The evaluation of working speed and depth influence on performance of the tine transducer for measuring tilth aggregate sizes

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Abstract: Design, construction and evaluation of a mechanical transducer to measure aggregate sizes in real time were conducted by the same authors. The spring tines were instrumented using the strain gauges and tested in field conditions. The main conclusion is that the spring tine transducers could be used as sensors to estimate the mean weight diameter of a given clod size distribution. In order to evaluate the influence of working speed and depth on performance of the tine transducer, factorial experiments were conducted based on randomized complete block design with three replications. Working speed and depth were investigated each at three levels. The results of the variance analysis showed that sensing speed and depth affect tine transducer performance independently. Sensing speed has a very little impact on performance of tine transducer but sensing depth has a significant impact on performance of tine transducer. Results also showed that the higher sensing depth and speed the higher horizontal force on the spring tines. Optimal sensing speed of 5 km h^{-1} was chosen in order to reduce the effect of inertia forces due to higher speeds than the critical speed and avoid of plastic deformation and failure of the tine. Mechanical transducer was calibrated with sensing depth of 70 mm in order to avoid getting into excessive force to the tines and considering the root depth of the various products in the soil.

Keywords: aggregate sizes, sensing speed, sensing depth, mechanical transducer, randomized complete block design, strain gauge

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1 Introduction

Conventional agriculture relies on tillage operations. At the beginning, mechanical tillage provided a good tilth for root and crop growth. However, with persistence of improper use of tillage instruments, they became one of the most important reasons for destruction and loss of quality of agricultural lands (Backingham and Arland, 1993). The main advantage of conservation tillage is soil conservation in semi-natural conditions, so that soil destruction by tillage and physical and chemical erosion is minimized. Soil aggregation is one of the main controlling factors of physical erosion and storage of nutrients and water flow. Knowing the soil aggregate size can be a crucial parameter in determining the degree of tillage that land is required. In order to improve the uniformity of seedbed by varying the degree of secondary tillage and also preparation of suitable seedbed for germination and crop growth, a real time measurement system is required. Aggregate size distribution is affected by management and thermal factors (Whiting et al., 2010). Management factors include tillage intensity, time and temperature factors include precipitation, intensity and number of cycles of soil wetting and drying, freezing and melting on the soil surface. Aggregate size distribution effects on the emergence of sprouts and flow of air, water and solution nutrients in the soil. Possibility of wind erosion decreases with the increasing aggregate

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size so that large aggregates cause reduction in wind speed (Braunack, 1991). The development of real time and continuous sensing systems for soil properties provides a valuable tool to obtain inexpensive and rapid information about the soil current status and future management of soil in the context of precision agriculture. Development of real time and continuous sensing systems for soil physical and mechanical properties provides a valuable tool to obtain inexpensive and rapid information of soil current status and future management in the context of precision agriculture. The mechanical transducer to measure aggregate sizes in real time was designed and fabricated by the authors (Isavi, 2012). The main purpose of this research is to evaluate the influence of working speed and depth on performance of the tine transducer.

2 Materials and methods

Mechanical transducer for measuring tilth aggregate sizes was introduced by Bogrekcia and Godwin (2007). Mechanical sensing systems using the effects of clod size on the vibrational characteristics of the spring tines provide useful instrument for evaluation of soil aggregate size distribution, thus provide a reliable and inexpensive method of measuring with minimal damage to soil structure.

Specific conclusions obtained by Bogrekciaand Godwin (2007)are presented below.

1) The S tine is the most promising implement shape as it has the lowest natural frequency.

2) The root mean square error (RMSE) was found as 13 mm for the effect of sensing depth on clod size measurement. It is suggested that the depth control mechanism can be used where the RMSE of 13 mm is not tolerable.

3) The increase in the measurement speed results increase in the mean forces of the tine transducer. The clod size (MWD) can be estimated with an RMSE of 3.5 mm. The speed of the measurement can be ignored to classify soil tilth since 3.5 mm clod sizes so small when the standard deviation is used as the criteria.

