scientific Research' grant Bulgarian scientific Periodicals.

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Student's campus, 6000 Stara Zagora
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ISSN 1313 - 8820 (print)
ISSN 1314 - 412X (online)

Volume 9, Number 3
September 2017

AGRICULTURAL SCIENCE AND TECHNOLOGY

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An International Journal Published by Faculty of Agriculture,
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AGRICULTURAL SCIENCE AND TECHNOLOGY, VOL. 9, No 3, pp 218 - 222, 2017
DOI: 10.15547/ast.2017.03.040

Production Systems

Justification of a method for determining the moment for switching on the level one signaling of filled grain harvester hoppers

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(Manuscript received 4 January 2017; accepted for publication 11 April 2017)

Abstract. *The main issue in the joint operation of a grain harvester and a transport vehicle is determining the moment when the vehicle has to start travelling to the harvester, so that it will arrive at it when the hopper is full. The result of the incorrect determining of that moment is that the productivity of the transport vehicle is not efficiently used and in the case when the hopper is unloaded at a harvester stantstill position, the harvester productivity is also reduced due to more frequent stops. The article proposes a method for determining the part of the grain harvester hopper volume after the filling of which the signalling shall be switched on indicating to the vehicle driver when to start moving toward the harvester. The results of real measurements are shown on different farms of the time of movement of the vehicle to the harvester for unloading. An analysis of the results has been made on the basis of the developed method as well and recommendations have been made to regulate the time of switching on the signalling. A nomogram has been proposed for determining the part of the grain hopper volume after the filling of which the signalling is to be switched on depending on the ratio between the time for moving of the vehicle and the time for filling the grain harvester hopper to the top.*

Keywords: grain harvester, grain level in the hopper, sensor position

Introduction

Grain harvesters use various technical means of signalling the grain hopper level of filling. There are two critical levels that are compulsory for automatic signalling:

- level one – the harvester signal lamp is switched on to notify the transport vehicle driver about forthcoming hopper filling. The harvester continues harvesting until level two is reached. When unloading with the harvester going to the edge of the field level one signalling is used for hopper filling (Delchev and Trendafilov, 2015; Delchev et al., 2016);

- level two – sound and light signalling is switched on in the cab, warning the operator to stop harvesting (full hopper). In certain cases hopper filling up to a specific volume (weight) multiple of the volume (load capacity) of the transport vehicle is signalled.

These levels are usually controlled by sensors installed in the harvester hopper, the position of which can be regulated (adjusted). Very important is to determine their precise position. When adjusting the second level sensor the aim is to use the grain hopper volume more efficiently without allowing overflowing or it is adjusted at a definite volume according to the volume of vehicles. The first level sensor is adjusted in such a way that after the produced signal to provide sufficient time for the vehicle to reach the harvester and at the time when the hopper is filled to the second level, i.e. when the harvester has to stop for unloading. In practice, the joint work between grain harvesters and vehicles is coordinated through it. The lack of such coordination (synchronization) is a prerequisite for downtime that results in extending the harvest time (Mihov, 2013). It has been established that with good organization, the waiting time for the vehicle by the harvester has been 9.25 min within one shift, while with poor organization – 54.9 min (Lhagvasuren et al., 2013). Also in premature unloading of incomplete hoppers the load capacity of the vehicle is not used efficiently (Delchev and Trendafilov, 2002).

The unloading of harvesters in movement also does not exclude the need to use signalling for fill-up of the grain hoppers. Even when unloading in movement unloading at standstill is also needed - over 18 % of unloadings (Niehaus, 2014). More and more often logistics systems based on information technologies are put into use, through which information is exchanged and the operation of harvesters and vehicles is synchronized ("Telematics", 2012; Machine Sync", 2013; "Claas Group", 2015). Although in this case harvesters are equipped with a device for measuring the quantity of grain entering the hopper (quantimeter), sensors for signaling the levels are also used.

Despite the great significance of precise adjustment of the sensor for first level of the harvester productivity and the efficiency of vehicles, there are no hard and fast rules and methodology for setting it. In the guidelines for operation of harvesters, various manufacturers normally indicate that the sensor is adjusted to alert the filling of 70% or 75% of the hopper volume without giving reasons. In practice enough attention is not paid either to the setting of first-level signalling. Very often it remains as it is set by the factory. The time of switching the first-level signalling for filling the grain hopper of harvesters depends on various factors - technical, agricultural, logistic, etc.

The objective of the study is to justify and propose a method for determining the time of switching the first level signaling expressed

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through percentage of filling the hopper volume depending on the conditions of work and the parameters of grain harvesters and vehicles.

