Ryszard MAŃCZAK, Marian JÓSKO, Dariusz ULBRICH
Poznan University of Technology, Poznań, Poland
Institute of Machines and Motor Vehicles
e-mail: ryszard.manczak@put.poznan.pl
e-mail: marian.josko@put.poznan.pl
e-mail: dariusz.m.ulbrich@doctorate.put.poznan.pl

METHODOLOGY AND STATION FOR DEGRADATION'S EVALUATION OF ADHESIVE BONDS TYPE COATING-SUBSTRATE. PART 2.

Summary

In the article is presented project and construction of test stand for degradation of bond between coating and substrate. The test stand is tested in dynamic condition. It is tested the stability of acoustic coupling between ultrasonic probes and substrate as well. Results of the test confirm the fulfillment of methodological assumptions and show a good applicability of the test stand for testing the degradation of adhesive bond type coating-substrate.
***Key words**: test stand, degradation, adhesion, ultrasound wave*

1. Introduction

A follow-up step of the research described in the first part of the article [1] is a project and construction of the station that allows to research a degradation process in adhesive bonds between coating and substrate. An analysis of component vectors in the coating bond model, especially the analysis of the input parameters vector *E(t)* and clutter vector *Z(t)*, results in distinguishing of a group of detailed construction assumptions for the station. The results of the analysis are shown in the table 1.

A fulfillment of the presented in the table 1 assumptions requires a specialist measurement equipment fixed to the station. The detailed assumptions No. 2.2.3 connected to usage of the air' climatic treatment are of significant relevance within other assumptions. It is presumed that the necessary air' climatic treatment of the station is provided by the located in the laboratory air conditioning system. Moreover, the fulfillment of assumptions about a running stability of the station requires a number of testing researches.

2. Project and construction of the station

On the base of detailed directives showed in the table 1 is completed a project of a station for researching of degradation process in adhesive bonds. An object-scheme of the station is shown in the fig. 1. The most important component of the station is an electrodynamics' generator supplied with a generator (19). The generator creates a signal of definite amplitude and frequency that is increased in an amplifier. The reinforced signal powers electrodynamics' generator that creates vertical oscillations. The oscillations are passed by a loading system to a sample. The generator has a pressurized air-cooled system (6). In comparison to the pressure in a pressurized air installation the pressure in a pressure control valve (22) is lower. A generator's temperature is supervised by a monitoring system (7) and (23). Parameters of power supply signal are controlled by a digital multimeter II (21).

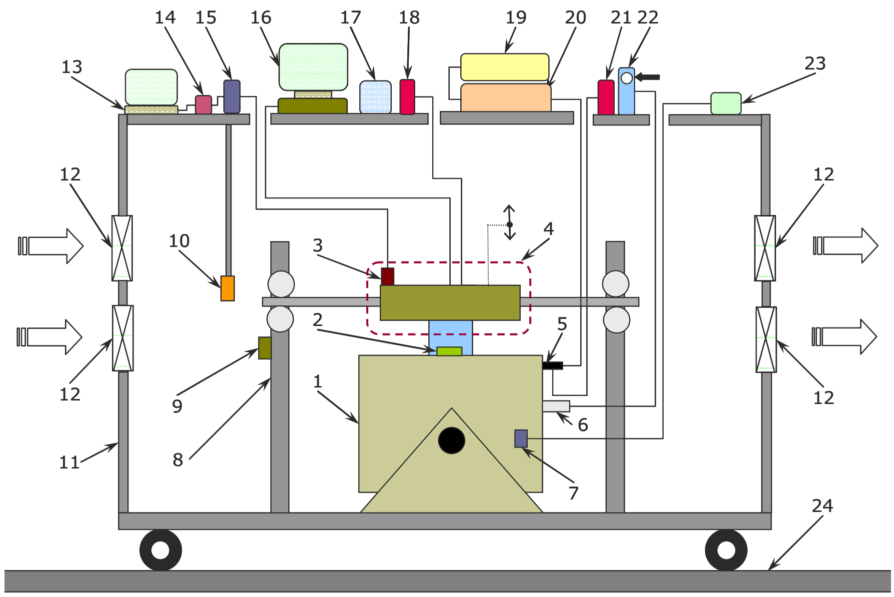

Fig. 1. Schema of the test stand: 1 – electrodynamics' generator, 2 – water balance, 3 – acceleration's sensor, 4 – test sample, 5 – generator's power unit, 6 – pressurized air, 7 – thermometer, 8 – supports, 9 – sensor of temperature and humidity, 10 – anemometer, 11 – case, 12 – ventilator, 13 – PC, 14 – oscilloscope, 15 – conditioner, 16 – ultrasonic flaw detector, 17 – sensor of temperature, humidity and pressure, 18 – multimeter I, 19 – signal's generator, 20 – amplifier, 21 – multimeter II, 22 – pressure control valve, 23 – display, 24 – substrate

