

## EXPERIMENTAL STUDIES OF THE PROTOTYPE DEVICE FOR SOIL APPLICATION OF DEHYDRATED DIGESTATE

### Summary

*The experimental results of the prototype device for soil application of dewatered digestate, consisting of a modernized manure spreader and aggregated disc harrow, are presented. The main purpose of the tests were stress measurements in the harrow's frame structure and the hitch attached to the manure spreader's chassis. The results of measurements were found to be very consistent in real conditions with the results of strength analyzes carried out on the computational model. The work was carried out at the Industrial Institute of Agricultural Engineering in Poznań as part of the BIOSTRATEG 1/269056/NCBR/2015 project co-financed by the National Center for Research and Development under the Biostrateg program.*

**Keywords:** digestate, soil application, spreader, hitch, disc harrow, experimental tests, stresses, working resistance

## BADANIA EKSPERYMENTALNE PROTOTYPU URZĄDZENIA DO DOGLEBOWEJ APLIKACJI ODWODNIONEGO POFERMENTU

### Streszczenie

*Przedstawiono wyniki badań eksperymentalnych prototypu urządzenia do doglebowej aplikacji odwodnionego pofermentu, składającego się ze zmodernizowanego rozrzutnika obornika i zagregowanej z nim brony talerzowej. Głównym celem badań były pomiary naprężeń w konstrukcji nośnej brony i zaczepie zamocowanym do podwozia rozrzutnika. Stwierdzono dużą zgodność wyników pomiarów w warunkach rzeczywistych z wynikami analiz wytrzymałościowych przeprowadzonych na modelu obliczeniowym. Prace przeprowadzono w Przemysłowym Instytucie Maszyn Rolniczych w Poznaniu w ramach projektu BIOSTRATEG 1/269056/NCBR/2015 dofinansowanego przez NCBR w ramach programu Biostrateg.*

**Słowa kluczowe:** poferment, aplikacja doglebowa, rozrzutnik, zaczep, brona talerzowa, badania eksperymentalne, naprężenia, opory robocze

### 1. Introduction

Important stages of agricultural machinery design work are modeling and simulations preceding the development of design documentation and prototype construction as well as experimental research of the prototype [3]. The purpose of model and simulation works is to eliminate errors in the construction of the prototype, which cause the necessity to correct them during the tests. The aim of experimental research is to check the prototype in real conditions and verify the assumptions and simulation analyzes, among others in the field of strength of the structure. Strength verification of the prototype is important both in relation to the supporting frame of the machine and the hitches connecting the two machines. An example of such a complex set is a new device, consisting of a spreader and disc harrow - a device for soil application of dehydrated digestate, which is a by-product generated during the production of biogas from organic substrates. Due to its properties, the digestate can be used as a valuable and cheap fertilizer, both in liquid and solid form after dehydration as a result of separation [1]. For the application of liquid digestate, liquid manure spreaders equipped with various systems for the distribution of digestate are commonly used, including, among others, surface or subsoil applicators [4], suspended on a three-point suspension system of a slurry tanker. However, for the application of a dehydrated digestate, resembling compost, it can use various types of spreaders [6], applying fertilizer on surface. The organic fertilizer spread on the field requires plowing or mixing with the soil in the next treatment, which, according to the Code of Good Agricultural

Practice, should be carried out no later than the next day [8].

At the Industrial Institute of Agricultural Engineering in Poznan, as part of the BIOSTRATEG 1/269056/NCBR /2015 project, a new device for soil application of dehydrated digestate was developed and tested [2]. The device consists of a modernized manure spreader and aggregated disc harrow, allowing simultaneous spreading and soil application of digestate.

### 2. Object, purpose and course of research

Experimental measurements were carried out on a prototype of a device consisting of a modernized manure spreader Tytan 18 and an attached, compact disc harrow with a working width of 3 m (Fig. 1). New elements of the modernized spreader are a auger-type beater that spreads the digestate low above the field surface and the harrow hitch. The disc harrow was equipped with a tire roller fixing the position of discs during operation and supporting the back of the harrow during transport.

The aim of the research was to measure working resistance generated by a disc harrow aggregated with a spreader and stress measurements in the harrow's frame structure and a hitch attached to the manure spreader's chassis. Strength analyzes, carried out on a computational model, showed compliance with the strength requirements in terms of allowable stresses for S355JO steel both for the manure spreader hitch and aggregated disc harrow [7], and the purpose of experimental measurements was to check the reliability of these analyzes.

