TRANSPORT PROBLEMS 2007
PROBLEMY TRANSPORTU Tom 2 Zeszyt 3

Tomasz ZAJĄC *, Franciszek W. PRZYSTUPA, Jacek SIPA
Wrocław University of Technology, Institute of Design and Exploitations of Machines
I. Łukasiewicza st. 7/9, 50-371 Wrocław, Poland
**Corresponding author*. E-mail: tomasz.j.zajac@pwr.wroc.pl

DEFORMATION OF THE GREAT COUPLING DIAPHRAGMS

Summary. Plastic deformation mode of the great coupling diaphragms is the subject matter of this article. The model has been created on the experimental way through the research on a wheel excavator. The presented analysis algorithm of the aggregated data is a basis for identification of the causes and the area of the plastic deformation in the great coupling diaphragms.

DEFORMACJA MEMBRAN SPRZĘGIEŁ WIELKOGABARYTOWYCH

Streszczenie. W artykule zaprezentowano własny model analityczny, opisujący plastyczną deformację membran sprzęgieł wielkogabarytowych. Omówiono badania doświadczalne zrealizowane na kołowej koparce wielonaczyniowej, które stanowiły podstawę do budowy modelu. Przedstawiono algorytm analizy zebranych danych, umożliwiający identyfikację przyczyn powstania zjawiska plastycznego odkształcenia się membran sprzęgieł wielkogabarytowych.

1. INTRODUCTION

The latest methods of construction analysis that are applied in designing machines and technical devices often enable to make use of thin-walled elements in the final design. As a result, there are possibilities that the base weight and dimensions of structures decrease which leads to reduction of manufacturing costs of so designed objects. However, the subject of thin-walled construction may cause specific strength difficulties connected with stability. A lot of so designed structures are large-size objects. They are especially sensitive to manufacture and assembly faults. Before assembling thin-walled elements are characterized by low rigidity which may cause additional difficulties in ensuring the required level of joint precision and a proper form of the object. It determines further operation of the devices. Different methods of strength analysis connected with stability problems, as distinct from traditional objects, need to be used in that case.

The classical theory of elasticity is a basis for assessment of stress and strain state of a structural component. However, it turns out to be useful only for low strain level that cannot ensure the full use of strength potential of construction or elements in many cases. The elasto-plastic analysis is necessary in that situation. It ensures obtaining the main information about the construction in case of monotonically increasing loads and in case of complicated loads changing their value in time. That is the reason for theoretical consideration and reliable experimental verification of the design assumptions, which should be an essential part in the modern design process.

2. EXPERIMENTAL TESTS

The great coupling diaphragm was the object of the tests. The diaphragm got damaged in the result of long-lasting exploitation of the power transmission unit of the bucket wheel. Plastic deformation – which could be seen even with the naked eye – was the reason of the coupling failure. For this reason, there was a necessity to formulate an analytical model of the observed breakdown, which could make possible to identify reasons of the plastic deformation of the diaphragm. Thanks to that, a diagnostic system could be developed and this kind of damage avoided in other technical conditions in the future [2].

Innovative design solutions of the power transmission unit of the bucket wheel, which were introduced in the examined wheel excavator, are characterized by a reduction gear connected with the bucket wheel by a high diameter but a thin diaphragm on one side. On the other side, the power transmission unit is fastened to the shaft by a low diameter diaphragm (Fig. 1). Torque transmission from the power unit to the bucket wheel is the main task of the great diaphragm.