Mechanical sensing systems using the effects of clod size on the vibrational characteristics of the spring tines pose an alternative to the visual sensing of soil tilth size as well as mechanical sieve for evaluation of soil aggregate size distribution. The success of a mechanical sensing system to measure the accurate and precise aggregate size distribution is dependent upon both sensing tool properties and the physical properties of the soil tilth.

Design, construction and evaluation of a mechanical transducer to measure aggregate sizes in real time were conducted by the same authors. The spring tines with strain gauges were used and tasted in field conditions.

Tine transducer shown in Figure 1 was designed and constructed by the authors (Isavi, 2012). In order to minimize errors due to rugged farmland and changes in working depth caused by that, mechanical transducer composing of three tines was constructed.

Figure 1 Tine transducer mounted on tractor

Tines made of spring steel were commercially available and inexpensive. Figure 2 shows the tine used for sensing clods sizes.

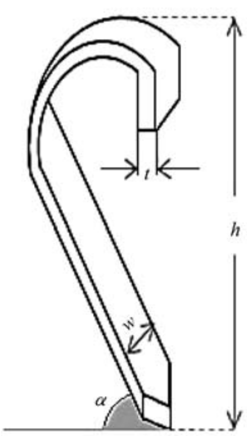


Figure 2 Spring tines used for sensing clods sizes

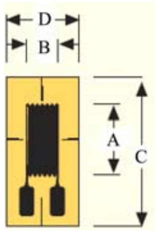
The key geometry and mechanical characteristics of spring tines are given in Table 1.

Table 1 Tine geometry and mechanical characteristics

Geometry characteristics	Value	Mechanical characteristics	Value
Height *h*/mm	660	Elasticity modulus E, GPA	190
Width *w*/mm	60	Poisson ratio	0.29
Thickness *t*/mm	5	Thermal expansion coefficient, $\frac{1}{°C}$	17.3×10^{-6}
Rake angle *α*	75°		

These tines with strain gauges were used and tasted in field conditions. In order to reduce errors caused by changes in working depth, three tines mounted on a chassis was used, which was pulled on the farm by a tractor. Two strain gauges were mounted on each tine; one to measure tension was mounted on the tines and another to measure compression was mounted under the tines and two strain gauges with 12 V power supply were used in the form of Wheatstone half-bridge circuit, in order to increase the accuracy of measurement with strain gauge and reduce the influence of temperature on the output results. Table 2 shows the characteristics of strain gauges used in the mechanical transducer.

Table 2 Characteristics of strain gauges used in the mechanical transducer

	Gauge factor	Nominal resistance	Dimensions/mm			
			A	B	C	D
	2.14	350 Ω	7.5	3.2	9.4	5.6

The bridge output corresponding to each tine was connected to a voltage amplifier to increases output voltage to 1000 times. Then the amplified voltage was stored on a memory card by a data acquisition system. Data acquisition system is designed so that every 0.1 seconds stores a voltage data and entire test takes 15 seconds so 150 voltage data will be stored in each test. The main conclusion obtained from mechanical transducer was that the spring tine transducers could be used as sensors to estimate the mean weight diameter of a given clod size distribution. Specific conclusions are represented below:

1) The higher diameter of the aggregates, the higher output voltage of the transducer;

2) The relationship between diameter and output voltage can be estimated with a linear equation as D= 13.827V-33.536 so that the coefficient of determination between estimated equation and obtained data equals R^2=0.93;

3) MWD obtained from tine transducer is 25% greater than the results from standard sieve analysis. In order to evaluate the influence of working speed and depth on performance of the tine transducer factorial experiments were conducted based on randomized complete block design with three replications (Valizadeh and Moghadam, 2009). Sensing speed at three levels: 5, 10 and 15 km h^{-1} and working depth at three levels: 70, 110 and 150 mm were investigated. According to the effects of sensing speed and depth, they were studied dependently, Therefore, there were two factors:

(1) A Factor : Speed

(2) B Factor: Depth

there were nine treatments and three replications for each treatment. Thus, 27 tests were performed and each one set at 15 seconds.

Field experiments were conducted on a clay loam soil tilth which was produced using a moldboard plow followed by chisel tines. The properties of soil are given in Table 3.