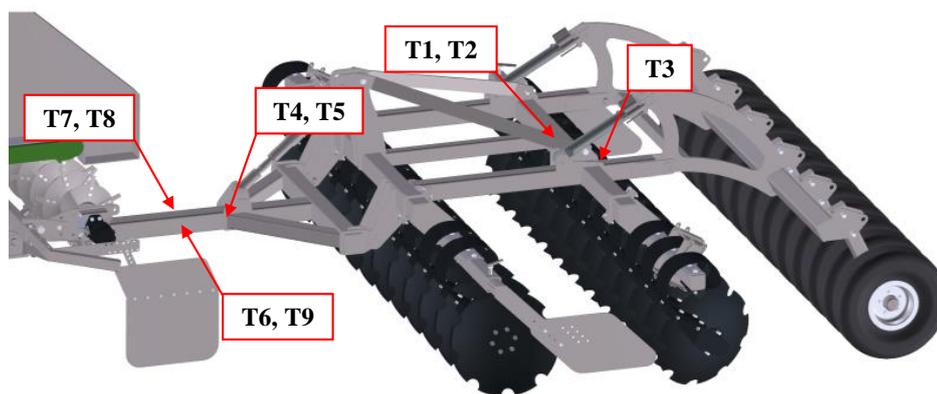
During the experimental tests a series of stress measurements was performed in various conditions occurring during work and transport rides as well as measurements of working resistance of the disc harrow. Tensometric sensors with the symbol TF 5/120, used to measure stresses in one direction, were used to record stresses. A measurement data acquisition set consisting of measuring equipment and software from the Hottinger company was used to record

and process measurement signals. Measurement signals from the mentioned sensors were registered using the Spider-8 equipment in a configuration including 32 measurement channels and Catman 5.0 software. Processing of measurement signals and visualization of results was carried out using the Matlab software. In total, 14 tensometers were placed on the frame of the device at critical points of the structure (Figs. 2-5).



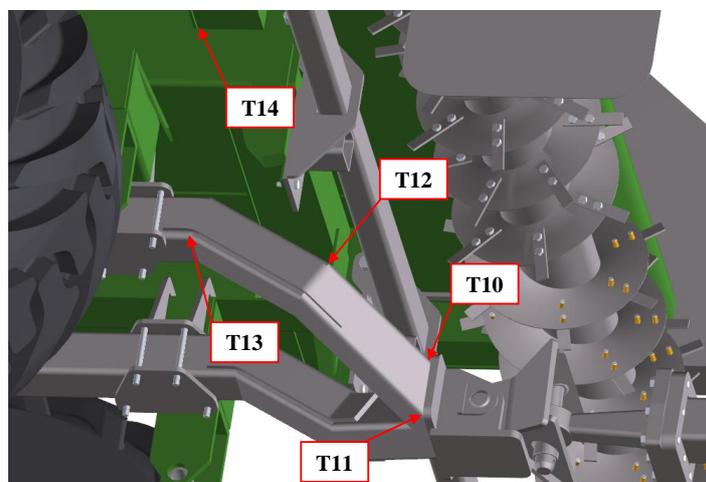
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Fig. 1. Prototype of the device for soil application of digestate  
Rys. 1. Prototyp urządzenia do dogłębowej aplikacji pofermentu



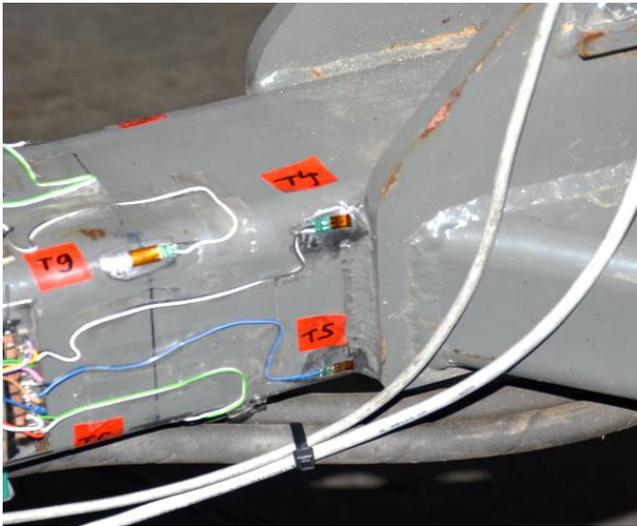
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Fig. 2. Scheme of the distribution of tensometers on a disc harrow  
Rys. 2. Schemat rozmieszczenia tensometrów na bronie talerzowej