Tab. 1. Detailed assumption of test stand project

Model components in a coating-substrate bond								Description	Particular assumptions for the stand construction
2.	Vector E(t)	2.2.	Degradation process of a bond	2.2.1.	Mechanical loads	2.2.1.1.	Amplitude	Influence of parameters vibration on the degradation process	Loading system of the sample with adjustable amplitude and frequency of vibration
						2.2.1.2.	Frequency		
				2.2.2.	Enforcements caused by assembly errors			Incorrect assembly of samples and coating may cause additional tensions in bonds	Joined support points of samples and elements for regulation and control of the settings of loading system
				2.2.3.	Environmental conditions	2.2.3.1.	Air temperature	Influence of environmental factor on degradation process	Assurance of air conditioning and constant speed value of air flow around stand
						2.2.3.2.	Air humidity		
						2.2.3.3.	Air flow		
3.	Vector S(t)	3.1.	Surface wave					Waves enable the research of adhesive bonds	Surface wave sensors in a percolating technology and longitudinal wave sensor in an echo-technology
		3.2.	Longitudinal wave						
		3.3	Other	3.3.1.	Change of signal's phase by reflection			Change of longitudinal wave phase at coating indicates losses of coating adhesion	Stand's project focused on possibility of measurements with longitudinal wave sensor on the side of adhesive coating
				3.3.2.	Change of coating thickness			Measurement of coating thickness with leptoskop allows to find deadhesions of coating	Stand's project focused on possibility of thickness measurements with leptoskop on the side of adhesive coating
4.	Vector Z(t)	4.1.	Distraction of input parameters	4.1.2.	Parameters instability on mechanical loadings			Instability of enforcement conditions may cause changes in degradation process	Continuous monitoring of amplitude value, vibration frequency, temperature, humidity and air flow speed
		4.2.	Distraction of diagnostic symptoms	4.2.1.	Influence of measurement elements			Any replacement in the equipment influences on results	Research made in whole on one selected and completed set of equipment
				4.2.2.	Influence of indicators affecting on ultrasonic parameters			Influence of indicators shown in fig. 2.31, especially defectoscope parameters and acoustic coupling	Research made by constant equipment parameters, assurance of acoustic coupling stability between ultrasonic sensors and substrate with strong neodymium magnets

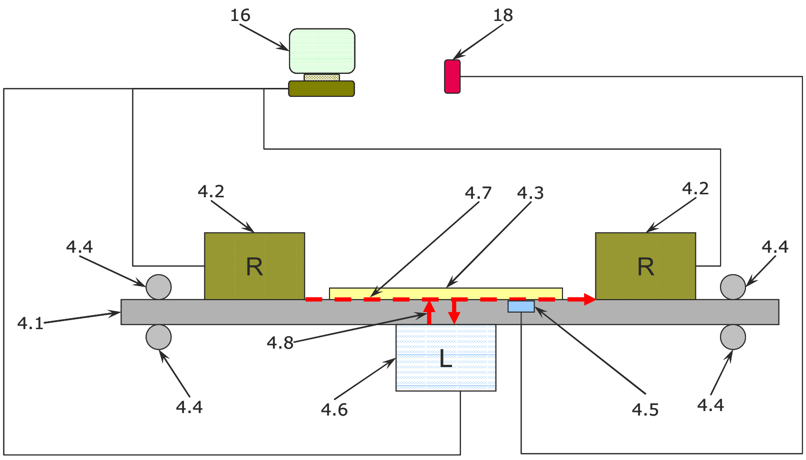

Fig. 2. Test sample and load system: 4.1 – slat, 4.2 – sensor of surface wave, 4.3 – coating, 4.4 – support, 4.5 – thermocouple, 4.6 – sensor of longitudinal wave, 4.7 – surface wave, 4.8 – ultrasonic longitudinal wave, 16 – ultrasonic flaw detector, 18 – digital multimeter I