Material and methods

To achieve the objective analytical relations are used to determine the time of filling the grain harvester hopper – t_T and the time for moving the vehicle to it for unloading – t_V. It is assumed that the vehicle has to reach the harvester at the time when then hopper is full to second level (100% of its volume). In order to achieve that scenario the vehicle has to start at a specific time when the hopper is filled to a specific level (first level of signalling) and travel the distance to the harvester at a specific speed. The moment of switching the first-level signaling is determined as the difference between the time of filling the hopper and the time of movement of the vehicle to the grain harvester ($t_T – t_V$). That difference is the time for filling the hopper to the first level – t_1. Using that difference (the time for filling the hopper to the first level) as ratio to the time for filling the entire hopper we get the relative share of time, respectively of the hopper volume, upon the filling of which the first level signalling has to be switched.

A study has been carried out of the time of movement of the vehicle to the grain harvester for unloading the hopper (t_V) and the time for reaction of the vehicle driver (t_n). The reaction time is the time from switching the signal lamp for first level of hopper filling till the start of the vehicle. Studies have been carried out on five farms without altering the harvest organization implemented in each of them. In all farms hopper unloading is done at harvester standstill and first-level signalling is switched at about 70% of filling the grain hopper volume. The time from switching the harvester signalling till the start of the vehicle and the time from the start of the vehicle till arrival under the unloading screw of the harvester have been determined through chronometry. Their minimum, maximum and average values are given. The average time for hopper filling (with no technological stops) differs insignificantly for the various grain harvesters since they have close technical parameters. It has been assumed that it is the same in all five farms t_T*=20 min = 1200 s.*

By using the results obtained through the observation and the resulting analytical relations, the percentage of filling the hopper at which first level signalling of harvesters has to be switched under the relevant working conditions is determined.

Results and discussion

Determining the time for filling the harvester grain hopper is made in the following logical sequence. The area that has to be harvested in order to fill in the harvester hopper is:

$$S = \frac{Q}{D} = \frac{V.\rho}{D}, \quad ha \tag{1}$$

where *S* is the harvested area from which one hopper is filled, *ha;*

Q – grain quantity that can be put in the hopper, *kg;*

D – yield per hectare, *kg/ha;*

V – grain harvester hopper volume, m^3*;*

ρ – volumetric weight of the grain, kg/m^3*.*

The distance travelled by the harvester for filling one hopper is:

$$L_o = L + L_T = \frac{10.S}{B.\beta} + L_T, \quad km \tag{2}$$

where L_o is the distance travelled by the harvester for filling the hopper, *km;*

L – length of the working move, *km*;

L_T – length of nonworking moves (turns) performed by the harvester, *km;*

B – the structural working width of the harvester header, *m;*

β – the coefficient of use of the working width.

The coefficient of use of the working moves is:

$$\varphi = \frac{L}{L + L_T} \tag{3}$$

After transforming (3) we obtain the following for the length of the nonworking moves

$$L_T = \frac{L}{\varphi} - L, \ km \tag{4}$$

After replacing (4) in (2) we obtain:

$$L_o = \frac{10.S}{B.\beta.\varphi}, \quad km \tag{5}$$

The time for filling the harvester hopper depends on its working speed and is determined by the relation:

$$t_T = \frac{L_o}{v_C}, \quad h \tag{6}$$

where Vc is the harvester working speed, *km/h*

After replacing (5) and (1) in (6) for the time of filling the hopper we obtain:

$$t_T = \frac{L_o}{v_C} = \frac{10.S}{B.\beta.\varphi.v_C} = \frac{10.V.\rho}{B.\beta.\varphi.v_C.D}, \quad h \tag{7}$$

The time for moving the vehicle to the grain harvester is:

$$t_V = \frac{L_V}{v_V}, \quad h \tag{8}$$

where L_V is the distance between the vehicle and the harvester, *km;*

V_v – the speed of the vehicle, *km/h.*

In the ideal situation the start of the vehicle has to take place at the moment of switching the first – level harvester signalling. It will reach the harvester after time t_V. At the moment of reaching the hopper has to be full and second-level of signalling has to be reached. In other words, the time for movement of the vehicle to the grain harvester t_V has to correspond to the time interval between switching first and second signalling levels.

With late switching of the first level of signalling (shorter interval), the hopper will be filled and the harvester will stop before the vehicle reaches it. This waiting of the vehicle is connected with stopping of the harvest and respective decrease in the daily productivity.