Source: own work / Źródło: opracowanie własne

Fig. 3. Scheme of distribution of tensometers on the manure spreader hitch  
Rys. 3. Schemat rozmieszczenia tensometrów na zaczepie rozrzutnika



Source: own work / Źródło: opracowanie własne

Fig. 4. T4 and T5 tensometer sensors on the disc harrows draught bar  
Rys. 4. Tensometry T4 i T5 na dyszlu brony talerzowej



Source: own work / Źródło: opracowanie własne

Fig. 5. T11 tensometer on the harrows hitch  
Rys. 5. Tensometr T11 na zaczepie do brony

### 3. Measurement results

The highest absolute values of stress recorded during all measurements occurred at points T4 and T5 located on the disc harrow draught bar. During the transport ride along the dirt road at the T5 point was a maximum positive stress value of 278 MPa (Fig. 6), and at T4 the highest negative stress value (-318 MPa). During transport, a relatively high level of stress (-197 MPa) was also recorded on the disc harrow frame at the T3 point located at the handle of the

hitching system support stay and the tire roller actuator. However, when working with recessed disc harrow, the stresses value at T4 point reached -313 MPa (Fig. 7). The stresses values recorded in the hitch attached to the manure spreader chassis are relatively small. The highest absolute values of stresses were recorded at point T13, in which the highest negative stress occurred during transport (-176 MPa), and during work the highest positive stress were 125 MPa.

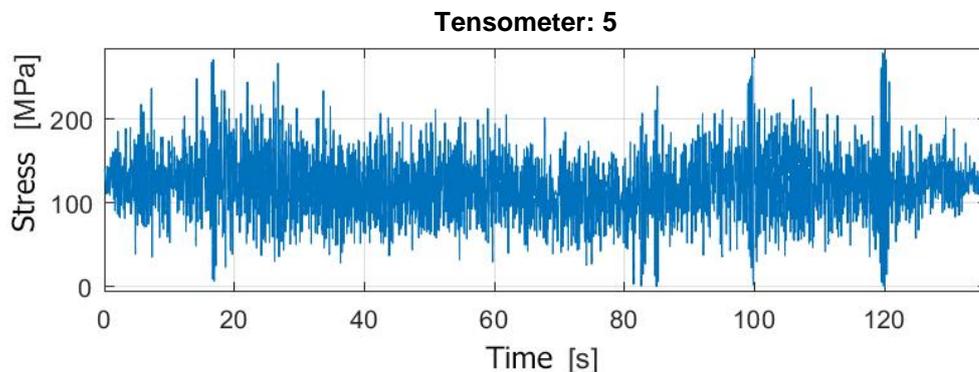


Fig. 6. Fatigue data at point T5 during transport  
Rys. 6. Przebieg naprężeń w punkcie T5 podczas transportu

Source: own work / Źródło: opracowanie własne

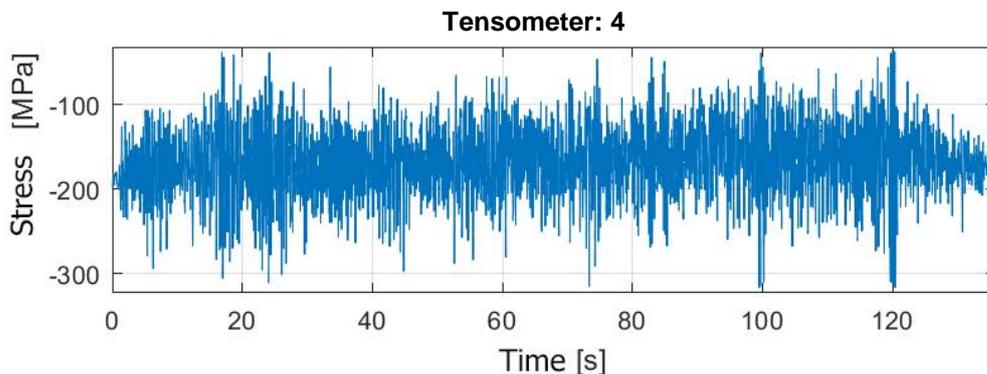


Fig. 7. Fatigue data at point T4 during work  
Rys. 7. Przebieg naprężeń punkcie T4 podczas pracy