Tab. 2. Test stand's research in the field of its proprietorial action

No.	Name	Description
1	Dynamic stability of stand's operation	Setting of the value's change for chosen magnitudes in a given operating time frame
2	Static stability of the acoustic coupling of ultrasonic sensors	Parameter's value setting for ultrasonic surface wave and for longitudinal wave on the sample No. 1 (according to PN-EN 12223)
3	Dynamic stability of the acoustic coupling of ultrasonic sensors	Setting of the parameter's value change for ultrasonic surface wave and for longitudinal wave in a given operating time frame

A sample with a propping up-, loading and measuring system marked with a short chain line (4) in the fig. 1 is shown in detail in the fig. 2. The sample fixed in supports (4.4) includes a metallic slat (4.1) covered with a coating (4.3). To the sample are fixed three sensors that are connected to an ultrasonic flaw detector (16).

Sensors of the ultrasonic surface wave (4.2), that work in a transverse technique, send out and receive a surface wave propagating along the bond's board (4.7) and a sensor of longitudinal wave (4.6), that works in the echo technique, enables creation of the wave as well as its reception after the wave is reflected from the bond board between a substrate and a coating (4.8). A thermocouple (4.5) and a digital multimeter I (18) allow to control the temperature of the bond between the substrate and the coat.

3. Project's profile and testing research

The operating stability of the stand allows to research a degradation process on a number of samples in the same recurrent conditions. An influence on the stand's operating stability have – first of all – components of input parameters vector *E(t)* and clutter vector *Z(t)*. Before the stand is used in the essential research, it is crucial to make some testing research on stand's appropriate operation in field of the operation stability of whole stand and the stability of the acoustic coupling between sensors and substrate (tab. 2).

4. Dynamic stability of stand's operation

The main goal of the research in the field of stand's dynamic operation stability is an assignment of the change in values of chosen parameters describing stand's operation and measurement system in the given period of time equal 300 minutes. There are registered values of such stand's operation parameters like: tension (voltage) and frequency of the power supplying signal for the generator, the temperature on the external and internal surface of the stand, the temperature of the generator's and metallic slat surface, external and internal air humidity, the temperature and flow speed of the air.

The research is completed with non-coated metallic slat fixed to the stand. Ultrasonic sensors are fixed to the slat with silicone glue to avoid an influence of the acoustic coupling change between the sensors and the substrate. Measurements are completed by power tension (voltage) U_z = 3 V and frequency f_z = 25 Hz in 20 minute intervals without stopping the stand.

Results of the research in the form of values' change of registered parameters are shown in the pictures 3 and 4.