With early switching of the first level of signalling (greater interval) the vehicle will reach the harvester earlier and will move after it till filling the hopper and activating the second level of signalling. This leads to unnecessary excessive compaction in the field by the vehicles and increase of its its fuel consumption. In undertaking unloading before triggering the second level of signalling (in order not to compact the field excessively) unfilled hoppers will be unloaded. The load capacity of vehicles will not be used effectively. If unloading is performed at standstill the daily productivity is decreased since the number harvester stops increases.

Therefore, for greater efficiency it is necessary to properly set the moment of switching the first level of signalling of the grain harvester hopper. This means to determine at what percentage of hopper filling the signalling shall be activated. If we deduct the time for movement of the vehicle to the harvester from the time for filling the hopper, we will obtain the time during which the harvester will operate until switching the first level of signalling:

$$t_1 = t_T - t_V, \quad h \tag{9}$$

where t_1 is the time for work of the harvester until reaching the first level of signalling, *h*

The relative share of that time compared to the time for filling the hopper is:

$$t_{1\%} = \frac{t_T - t_V}{t_T}.100 = \left(1 - \frac{t_V}{t_T}\right).100, \quad \% \tag{10}$$

After replacing (7) and (8) in (10) we obtain:

$$t_{1\%} = \frac{t_T - t_V}{t_T}.100 = \left(1 - \frac{L_V.B.\beta.\varphi.v_C.D}{10.V.\rho.v_V}\right).100, \quad \% \tag{11}$$

The quotient in parenthesis is the relative share of the hopper volume locked between two levels of signalling.

The time for filling the hopper is proportional to its volume (relation 7). Therefore, the relative share of the time for filling the hopper to the level of the first signalling $t_{1\%}$ is equal to the relative share of the hopper volume up to this level, i.e. relation (11) presents also the part of the hopper volume (in percentage) at the filling of which signalling shall be switched on. This relation can be presented as follows:

$$V_1 \equiv t_{1\%} = \left(1 - \frac{t_V}{t_T}\right).100, \quad \% \tag{12}$$

where V_1 is the part of the hopper volume in percentage, upon the filling of which harvester first-level signalling shall be switched on, %.

The results from the studies of the time for movement of vehicles to the grain harvesters t_v are given in Table 1, and its average values are presented on Figure 1. The average time for movement of the vehicles is 133,51 *s*, and it varies from 44.88 *s* to 396.42 *s*. It is noteworthy that the average time in all four farms (A1, A2, A3 and A5) has very similar values – between 44.88 *s* and 78 *s*, and is significantly less than the average time in farm A4 – 396.42 *s*. It has been established that in all farms the vehicles do not head immediately to the harvester upon switching of the first-level signalling for filling the hopper, but wait for some time. The waiting is the least in farm A4, in which the average travelling time is the longest. In that farm the vehicle reaches the harvester well before filling the hopper and continues moving until it is 100% filled. Naturally the vehicle travels longer distance, which is associated with unnecessary excessive compaction of the field and increased fuel consumption. In farms A1, A2, A3 and A5 vehicles leave much later after signalling for first-level hopper filling, but also arrive before the switching of the second-level signalling of the harvester. Most often unloading is done immediately and therefore an incomplete bunker is unloaded.

In Table 2 and Fiure 2 the results about the time from switching first-level signaling till start of the vehicles is presented. This is the time for reaction of the driver t_n to the signal given by the harvester. The table shows that vehicles start for the harvester 237.87 *s* on average after switching the sisgnalling system. Vehicles in farms A1, A2, A3 and A5 start much later (217.31 – 367.00 *s*), than in farm A4 (61.89 *s*).

Studies reveal that from a purely practical point of view the time from switching the first-level signalling for hopper filling till arrival of the vehicle at the grain harvester for unloading its hopper t_m can be presented in the following mode:

$$t_m = t_n + t_V, s \tag{13}$$

The results show that the average value of that time for the studied farms is:

$$t_m = 237.87 + 133.51 = 371.38\ s \tag{14}$$

The time in which drivers of the vehicles wait before heading to the harvester (reaction time of the driver) is significantly greater than the travel time to the harvester – 64 % against 36 %. Therefore, improper setting of the time of switching the first-level signaling does not allow drivers to depart and, respectively, arrive at the right time at the harvesters, but rather confuses them. They intuitively choose the time of departure, thus resulting in unloading of a partially filled hopper, unnecessary movement of the vehicle in the field and ultimately lower productivity of harvesters and vehicles. Therefore, the ideal situation which has to be used for setting the sensors is when $t_m = t_V$, and $t_n = 0$ (time for reaction of the vehicle driver – t_n).