Table 3 Soil properties

Kind	Soil texture			Moisture %	Tillage
	Sand %	Silt %	Clay %		
Clay loam	20	25	55	18.65	Moldboardplowfollowed by chisel tines

Analysis of variance (ANOVA) is the method used to compare continuous measurements to determine if the measurements are sampled from the same or different distributions.

The effects of factors and their interaction influence on each other and variations coefficient were calculated by using MSTAT-C software (Alizadeh and Tarinejhad, 2010).

3 Results and discussion

3.1 Variance analysis of factorial tests based on randomized complete block design

Analysis of variance (ANOVA) is the method used to compare continuous measurements to determine if the measurements are sampled from the same or different distributions. It is an analytical tool used to determine the significance of factors on measurements by looking at the relationship between a quantitative “response variable” and a proposed explanatory “factor.” This method is similar to the process of comparing the statistical difference between two samples, in that it invokes the concept of hypothesis testing. Instead of comparing two samples, however, a variable is correlated with one or more explanatory factors, typically using the F-statistic. From this F-statistic, the P-value can be calculated to see if the difference is significant. For example, if the P-value is low ($P\text{-value}<0.05$ or $P\text{-value}<0.01$ - this depends on desired level of significance), then there is a low probability that the two groups are the same. The method is highly versatile in that it can be used to analyze complicated systems, with numerous variables and factors (Alizadeh and Tarinejhad, 2010).

In order to assess the effects of the working depth and speed on the performance of the tine transducer, speed at three levels: 5, 10 and 15 km/h and depth at three levels: 70, 110 and 150 mm were studied dependently. Therefore, there were two factors:

(1) A Factor or Speed

(2) B Factor or Depth

The effects of factors and their interaction influence on each other and variations coefficient were calculated by using MSTAT-C software (Alizadeh and Tarinejhad, 2010). For each treatment three repetitions were considered. The results of the average voltage obtained from each treatment in each replication are given in Table 4.

Each data is derived from the average of 100 voltage obtained by the mechanical transducer from each test. Table 4 shows the results of variance analysis of these factorial tests. These tests are repeated three times and results are from three repetitions.

According to Table 5, it can be resulted that speed with F=8.62 significant at the 1% probability level therefore can be said that the output voltage increases with increasing tine speed in the soil. Depth with F=199.89 significant at the 1% probability level therefore output voltage increases with increasing working depth in the soil.

Table 4 The results of the average voltage obtained from each treatment in each replication

Treatment/ Repetitions	V5 D70	V10 D70	V15 D70	V5 D110	V10 D110	V15 D110	V5 D150	V10 D150	V15 D150
1	3.66	3.19	3.62	4.53	4.91	6.75	7.94	8.06	9.14
2	3.54	3.71	3.60	4.93	5.82	5.86	7.12	7.32	8.89
3	2.94	3.51	3.73	4.97	5.32	5.84	7.77	8.17	8.16

Table 5 The results of variance analysis of factorial tests

K Value	Source	Freedom degree	Sum of squares	Mean of squares	F Value	F5%	F1%	
1	Repetitions	2	0.025	0.013	0.0529	3.63	6.23	
2	(A) Factor	2	4.09	2.04	8.62	3.63	6.23	**
4	(B) Factor	2	94.79	47.39	199.89	3.63	6.23	**
6	(AB)	4	1.08	0.27	1.14	3.01	4.77	
-7	Error	16	3.79	0.24				
	Sum	26	103.78					

Note: ** : significant at the 1% probability level.

F value comparison of two speed and depth factors indicate that the effects of depth factor is far more than speed, so that it can be ignored of the speed factor versus depth.

Considering F=1.13 for the interactions of depth and speed factor, it can be concluded that the influence of depth and speed factors on each other is not significant and these factors are independent.

Coefficient of variation (C.V.) of test was obtained 8.63%, so it can be said that experiments have been conducted with appropriate accuracy.

3.2 Evaluate the effects of sensing speed

Schuring and Emori (1964) studied the effects of forward speed on the horizontal and vertical forces exerted on the tines in the soil (Alimardani, 2008). They concluded that the effects of speed should be considered at higher speeds than a specified amount called the critical speed. At higher values of critical speed, the inertia effect of the soil mass should be considered in the calculations to predict the forces on tines. They suggested Equation (1) for calculating the critical speed.

$$v_c = \sqrt{5gw} \tag{1}$$

where, *g*: the acceleration of gravity; *w*: width of the tine.