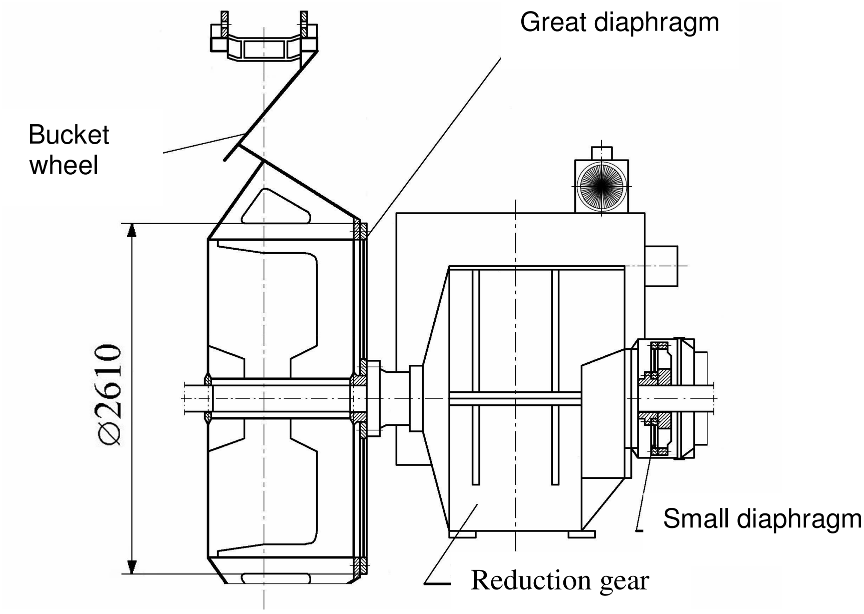

Fig. 1. Innovative design of the power transmission unit of the bucket wheel of an excavator
Rys. 1. Nowatorskie rozwiązanie układu napędowego koła czerpakowego koparki

Cumulative data of pre-measurements carried out by strip mine engineers showed clearly the occurrence of the plastic deformation of the thin-walled element that had been designed as a flat plate. Industrial methods were used to make measurements, therefore available information was insufficient for carrying out precise analysis in order to explain the reasons of the permanent deformation. Thereby it was impossible to decide if the element could still meet the basic structural requirements. That is why more precise experimental tests in operating conditions of the great coupling were carried out. The way of making measurements was adjusted to the requirements of further analysis, the aim of which was describing performance of the thin-walled elements in the state of plastic deformation.

2.1. Measurement of the deformation

Experimental tests concerning performance of the great coupling diaphragm, operating under complex loads, were carried out on the bucket-wheel excavator while mining in ordinary exploitation conditions [1]. In order to determine the degree of the great coupling diaphragm deformation, the tests were carried out with the use of electrical inductive displacement sensors [4].

Eight inductive displacement sensors with measurement base ± 10 mm and ± 15 mm were used to measure deformation perpendicular to the diaphragm's surface. The sensors were located on the steel stringer that, by means of a special construction, was rigidly fixed to the power transmission gear housing. Figure 2 presents the sensors' position.