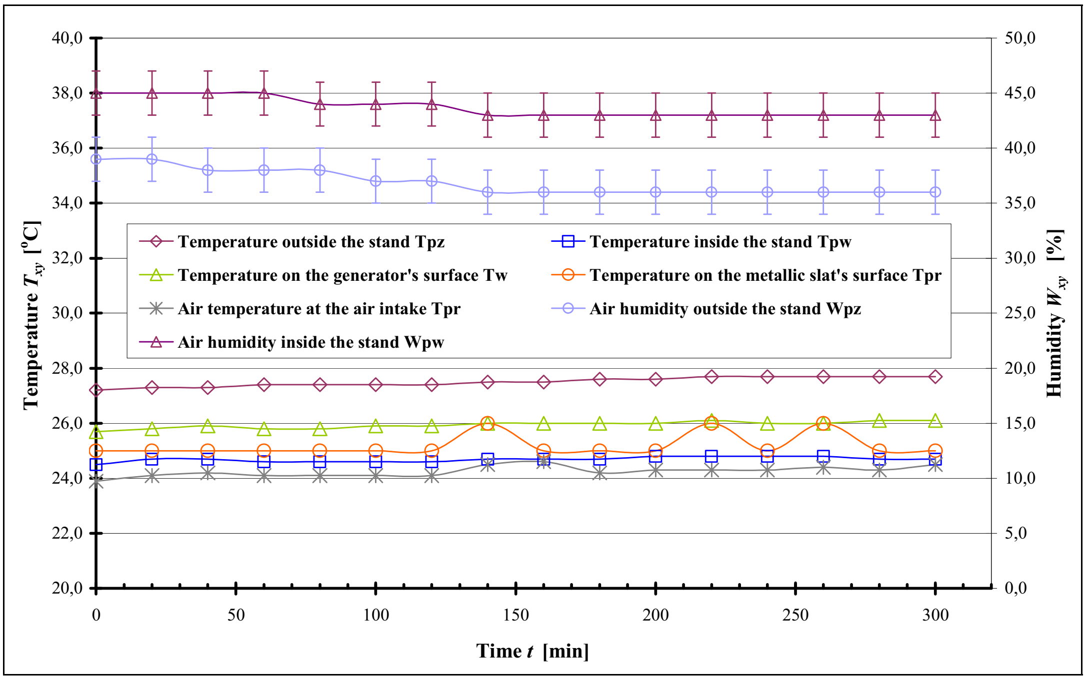

Fig. 3. Stability testing of the test stand – part 1

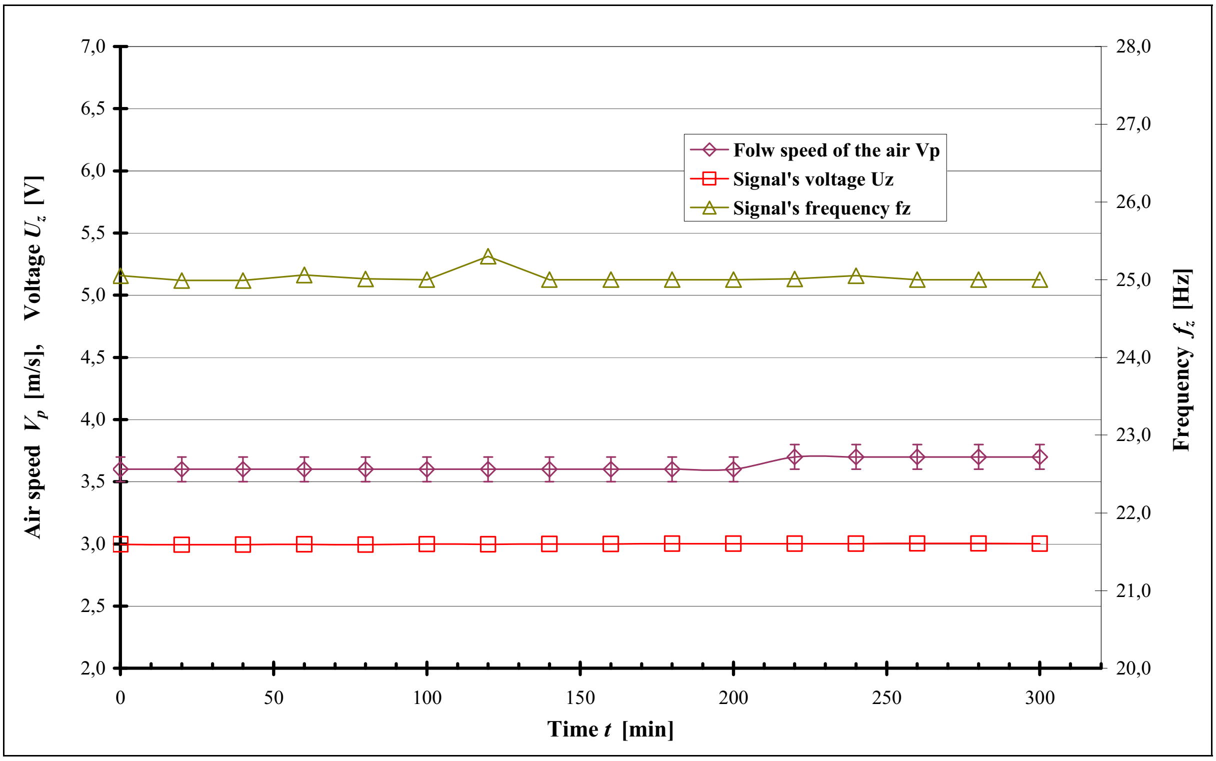

Fig. 4. Stability testing of the test stand – part 2

Tab. 3. Measurements results of the static stability of ultrasonic probe's coupling

