

Determination of the Dynamic Modulus of Linear Deformations of Reinforced Highly Filled Polymer Concrete Composites During Curing

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Abstract. The objects of this study are reinforced polymer concrete composites with epoxy matrix and mineral dispersion fillers. Dynamic modulus of linear deformations has been measured according the standardized dynamic testing method ASTM E1876 - 02. The quantitative values of the modulus are obtained by the action of longitudinal and bending. After statistical processing of the obtained results has been established the influence of fiber in the composition on the dynamic characteristic.

Keywords: vibrations, dynamic, epoxy based concrete, high strength polymer concrete, fillers, reinforced.

I. INTRODUCTION

Polymer concrete (PB) composites are widely used in engineering practice, as alternative materials for bodies and housings of metal-cutting machines. The application of these composites as alternative non-metallic structural materials is an innovative activity that creates prerequisites for improving technical and operational qualities of the manufactured machines and devices such as:

- Static and dynamic stability;
- Thermal behavior;
- Corrosion resistance;

The epoxy-based PB composite used in this study has high strength and good wear resistance, sliding property, and UV stability [1]-[6]. In recent years, the use of organic and inorganic fillers, as well as waste up to 5%, has been

observed in polymer concrete to improve and modify its properties [8]-[12]. The article has an experimental focus and its main goals are:

- determining the influence of the amount of fibers on the dynamic modulus of linear deformations.
- study on change of the dynamic modulus of linear deformations during the curing of PB composites.

The composites were manufactured and tested in the laboratories of TU-Sofia, branch Plovdiv.

II. MATERIALS AND METHODS

Determination of the dynamic modulus of linear deformations due to longitudinal and flexural fundamental freely damped oscillations.

The specimen is placed on prismatic supports clamped immovably to a base. The supports are located at a distance of 0.224l from both ends of the specimen, according to ASTM E1876-15 [7]. Impulse dynamic impact is applied to the beam with an exciter -type impact hammer, Fig.1. In this way, model of an oscillating dynamic system with distributed parameters is created.

Print ISSN 1691-5402

Online ISSN 2256-070X

<https://doi.org/10.17770/etr2023vol3.7296>

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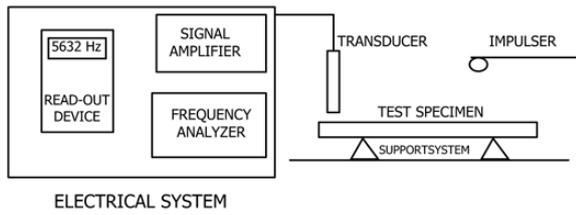


Fig. 1. Vibration test setup.

The dynamic modulus is defined as follows:

$$E_D = 0.9465(mf_f^2 / b)(l^3 / h^3)T_1 \quad (1)$$

where:

- E_D - dynamic modulus of Young;
- m - beam mass;
- b - beam width;
- l - beam length;
- h - beam thickness;
- f_f - Fundamental flexural resonance frequency

Fig.2 ;

T_1 - Correctional coefficient.

$$T_1 = \frac{1.000 + 6.585(1 + 0.0752\mu + 0.8109\mu^2)(h/l)^2 - 0.868(h/l)^4 - 8.340(1 + 0.2023\mu + 2.173\mu^2)(h/l)^4}{1.000 + 6338(1 + 0.1408\mu + 1.536\mu^2)(h/l)^2} \quad (2)$$

where:

μ - Coefficient of Planck

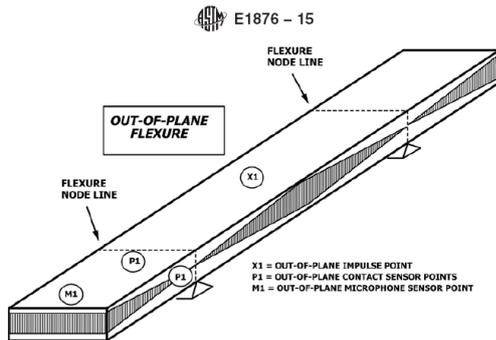


Fig. 2. Measurement of the vibrations of torque.

Determination of dynamic modulus from due to longitudinal free damped vibrations :

The specimen is placed on prismatic supports clamped immovably to a base. At one end of the beam, a frontal impulse dynamic impact is applied, and on the opposite side, the frontal response is measured using a microphone, Fig.3. In this way, longitudinal free damping oscillations are realized. The dynamic modulus of elasticity E_I will be determined according to the formula:

$$E_I = 4f_l^2 l^2 \rho_o \quad (3)$$

where:

- f_l - fundamental frequency in longitudinal vibrations
- l - length of a sample
- ρ_o - density of a sample

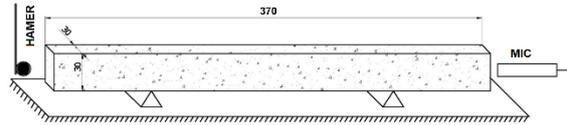


Fig. 3. Longitudinal vibration reasearch setup.