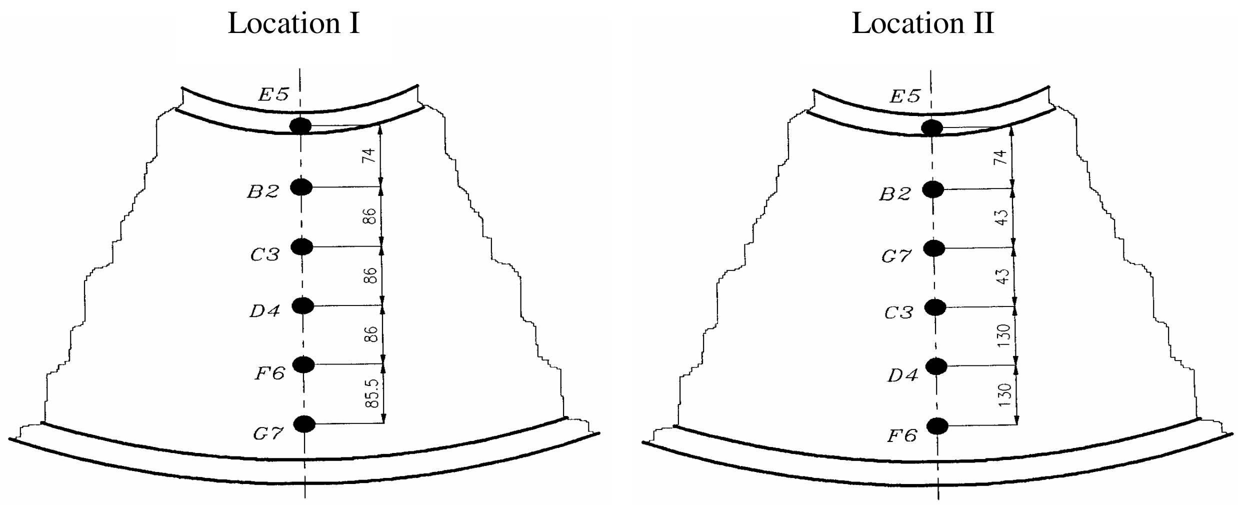

Fig. 2. Position of the displacement sensors on the steel stringer
Rys. 2. Rozmieszczenie czujników przemieszczeń na stalowej listwie

The measurement of the diaphragm deformation was made by turning the unloaded bucket wheel with the use of its supportive power transmission. At the same time, signals from all inductive displacement sensors situated on the steel stringer were continuously recorded. After a full rotation, the bucket wheel was stopped. The measurements were carried out three times to check repeatability of the results. After relocation of a few displacement sensors on the steel stringer, the measurements were carried out again by using the same procedure. Finally, characteristics of the diaphragm deformation change in the function of angular displacement were obtained (Fig. 3). The results unequivocally show the fact of plastic deformation of the diaphragm. Two characteristic fragments on the diaphragm can be observed where the highest deformation occurred.

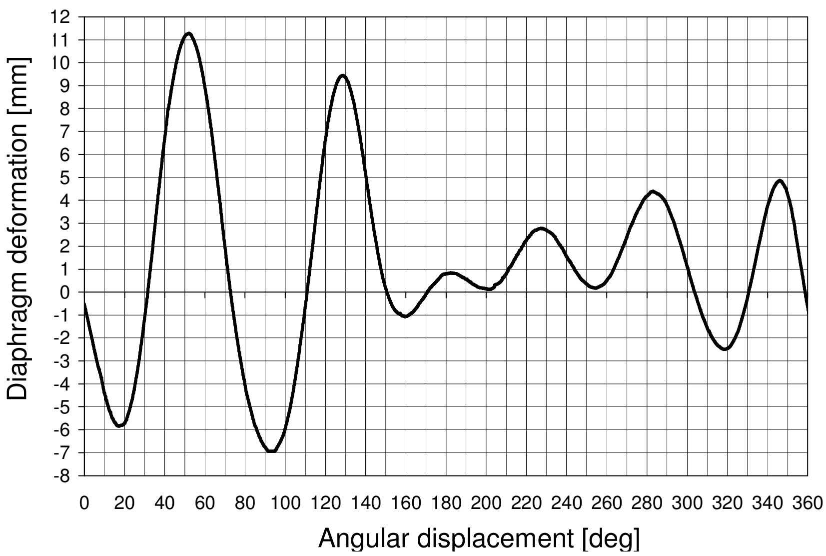

Fig. 3. Example graph of the measured value on the displacement sensors
Rys. 3. Przykładowy wykres wartości zmierzonych czujnikiem przemieszczeń

2.2. Measurement of stresses

Because the observed deformation of the great coupling diaphragm could be the reason of value increase and irregular distribution of stresses, it was advisable to evaluate stresses occurring in the diaphragm at a normal operation of the excavator. Stress measurements were made by means of electric resistance wire strain gauges [3]. The extensometers were stuck in a few points nearby the places where the highest deformation was noticed. Two extensometers were fixed at each of the points: radially and axially [1]. Additional compensatory extensometers were stuck in every point to obtain the complete Wheatstone bridge. Detailed configuration of measuring points presents fig. 4.