No.	W_R [dB]	T_R [µs]	fr_R [MHz]	b_R [MHz]	W_L [dB]	T_L [µs]	fr_L [MHz]	b_L [MHz]	d_L [µs]
1	39,00	9,639	2,18	0,77	35,75	8,556	9,56	1,52	0,78
2	38,75	9,639	2,18	0,84	35,75	8,556	9,56	1,52	0,78
3	38,50	9,611	2,18	0,84	35,50	8,556	9,56	1,52	0,78
4	38,25	9,111	2,18	0,84	35,75	8,556	9,56	1,62	0,78
5	38,00	9,639	2,18	0,84	35,75	8,556	9,56	1,62	0,78
6	38,75	9,611	2,18	0,84	35,75	8,556	9,56	1,55	0,78
7	38,75	9,639	2,18	0,77	36,00	8,556	9,56	1,55	0,78
8	39,25	9,111	2,18	0,84	35,75	8,556	9,56	1,55	0,78
9	38,25	9,639	2,18	0,77	35,50	8,556	9,56	1,55	0,78
10	38,75	9,639	2,18	0,84	35,75	8,556	9,56	1,55	0,78
average	**38,625**	**9,5278**	**2,180**	**0,819**	**35,725**	**8,5560**	**9,560**	**1,555**	**0,780**
standard deviation	0,38	0,22	0,00	0,03	0,14	0,00	0,00	0,04	0,00
clutter coefficient	0,98	2,31	0,00	4,13	0,40	0,00	0,00	2,37	0,00

Legend:		Measurement error:
W_R [dB]	Gain of the surface wave on increased impulse of 0,4 H	+/- 0,25 dB
T_R [us]	Propagation time for a surface wave	+/- 0,03 us
fr_R [MHz]	Resonant frequency of surface wave spectrum	+/- 0,01 MHz
b_R [MHz]	Band of surface wave spectrum	+/- 0,01 MHz
W_L [dB]	Gain of the longitudinal wave	+/- 0,25 dB
T_L [us]	Propagation time of longitudinal wave on increased impulse of 0,4 H	+/- 0,03 us
fr_L [MHz]	Resonant frequency of longitudinal wave spectrum	+/- 0,01 MHz
b_L [MHz]	Band of longitudinal wave	+/- 0,01 MHz
d_L [us]	Approach zone length of longitudinal wave	+/- 0,03 us