The experimental samples have a shape of a rectangular parallelepiped (beam type) with dimensions 30x30x370mm, Fig.3. They comply to the generally accepted standardization norms for polymer concrete samples. The number of PB compositions is 3, for which a total of 9 test bodies were cast (3 pieces of each composition). A vibration stand with an inverter control was used during casting, Fig.4. The samples have been vibrated for 20 min.



Fig. 4. Vibration stand.

The mold for casting the test samples is three-nested, detachable, made of wood material, Fig.5. To eliminate random errors, the equipment allows simultaneous receipt of three test samples from one PB composition.



Fig. 5. Casting shape type b.

The total amount of the mixture is taken equal to unity (or 100%), and is a part of the I component in the mixture. The components meet the following conditions:

$$X_1 + X_2 + X_3 + X_4 = 100\% \quad (4)$$

The following materials for the individual components are used:

X_1 - binder – epoxy resin

X_2 - fine filler - quartz flour;

X_3 -, PP Fibers M12 ;

X_4 - granular filler – fine and course sand.

TABLE 1 COMPONENTS

N _o	X1	X2	X3	X4
4	16%	3.5%	0.3%	80.2%
5	16%	3.5%	0.0%	80.5%
6	16%	3.5%	0.7%	79.8%

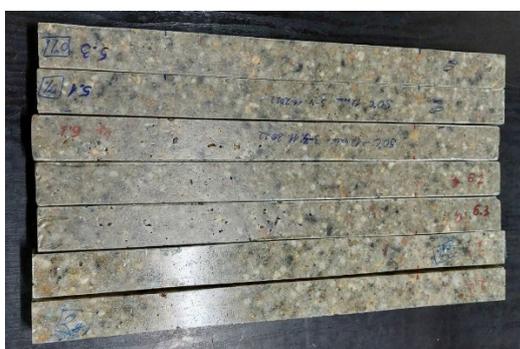


Fig. 6. PB samples.

The mass of the PB samples, Fig. 6, was measured using an electronic balance, Fig. 7 with an accuracy of 1g.



Fig. 7. Electronic balance.

III. RESULTS AND DISCUSSION

Fig. 8 shows the experimental setup for determining the two types of dynamic modules.



Fig. 8. Experimental set up.

The data about the value of the frequencies necessary for the calculation of the modules is obtained from the autospectral characteristic, Fig.9-10.

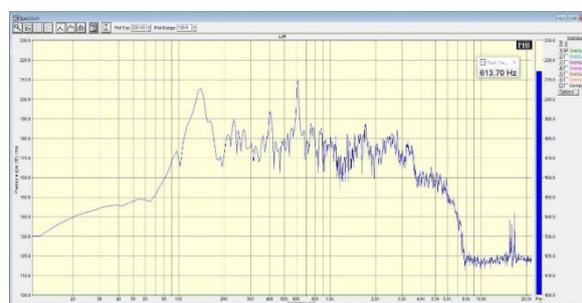


Fig. 9. Flexural spectral analysis of 5.3 day 120.



Fig. 10. Longitudinal spectral analysis of 5.3 day 120.

The obtained experimental results for the modulus of linear deformations are structured in tabular form. Table 2 presents the results of testing of sub-base 6 on longitudinal and flexural vibrations. Accordingly, Tables 3 and 4 present another results for the 5th and 6th sample.

TABLE 2 EXPERIMENTAL RESULTS

	N _o	f_l [Hz]	f_f [Hz]	E_l [Pa]	E_f [Pa]
Day 2	6.1	4107	533	1.78E+10	1.18E+10
	6.2	4112	608	1.79E+10	1.55E+10
	6.3	4032	538	1.72E+10	1.20E+10
Day 8	6.1	4200	581	1.87E+10	1.40E+10
	6.2	4360	570	2.01E+10	1.37E+10
	6.3	4280	592	1.94E+10	1.46E+10
Day 13	6.1	4263	603	1.92E+10	1.51E+10
	6.2	4374	576	2.02E+10	1.39E+10
	6.3	4322	597	1.98E+10	1.48E+10
Day 21	6.1	4235	581	1.90E+10	1.40E+10
	6.2	4363	570	2.01E+10	1.37E+10
	6.3	4321	592	1.98E+10	1.46E+10
Day 120	6.1	4242	589	1.90E+10	1.44E+10
	6.2	4333	570	1.99E+10	1.37E+10
	6.3	4274	597	1.93E+10	1.48E+10