Term critical peed was introduced by Schuringand Emori (1964), edited by Godwin and Wheeler (1996). They took advantage of the effective width of narrow tines equal to w+0.6d in order to obtain critical speed of narrow tines where (d) is the working depth of tines (Mckeyes, 1985). Therefore, the critical speed for the narrow tines will be:

$$v_c = \sqrt{5g(w+0.6d)} \tag{2}$$

Thus, the critical speeds for tine transducer in depth of 70, 110 and 150 mm were obtained 8, 9 and 10 km h^{-1} respectively.

Figure 3 shows the voltage output at speeds of 5, 10 and 15 km h^{-1} at depth of 70, 110 and 150 mm.

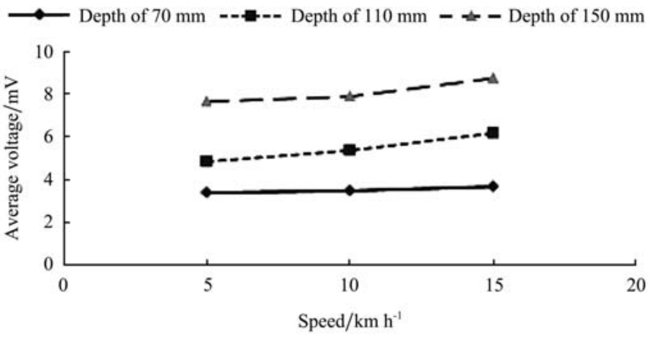


Figure 3 The voltage output at speeds of 5, 10 and 15 km/h

Figure 3 and also the results of variance analysis shows that the difference between the output voltage of three speed levels 5, 10 and 15 km h^{-1} in different depth is small.

At 70 mm working depth, with increase of speed from 5km/h^{-1} to 10 km h^{-1}, the output voltage increases approximately 2.5% and with the increase from 10 km h^{-1} to 15 km h^{-1}, the output voltage increases approximately 5%. At 110 mm working depth, with the increase speed from 5 km h^{-1} to 10 km h^{-1}, the output voltage increases approximately 12% and with the increase from 10 km h^{-1} to 15 km h^{-1}, the output voltage increases approximately 15%. At 150 mm working depth, with the increase speed from 5 km/h^{-1} to 10 km h^{-1}, the output voltage increases approximately 3% and with the increase from 10 km/h^{-1} to 15 km h^{-1}, the output voltage increases approximately 11%.

As well rResults also showed the higher sensing speed the higher horizontal force on the spring tines.

Speed of 5 km h^{-1} was chosen as the optimal speed in order to reduce the effects of inertia force of the soil mass due to higher speeds than the critical speed and also prevent plastic deformation or failure of tines at high speed.

3.3 Evaluate the effects of working depth

Reece (1965) proposed the displacement of soil general equation to describe the cutting soil required forces with an instrument, as follows (Mckeyes, 1985):

$$P = (\gamma d^2 N_\gamma + cdN_c + qdN_q)w \tag{3}$$

where, *P*: The total instrument power; γ: Soil density; *d*: Instrument working depth under the ground; *c*: Soil cohesion strength; *q*: Passive pressure applied on the soil surface; *w*: instrument width; *Nc*, *Nγ* and *Nq*: the factors that not only depend on the frictional resistance of the soil but also instrument geometry and soil stability properties in contact with the instrument.

Geometric variables of the instrument that have effect on the N factors including: angle of the instrument relative to the horizon, possible instrument curvature and depth to width ratio in a narrow instrument.

According to Equation (3), applied force on the tines can be divided into three components. The first component comes from the soil weight and it is proportional with the square of depth. Second and third components return to the cohesion and passive pressure applied on the soil surface, respectively, that both are directly proportional to working depth.