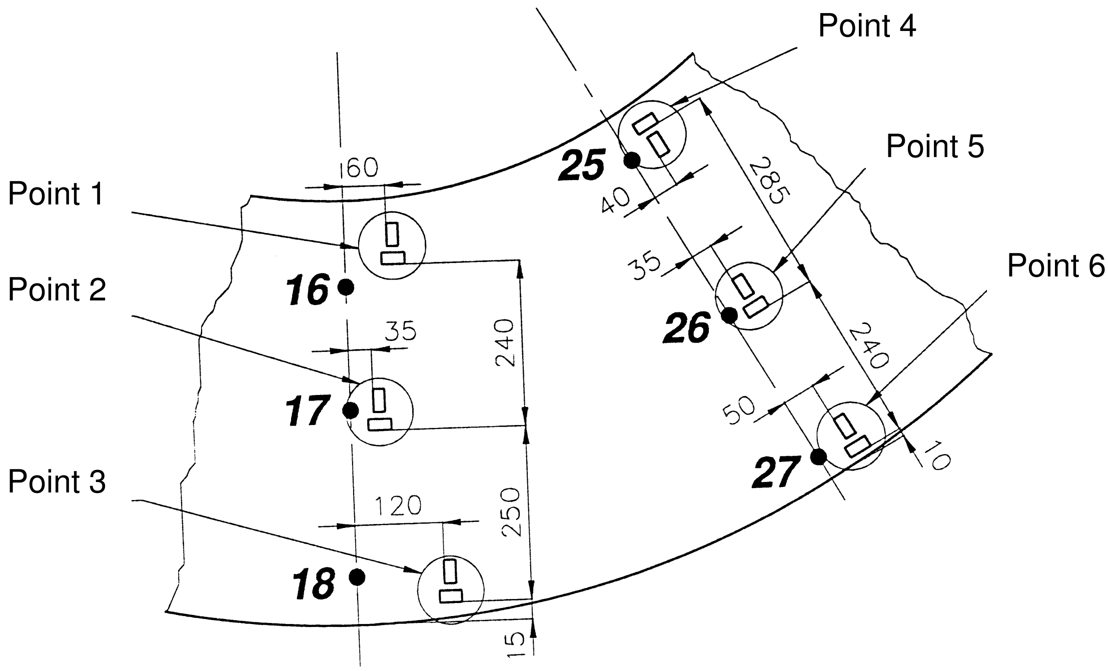

Fig. 4. Position of the measuring points on the great diaphragm
Rys. 4. Rozmieszczenie punktów pomiarowych na membranie dużej

Measurements were carried out during mining in normal exploitation conditions of the excavator. The measuring points had to be connected with the resistance bridge in such way that the diaphragm could rotate easily. It caused certain limitations of simultaneously recording results from all measuring points. The obtained results were converted so that the value of stresses could be assessed. An example of stress changes in one of the measuring points is presented in Fig. 5 and in Fig. 6.

Results of the measurements shows that in the area of permanent diaphragm deformation, confirmed by the deformation measurement, dynamic stresses which arises there, are of a high value and change depending on the bucket wheel position. The obtained stress values may even increase, because the measurements were carried out in exploitation conditions, but excluding the extreme situation when the bucket wheel hits a stone and stops short. Additionally, the dynamic stresses evaluated on the basis of the measurements should be considered as sufficiently dangerous, because they do not take static stresses into account.

3. DEFORMATION ANALYSIS ALGORITHM

The presented experimental tests were carried out in order to make use of cumulative data in the analysis of large-size thin-walled elements' performance in a plastic state. The main task of this analysis is to characterize the reason of the plastic deformation occurrence in great coupling diaphragm. It can prevent this kind of undesirable events in future. Besides, information about a deformed element obtained in that way guarantees its further safe operation even though the structure no longer meets the design assumptions. Algorithm, according to which the analysis of the diaphragm deformation was made, is presented in Fig. 7.