Source: own work / Źródło: opracowanie własne

The recorded stress values at measuring points T1-T3 and T6-T14 did not exceed the stress level allowed for steel S355JO. On this basis, it can be concluded that the design of the device at these points meets the requirements of permanent fatigue strength. However, for the T4 and T5 measuring points, for which the highest level of static stress constituents was registered, an additional analysis was carried out, taking into account the effect of stress dynamics on unlimited fatigue durability. For selected stress runs the procedure of counting cycles and semi-cycles was carried out using the rain flow counting method, and the results were plotted on Goodman-Smith charts (Figs 8 and 9). Analysis of the results shows that point T4 works in the range of unlimited fatigue durability (Fig. 9), and at T5 the stresses exceed the conditions assumed for unlimited fatigue durability (Fig. 8). A detailed analysis of the recorded stress courses for this point indicates that during one pass only four cycles do not meet the conditions, which gives only 120 cycles

within one working hour. Therefore, these exceedances can be regarded as impulse, not dangerous for the construction.

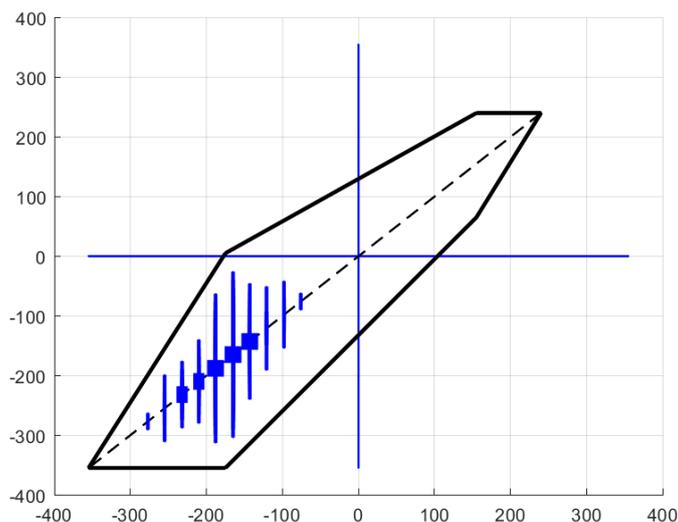
The average of the maximum stresses registered during the prototype tests was compared with the results of strength analyzes carried out on computational models. It was found that the distribution of stresses recorded during the tests with the results of calculations was very consistent, and the differences found at some measurement points most probably result from the simplifications in the computational model and from the unavoidable inaccuracies of the measurements. In the case of transport, the biggest differences occurred at measuring points T4 and T5, in which the measurements showed higher stresses and at the T1 point, in which the measurements showed lower stresses (Fig. 10). In contrast, in the case of work the greatest differences occurred at the T4 point, in which the measurements showed higher stresses and at points T6 and T8, in which the measurements showed lower stresses (Fig. 11).



Source: [2] / Źródło: [2]

Fig. 8. Goodman-Smith chart for the T5 point during transport

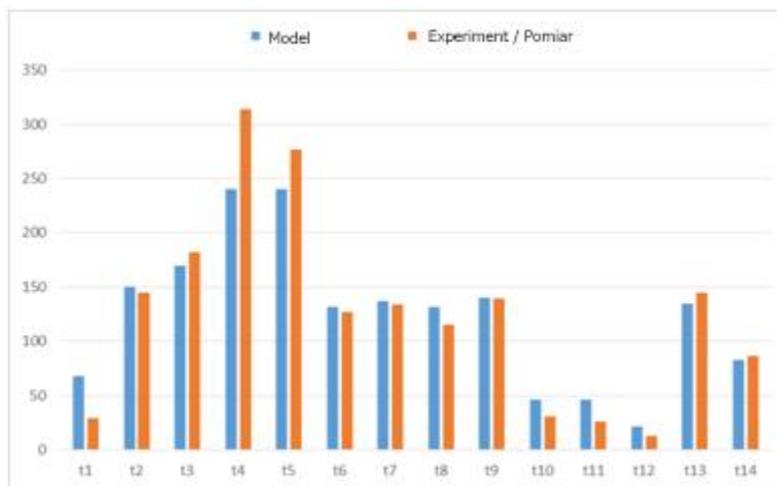
Rys. 8. Wykres Goodmana-Smitha dla punktu T5 podczas transportu



Source: [2] / Źródło: [2]