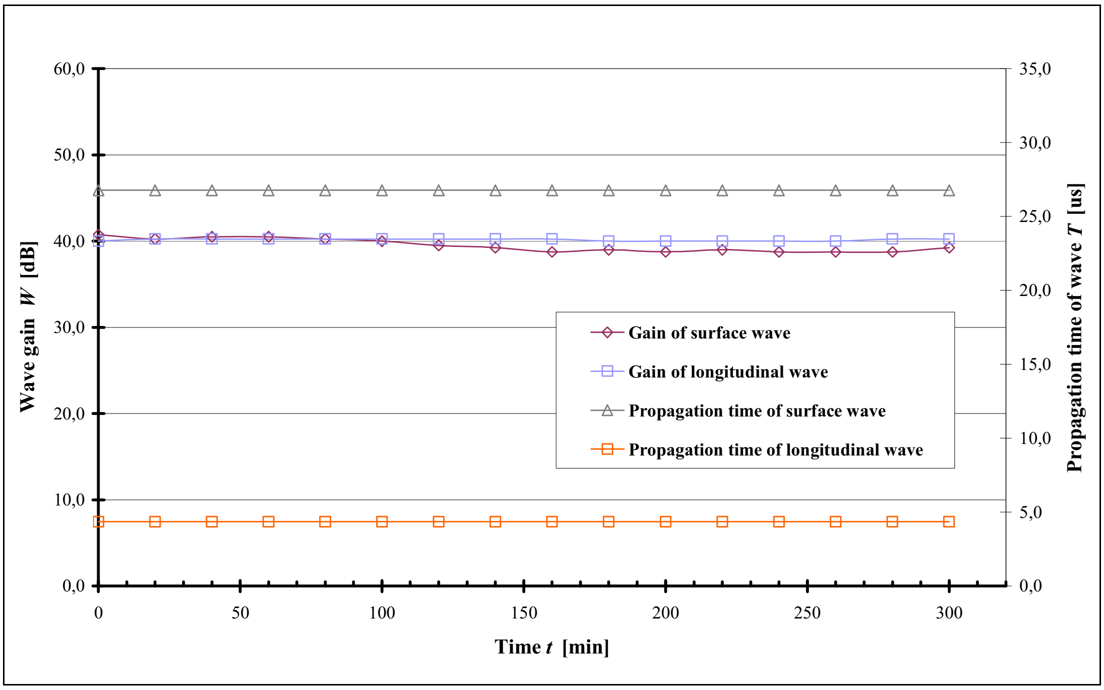

Fig. 5. Measurements results of the dynamic stability of ultrasonic probe's coupling – part 1

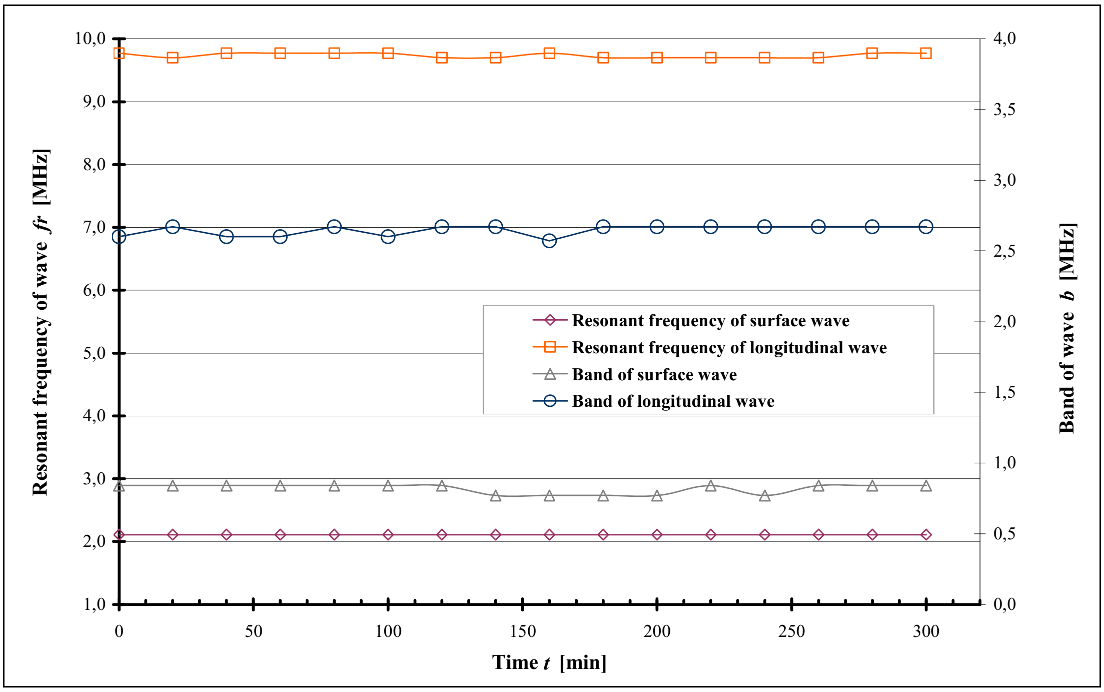

Fig. 6. Measurements results of the dynamic stability of ultrasonic probe's coupling – part 2

5. Static stability of the acoustic coupling of ultrasonic sensors

Despite the progress in the field of ultrasonic research, providing the researched environment with a constant and recurrent acoustic coupling between ultrasonic sensor and a researched object is still an important challenge that must be faced in practice while carrying out the researches. A research execution on the ferromagnetic surfaces allow to get a relatively constant clamp force to the substrate with magnets firmly fixed to the sensors [2]. Ultrasonic sensors have strong neodymium magnets glued to the external surface of the case. Usage of neodymium magnets requires first of all an effectiveness test of the solution by the testing of a coupling constancy in static conditions. According to PN-EN 12223 for this porpoise is used a normalized sample No. 1 [3]. To the sample surface, covered with a coupling gel Echotrace by K. Deutsch, are applied two sensors of surface wave fixed in a distance of 40 mm from each other and sensor of longitudinal wave. The sensors are separated from the substrate, the rest of coupling gel is removed from the substrate, the sensors are coated with new portion of coupling gel and fixed to the substrate again. Each time are measured following ultrasonic parameters' values: wave gain, time of wave propagation, resonant frequency and band of wave. For the sensor of longitudinal wave is measured in addition a time value of the wave propagation through the approach zone created by the protective layer of the sensor and the coupling gel. Measurements are repeated ten times and its results are shown in the table No. 3.