By using relation (12) and the results obtained from our

Table 1. Time for movement of the vehicle to the grain harvester

Agricultural farms	Number of measurements	Time for movement of the vehicle to the grain harvester, t_V, *s*		
		t_V *min*	t_V *max*	$\overline{t_V}$
A1	6	54	99	74.16
A2	17	12	80	44.88
A3	19	41	114	74.11
A4	19	118	558	396.42
A5	6	28	181	78.00
Average, s		50.6	206.4	133.51

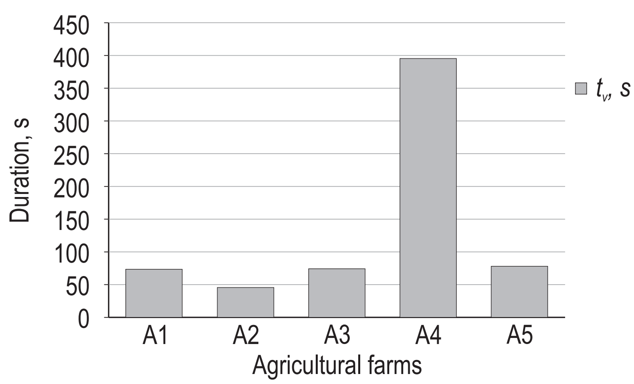

Figure 1. Average time for movement of the vehicle to the grain harvester for the various farms

Table 2. Time from switching the harvester signalling till start of the vehicle (time for reaction of the vehicle driver – t_n)

Agricultural farms	Number of measurements	Time for movement of the vehicle to the grain harvester, t_n, *s*		
		t_V *min*	t_V *max*	$\overline{t_n}$
A1	6	174	414	274.00
A2	17	191	535	367.00
A3	19	114	411	217.31
A4	19	24	99	61.89
A5	6	166	450	269.16
Average, s		133.8	381.8	237.87

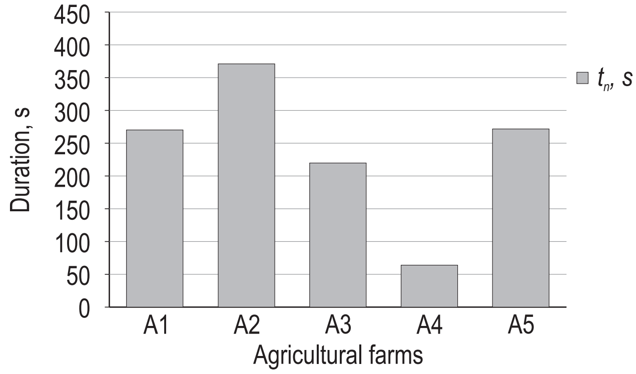

Figure 2. Average time from switching the signalling till start of the vehicle

observations (Table 1) the part of the grain hopper volume has been determined (in percentage), at which signalling has to be switched on. The results are given in Table 3. It is evident that switching first-level signalling has to take place at filling of about 93 – 96% of the grain hopper volume, on average. This will be a signal to the vehicle to head immediately to the harvester. In this way the unnecessary movement of vehicles in the field will be reduced and their load capacity will be more fully used, since the grain hopper will be filled to a greater degree. Significantly different is the part of the grain hopper volume in percentage in which the harvester signalling system in

Table 3. Part of the grain hopper volume in percentages, upon the filling of which the harvester signalling shall be switched on

Agricultural farms	Part of the grain hopper volume, %		
	V_{1min}	V_{1max}	$\overline{V_1}$
A1	91.8	95.5	93.82
A2	93.4	99.9	96.26
A3	90.5	96.6	93.83
A4	53.5	90.2	66.96
A5	84.9	97.7	93.50
Average, %	82.82	95.98	88.87