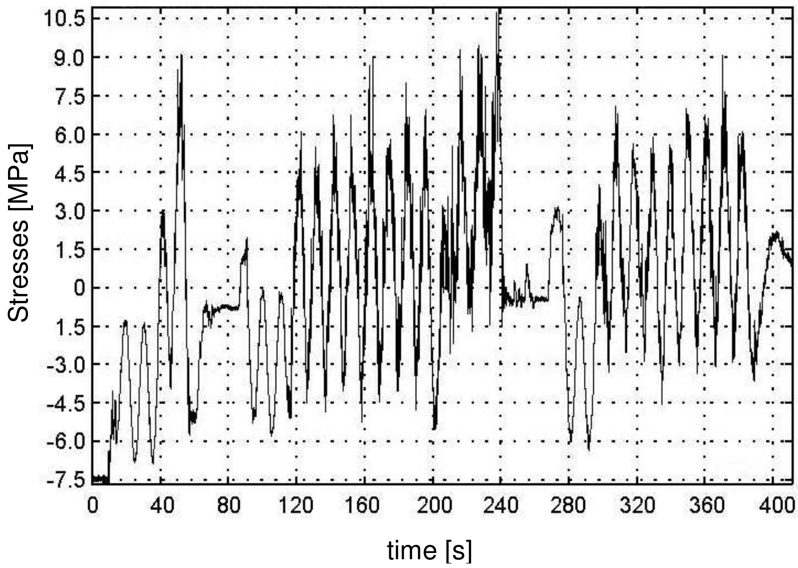

Fig. 5. Course of circumferential stress changes on the great diaphragm
Rys. 5. Przebieg zmian naprężeń obwodowych dla membrany dużej

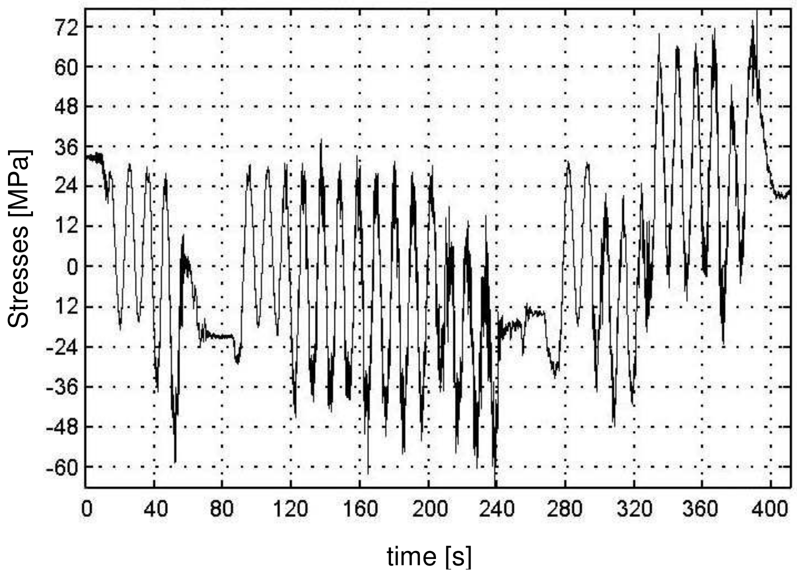

Fig. 6. Course of radial stress changes on the great diaphragm
Rys. 6. Przebieg zmian naprężeń promieniowych dla membrany dużej

On the basis of models showing deflection of thin-walled rectangular plates subjected to complex loads taken from literature [5], an analogical model for the tested large-size diaphragm was proposed. It was conventionally represented as the rectangular plate with sides' dimensions equal to the radius and circumference of the diaphragm.