Payne (1956) stated that in narrow tines the effects of displacement of soil toward the outside of tines edges were greater than the central part of the tines front. For these tines soil failure will be three dimensional (Alimardani, 2008). Prediction equations for three dimensional failures were developed by Payne (1956) and Hettiaratchi and Reece (1967). Thus, according to the subjects mentioned, it can be said at narrow tines in addition to component proportional to the passive earth pressure, there are other component that are affected by the side effect of tines edges and the lateral meniscus part which is directly proportional to working depth.

Figure 4 shows the output voltage at the depth of 70, 110 and 150 mm and a constant speed of 5 km h^{-1}.

Figure 5 shows the output voltage at depth of 70, 110 and 150 mm and a constant speed of 10 km h^{-1}.

Figure 6 shows the output voltage at depth of 70, 110 and 150 mm and a constant speed of 15 km h^{-1}.

Figure 7 shows the output voltage at constant depths of 70, 110 and 150mm and speeds of 5, 10 and 15 km h^{-1}.

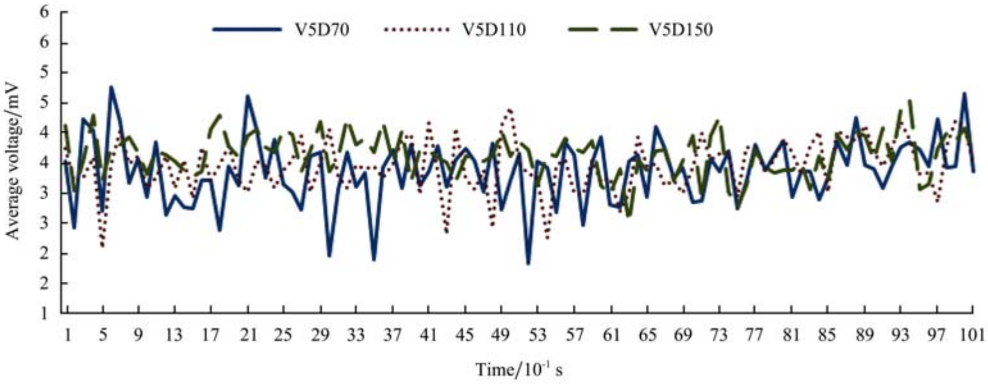


Figure 4 Output voltage at depth of 70, 110 and 150 mm and a constant speed of 5 km h^{-1}

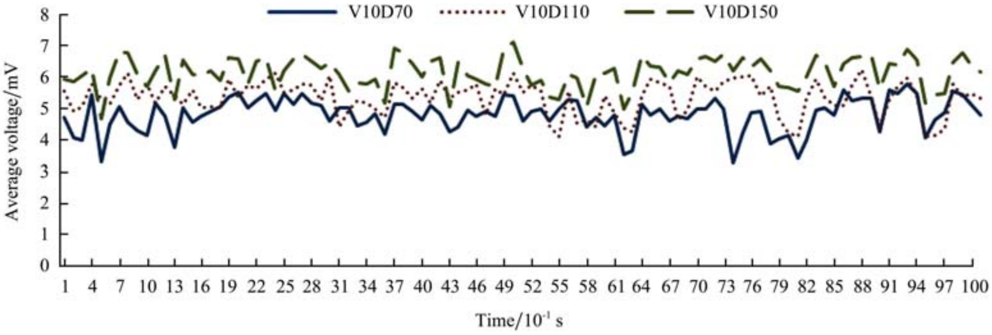


Figure 5 Output voltage at depth of 70, 110 and 150 mm and a constant speed of 10 km h^{-1}