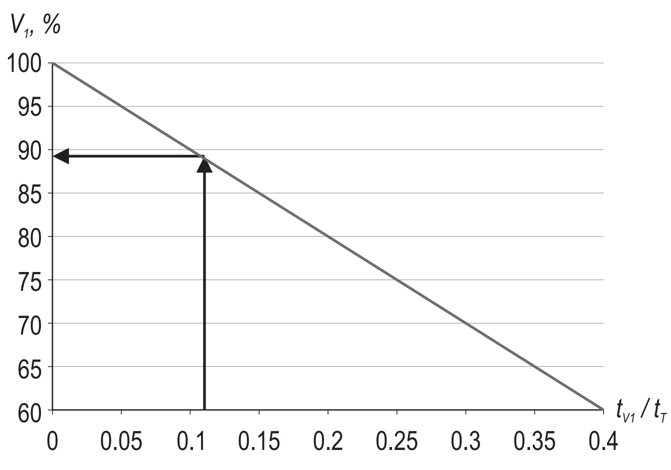

Figure 3. Nomogram for determining the part of the hopper volume V1 in percentages for switching the first level signaling of the grain harvester

farm A4 has to be switched on. This is due to the fact that in this farm first-level signalling is not correctly set, vehicles start almost immediately after the switching the signalling and follow the harvester for a long time until its hopper is filled. As can be seen from Table 1, the average travelling time to the grain harvester is significant – 396.42 *s*. In other words, this is not the actual travelling time to the grain harvester because it includes the time for simultaneous movement of vehicle and harvester waiting for filling the hopper at 100%. This logistics of simultaneous work in that farm has been adopted in order to ensure higher productivity of the harvester and fuller utilization of the load capacity of the vehicle. This could be achieved by much more efficient correct setting of the sensor for first-level signalling of the hopper filling. In other words, the results from the farm are not representative.

It should be noted that the exact timing of switching the first-level signaling for hopper filling is a variable and depends on many factors related to the specific harvesting conditions and technical parameters of harvesters and vehicles (see relation 11). Nevertheless, the sensor can be adjusted quite accurately for specific harvesting conditions by using the developed nomogram shown in Figure 3. It is used to determine the part of the hopper volume V_1 in percentage, at the filling of which signalling shall be switched on, i.e. the position of the first-level sensor. In order to use it, it is necessary to measure the time of travelling of the vehicle to the harvester (t_v) and the time of filling the grain hopper (t_T). The quotient of the two times (t_v/t_T) is put on the abscissa of the graph. From this point a perpendicular is drawn to the slanted line and from by the ordinate the volume V_1 for switching the signalling system is determined. Figure 3 shows an example where for t_v/t_T = 0.11, V_1= *89%*.

Conclusion

It has been established that sensors for first level of hopper filling in the studied five farms are not properly set, and the light signal is emitted to the vehicles significantly earlier than necessary. As a result, drivers of vehicles intuitively choose the time of departure, leading unloading a partially full hopper, unnecessary movement of the vehicle in the field and ultimately lower productivity of harvesters and vehicles. Analytical relations have been obtained and a method has been proposed for determining the moment of switching the first level of signalling in the grain harvester hopper expressed as percentage of filling the hopper volume depending on the working conditions and the parameters of the machines. By using the proposed method is has been found that in the studied farms harvester signalling has to be switched on at filling of about 93 – 96% of the hopper volume. A nomogram has been developed to determine the part of the hopper volume in percentage at which first-level signalling is switched on, depending on the ratio between of travel time of the vehicle and the time of filling the harvester hopper. It can be used in the practical adjustment of the sensor position for the first level.

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Simm G, Lewis RM, Grundy B and Dingwall WS, 2002. Responses to selection for lean growth in sheep. Animal Science, 74, 39-50

Books: Author(s) surname and initials, year. Title. Edition, name of publisher, place of publication. Example:

Oldenbroek JK, 1999. Genebanks and the conservation of farm animal genetic resources, Second edition. DLO Institute for Animal Science and Health, Netherlands.

Book chapter or conference proceedings: Author(s) surname and initials, year. Title. In: Title of the book or of the proceedings followed by the editor(s), volume, pages. Name of publisher, place of publication. Example:

Mauff G, Pulverer G, Operkuch W, Hummel K and Hidden C, 1995. C3-variants and diverse phenotypes of unconverted and converted C3. In: Provides of the Biological Fluids (ed. H. Peters), vol. 22, 143-165, Pergamon Press. Oxford, UK.

Todorov N and Mitev J, 1995. Effect of level of feeding during dry period, and body condition score on reproductive performance in dairy cows,IXth International Conference on Production Diseases in Farm Animals, September 11–14, Berlin, Germany.

Thesis:

Hristova D, 2013. Investigation on genetic diversity in local sheep breeds using DNA markers. Thesis for PhD, Trakia University, Stara Zagora, Bulgaria, (Bg).

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Animal welfare

Studies performed on experimental animals should be carried out according to internationally recognized guidelines for animal welfare. That should be clearly described in the respective section “Material and methods”.

AGRICULTURAL
SCIENCE AND TECHNOLOGY

Volume 9, Number 3
September 2017

Journal web site:
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