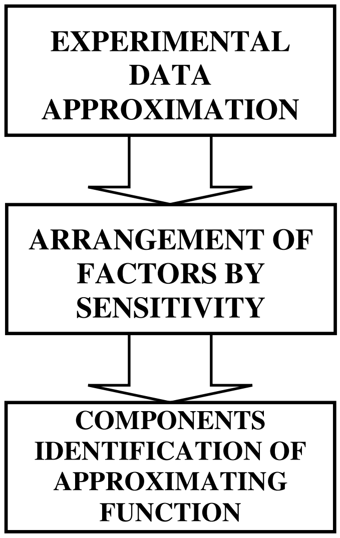

Fig. 7. Analysis algorithm of function describing the diaphragm deformation
Rys. 7. Algorytm analizy funkcji opisującej deformację membrany

By the abovementioned analogy the formula describing deflection of the great coupling diaphragm was derived:

$$w_i(\varphi) = a_0 + \sum_{n=1}^{N} a_n \sin\frac{n\pi\varphi}{360} \tag{1}$$

where: φ – angular displacement of the diaphragm (in degrees), n – quantity of sinusoidal half-waves of circumferential deflection, a_0, a_n – certain constant factors.

Because the measurement of deformation was made by using electrical inductive displacement sensors located in radial direction, displacements perpendicular to the element's surface along the whole circumference were recorded. In order to derive a specific analytical form of the formula describing the diaphragm deflections it was necessary to estimate values of the factors for all radiuses by using data approximation with formula (1).

Evaluation procedure of proper factors consist in approximating experimental data by using formula (1) for successive values of parameter n. Factors quantity was assumed in order to obtain sufficiently precise approximation of experimental data (confidence level 95%) (Fig. 8). Suitable values of factors a_0 and a_n were calculated for all functions by using least squares method.

After complete forms of functions approximating results obtained in experimental tests were estimated for all radiuses, a problem of arrangement evaluated components of function was approached according to their sensitivity. As the sensitivity criterion influence of the component that included the parameter n on a form of approximating function was assumed. It was done by comparing values of mean square deviation assessed after the considered component was removed.

That arrangement of approximating function components enabled to identify basic parts – characterizing their connection with external force and also with reaction of the system to this force. Thanks to this it is possible to:

- determine the form of force that causes the plastic deformation of the diaphragm,
- localize the area along the radius where the force occurs.

Components which have the biggest influence on the form of approximating function have to be taken under consideration. Table 1 presents, for all radiuses, basic components which have the biggest influence on the function structure.

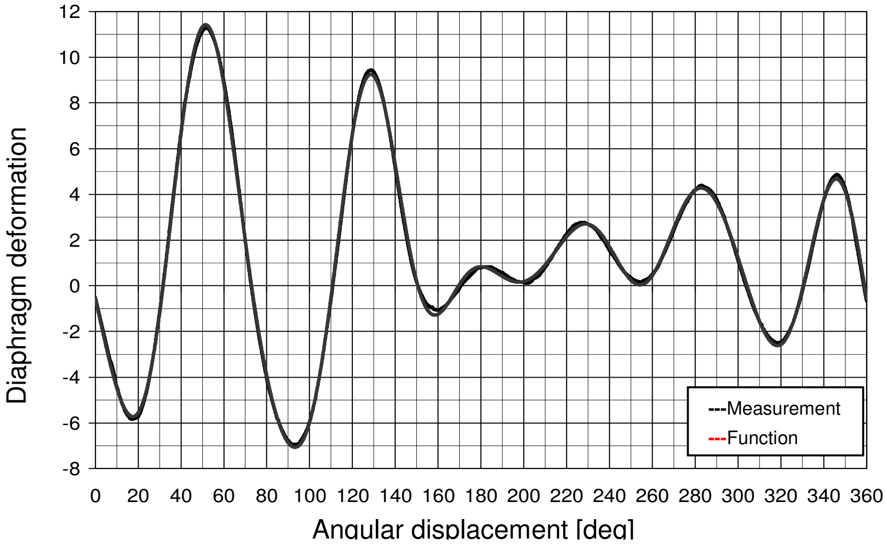

Fig. 8. Example graph of function approximating diaphragm deformation
Rys. 8. Przykładowy wykres funkcji aproksymującej deformację membrany