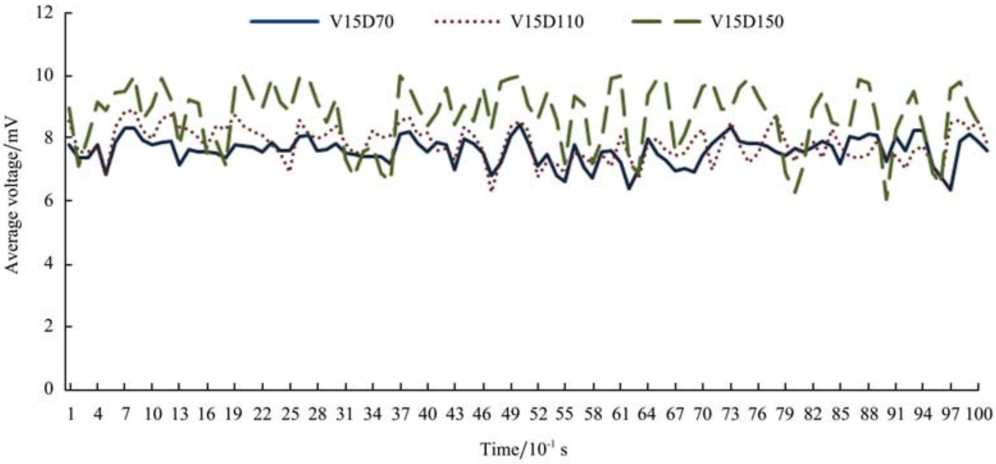


Figure 6 Output voltage at depth of 70, 110 and 150 mm and a constant speed of 15 km h^{-1}

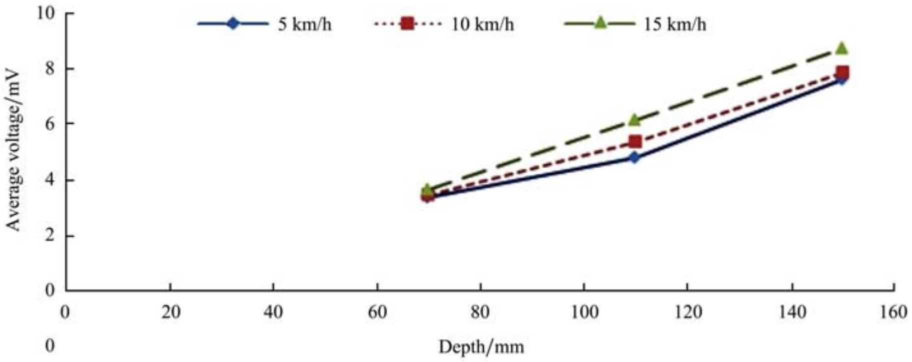


Figure 7 Output voltage at constant depths of 70, 110 and 150 mm

According to Figure 7 and the results of variance analysis shows that there is a great difference between the output voltage of three depths levels 70, 110 and 150 mm in different speeds.

At 5 km h^{-1} sensing speed, with the increase working depth from 70 to 110 mm, the output voltage increases approximately 43% and with the increase from 110 to 150 mm, the output voltage increases approximately 58%. At 10 km/h^{-1} sensing speed, with increase working depth from 70 to 110 mm, the output voltage increases approximately 54% and with increase from 110 to 150 mm, the output voltage increases approximately 47%. At 15 km h^{-1} sensing speed, with increase working depth from 70 to 110 mm, the output voltage increases approximately 68% and with increase from 110 to 150 mm, the output voltage increases approximately 42%.

Results showed that output voltage increased with the increasing working depth so it can be said that the higher working depth, the higher horizontal force on the spring tines.

The amount of root penetration in soil and also the limitations of tines resistance against the horizontal forces should be considered in order to choose the optimal working depth for mechanical transducer tines. Since the possibility of tines failure at the depth of 110 and 150 mm and due to various amounts of roots penetration of different products, depth of 70 mm is recommended as the optimal working depth.

4 Conclusion

In order to evaluate the influence of working speed and depth on performance of the tine transducer factorial experiments were conducted based on randomized complete block design with three replications in a tilth provided with moldboard plow followed by chisel tines. Working speed and depth were investigated each at three levels. The main results are as follows:

1) The higher sensing speed the higher horizontal force on the spring tines.

2) Speed of 5 km h^{-1} was chosen as the optimal speed in order to reduce the effects of inertia force of the soil mass due to higher speeds than the critical speed and also prevent plastic deformation or failure of tines at high speed.

3) Output voltage increase with increasing working depth so it can be said that the higher working depth, the higher horizontal force on the spring tines.

4) Since the possibility of tines failure at the depth of 110 and 150 mm and due to various amounts of roots penetration of different products, depth of 70 mm is recommended as the optimal working depth.

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