6. Dynamic stability of acoustic coupling of ultrasonic sensors

Considering a character of specified research planned on the stand, after the test of the acoustic coupling stability in constant conditions, it is tested in dynamic conditions as well. It is made a similar research to the one on static operating stability of the stand focused this time on registering parameters' values of ultrasonic waves (gain, propagation time, resonant frequency, band). The ultrasonic sensors are fixed to a metallic substrate with magnets and the coupling gel Echotrace by K. Deutsch. The research is made by the power voltage (tension) U_z=3V and frequency f_z=25 Hz in a period of time equal 300 minutes and the values of ultrasonic parameters are measured in 20 minute intervals. Registered values are shown in the fig. 5 and 6.

7. Results analysis and conclusions

Analysis of the dates shown in the fig. 4 and 5 points at value constancy of all supervised parameters while researching the dynamic operating stability of the stand. Detailed results registered in the research have values of the standard deviation within values of measurement errors.

The results of research on static and dynamic acoustic coupling stability of ultrasonic sensors have in most cases the value of the standard deviation comparable to the value of specified measurement errors and value of the coefficient of variation not higher than 4,5 %. Constant values of propagation time through the approach zone for the longitudinal wave (table 3) confirm that between a sensor and a substrate, thanks to the strong magnets, is settled each time a gel coating of a constant thickness. While completing the measurements in the dynamic conditions it is found as possible to continue the research without switching off the operating electrodynamics' generator. It seems to be helpful by setting the guidelines of the research proceeding at the stand.

An acoustic coupling of sensors and a sample substrate, while research on dynamic stability of the stand and research on dynamic stability of acoustic coupling, is provided with the silicone and gel. The other indicators are at the same level. Silicone suppresses the wave in a higher degree, what results in a higher gain values of surface wave (at above 13 dB) as well as of longitudinal wave (at above 8 dB) in comparison to values registered, while research with iron as a coupling substance. A thicker coupling layer of silicone causes an increase of transition time of surface and longitudinal wave impulse.

On the ground of analysis above can be stated the following:

- Drafted and constructed stand for the research of degradation process of the bond meets all posted methodical requirements.
- The stand assures a high operating stability of loading and measurement systems.
- A type of acoustic coupling between a sensor and a substrate influences on parameters values of ultrasonic wave.

There are premises to take into consideration a possibility of implementation of the stand to the researches on degradation process of bonds between coating and substrate. The results of the test confirm that the creation of recurrent conditions for research of samples' degradation is successful. As recurrent conditions should be implied i.a. constant acoustic coupling value that allows to confront detailed results of the research.

8. References

[1] Mańczak R., Jósko M.: Methodology and station for degradation's evaluation of adhesive bonds type coating-substrate – part 1. Journal of Research and Applications in Agricultural Engineering, 2012, vol. 57 (1), s. 105-108.

[2] http://www.ultra.wroclaw.pl.

[3] PN-EN 12223.

METODYKA I STANOWISKO DO BADAŃ DEGRADACJI POŁĄCZEŃ ADHEZYJNYCH TYPU POWŁOKA-PODŁOŻE. CZĘŚĆ 2.

Streszczenie

W artykule zaprezentowano projekt i wykonanie stanowiska do badań degradacji adhezyjnych połączeń powłok z podłożem. Stanowisko poddano badaniom stabilności pracy w warunkach dynamicznych. Zweryfikowano także stabilność sprzężenia akustycznego między głowicami ultradźwiękowymi a podłożem. Uzyskane rezultaty potwierdziły spełnienie przez stanowisko założeń metodycznych oraz jego przydatność do prowadzenia badań degradacji połączenia adhezyjnego typu powłoka-podłoże.

Słowa kluczowe: *stanowisko badawcze, degradacja, adhezja, fala ultradźwiękowa*