Table 1

Function components that have
the biggest influence on an approximation form

No.	Symbol of sensor	Relative location of a sensor along the diaphragm radius	Quantity of half-waves of circumferential deflection ***n***
1	B2	0,074	10
2	G7 (II)	0,146	10
3	C3	0,218	1
4	D4 (I)	0,363	1
5	D4 (II)	0,437	1
6	F6 (I)	0,508	9
7	G7 (I)	0,651	9
8	F6 (I)	0,655	9

It was established on the basis of arrangement of the approximating function components presented in table 1 that elements n=1 are connected with external forces, whereas elements n=9 and n= 10 are connected with a reaction of the system to these external forces. It is confirmed in the interpretation of parameter n which determines quantity of sinusoidal half-waves of the diaphragm circumferential deflection in accordance with formula (1). On these grounds it can be stated that the external force has the form of a concentrated force in a small area, and the place of application is located in a distance of 0,218 ÷0,437 between the rings counting from the internal ring. It is the area where sensors C3 and D4 are fixed (Fig. 2).

4. SUMMARY

The subject presented in this article is especially important for designing big power transmission systems. In basic machines of surface mining the power systems attain 2500 kW. Thin-walled elements, for example the great coupling diaphragm, are more and more frequently used in these structures as elements transmitting power. Damage occurring in that connection may cause a serious failure in power transmission system of an excavator. In consequence, mine can suffer a big loss when the excavator has to be removed from operation. Therefore, the problem of ensuring operational reliability for large-size thin-walled elements is very important.

When using proposed algorithm in deformation analysis of the great coupling diaphragm, it is possible to obtain information about a form of external force and a place where the force is applied and initiates plastic deformation of an element. Thus acquired knowledge about reasons of the plastic deformation occurrence and location of original deformation area enables to generalize the problem also for other load and geometrical cases. It is possible to make numerical analysis (finite element method) in order to predict behaviour of deformed large-size thin-walled elements in further exploitation process.

Information obtained as a result of the diaphragm deformation analysis can be used later to make a decision concerning further exploitation of the deformed element. The presented measurement methods including application of the inductive displacement sensors and electric resistance wire strain gauges are recommended to determine the degree of diaphragm deformation.

Literature

1. Dudek D., Rusiński E. i inni: *Wykonanie badań i obliczeń membranowego połączenia koła czerpakowego koparki SRs-1200/1 odkrywka Jóźwin, z przekładnią KPA 75 w KWB „Konin”*. Raport Serii Sprawozdania nr S 066/99, Instytut Konstrukcji i Eksploatacji Maszyn Politechniki Wrocławskiej, Wrocław 1999.
2. Przystupa F. W.: *Proces diagnozowania w ewoluującym systemie technicznym.* Prace Naukowe Instytutu Konstrukcji i Eksploatacji Maszyn Politechniki Wrocławskiej, nr 83, s. Monografie, 29, Wrocław 1999.
3. Roliński Z.: *Tensometria oporowa. Podstawy teoretyczne i przykłady zastosowań.* Wydawnictwo Naukowo-Techniczne, Warszawa 1981.
4. Szumielewicz B., Słomski B., Styburski W.: *Pomiary elektroniczne w technice.* Wydawnictwo Naukowo-Techniczne, Warszawa 1982.
5. Zając T.: *Stany graniczne wielkogabarytowych sprzęgieł membranowych.* Rozprawa doktorska, Instytut Konstrukcji i Eksploatacji Maszyn Politechniki Wrocławskiej, Wrocław 2005.

Received 22.10.2007; accepted in revised form 23.11.2007