Fig. 9. Goodman-Smith chart for the T4 point during work

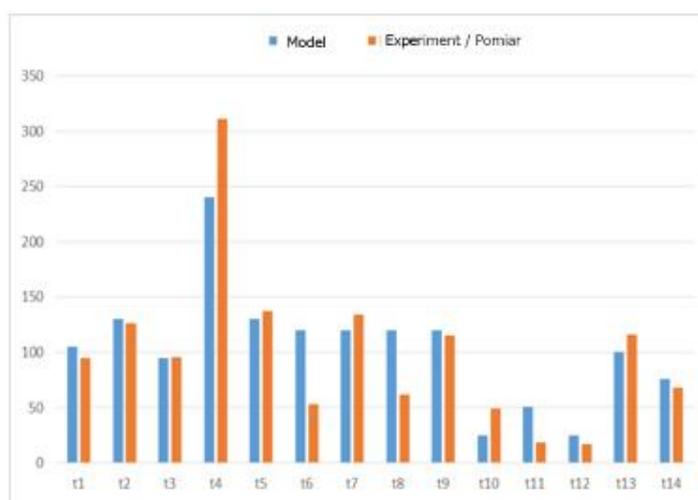
Rys. 9. Wykres Goodmana-Smitha dla punktu T4 podczas pracy



Source: own work / Źródło: opracowanie własne

Fig. 10. Comparison of stresses measured while transport (orange) with estimated on a computational model (blue)

Rys. 10. Porównanie naprężeń zmierzonych podczas transportu (pomarańczowy) z odczytanymi na modelu obliczeniowym (niebieski)

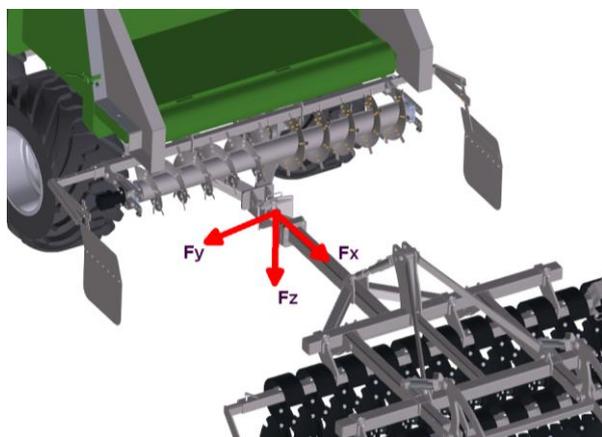


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Fig. 11. Comparison of stresses measured while working (orange) with estimated on a computational model (blue)

Rys. 11. Porównanie naprężeń zmierzonych podczas pracy (pomarańczowy) z odczytanymi na modelu obliczeniowym (niebieski)

During the experimental tests, the forces with which the disc harrow influences the manure spreader hitch were also determined (Fig. 12).



Source: own work / Źródło: opracowanie własne

Fig. 12. Diagram of the distribution of forces on the hitch

Rys. 12. Schemat rozkładu sił na zaczepie

T6-T9 tensometric sensors glued on the disc harrow draught bar were used for the measurements, and in order to determine the load forces of the machine at the point of aggregation, the method discussed in detail by Spadło in the doctoral dissertation [5] was used. The average value of the longitudinal force  $F_x$  corresponding to the disc harrow's working resistance, determined during experimental research, was 1638 daN. This value corresponds to the working resistance, estimated during simulation analyzes at the level of 1524 daN. In contrast, the maximum value of the longitudinal force  $F_x$ , determined during the tests, was 2190 daN and corresponds to the maximum working resistance of the disc harrow in simulation analysis, which after taking into account the dynamic surplus  $k_d = 1,6$  was 2144 daN.

#### 4. Conclusions

1. Experimental tests of the prototype device for soil application of digestate, carried out during work and transport journeys, demonstrated the fulfillment of the strength requirements by the supporting frame of the disc harrow and the hitch fastened to the chassis of the spreader.

2. The highest values of stresses were recorded on the disc harrow, but the analysis taking into account the effect of stress dynamics on unlimited fatigue durability showed that they are harmless to the structure.
3. Distribution of stresses recorded during tests is consistent with the results of simulation analyzes, and the biggest differences between the results of calculations and measurements occurred at points located on the harrow's draught bar.
4. Working resistances of disc harrow aggregated with a manure spreader, determined during experimental research, correspond to the working resistances estimated during simulation analyzes on a computational model.

## 5. References

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