TABLE 3 EXPERIMENTAL RESULTS

	ξ_i	f_l [Hz]	f_f [Hz]	E_l [Pa]	E_f [Pa]
Day 2	5.1	4608	608	2.25E+10	1.54E+10
	5.2	4635	603	2.27E+10	1.53E+10
	5.3	4591	603	2.23E+10	1.51E+10
Day 8	5.1	4613	614	2.25E+10	1.57E+10
	5.2	4656	608	2.29E+10	1.56E+10
	5.3	4618	608	2.26E+10	1.54E+10
Day 13	5.1	4586	608	2.23E+10	1.54E+10
	5.2	4700	614	2.34E+10	1.58E+10
	5.3	4672	614	2.31E+10	1.57E+10
Day 21	5.1	4618	614	2.26E+10	1.57E+10
	5.2	4688	614	2.32E+10	1.58E+10
	5.3	4665	614	2.30E+10	1.57E+10
Day 120	5.1	4595	614	1.57E+10	2.23E+10
	5.2	4667	608	1.56E+10	2.30E+10
	5.3	4646	614	1.57E+10	2.28E+10

TABLE 4 EXPERIMENTAL RESULTS

	ξ_i	f_l [Hz]	f_f [Hz]	E_l [Pa]	E_f [Pa]
Day 2	4.1	4175	600	1.88E+10	1.50E+10
	4.2	4189	608	1.87E+10	1.56E+10
	4.3	4177	603	1.87E+10	1.51E+10
Day 8	4.1	4197	603	1.86E+10	1.51E+10
	4.2	4185	608	1.86E+10	1.56E+10
	4.3	4187	608	1.85E+10	1.54E+10
Day 13	4.1	4245	600	1.91E+10	1.50E+10
	4.2	4247	608	1.91E+10	1.56E+10
	4.3	4245	608	1.91E+10	1.54E+10
Day 21	4.1	4253	603	1.91E+10	1.51E+10
	4.2	4237	608	1.90E+10	1.56E+10
	4.3	4274	609	1.93E+10	1.54E+10
Day 120	4.1	4247	602	1.91E+10	1.51E+10
	4.2	4242	608	1.90E+10	1.55E+10
	4.3	4265	608	1.92E+10	1.54E+10

TABLE 5 CHANGA OF THE MODULUS

	Longitudinal			Flexural		
	6.1	6.2	6.3	6.1	6.2	6.3
Day 2	1.78E+10	1.79E+10	1.72E+10	1.18E+10	1.55E+10	1.20E+10
Day 8	1.87E+10	2.01E+10	1.94E+10	1.40E+10	1.37E+10	1.46E+10
Day 13	1.92E+10	2.02E+10	1.98E+10	1.51E+10	1.39E+10	1.48E+10
Day 21	1.90E+10	2.01E+10	1.98E+10	1.40E+10	1.37E+10	1.46E+10
Day 120	1.90E+10	1.99E+10	1.93E+10	1.44E+10	1.37E+10	1.48E+10
Delta	7.7%	13.1%	14.9%	28.0%	13.8%	23.1%
	11.93%			21.63%		

TABLE 6 CHANGING OF THE MODULUS

	Longitudinal			Flexural		
	4.1	4.2	4.3	4.1	4.2	4.3
Day 2	1.84E+10	1.86E+10	1.85E+10	1.50E+10	1.56E+10	1.51E+10
Day 8	1.86E+10	1.85E+10	1.85E+10	1.51E+10	1.56E+10	1.54E+10
Day 13	1.91E+10	1.91E+10	1.91E+10	1.50E+10	1.56E+10	1.54E+10
Day 21	1.91E+10	1.90E+10	1.93E+10	1.51E+10	1.56E+10	1.54E+10
Day 120	1.91E+10	1.90E+10	1.92E+10	1.51E+10	1.55E+10	1.54E+10
Delta	3.8%	3.0%	4.7%	0.9%	0.0%	1.9%
	3.8%			0.93%		

TABLE 7 CHANGING OF THE MODULUS

	Longitudinal			Flexural		
	5.1	5.2	5.3	5.1	5.2	5.3
Day 2	2.25E+10	2.27E+10	2.23E+10	1.54E+10	1.53E+10	1.51E+10
Day 8	2.25E+10	2.29E+10	2.26E+10	1.57E+10	1.56E+10	1.54E+10
Day 13	2.23E+10	2.34E+10	2.31E+10	1.54E+10	1.58E+10	1.57E+10
Day 21	2.26E+10	2.32E+10	2.30E+10	1.57E+10	1.58E+10	1.57E+10
Day 120	2.23E+10	2.30E+10	2.28E+10	1.57E+10	1.56E+10	1.57E+10
Delta	1.4%	2.8%	3.6%	1.8%	3.6%	3.6%
	2.59%			3.00%		

As can be seen from the obtained experimental results in the tables above, the modulus of PB composites was tested at 2, 8, 13, 21, 120 days.

The percentage change of the modulus of linear deformations during the curing of the samples was calculated. The results are tabulated in Tables 5-7.

For a better visualization of, the results are presented graphically, Fig.11 -16.

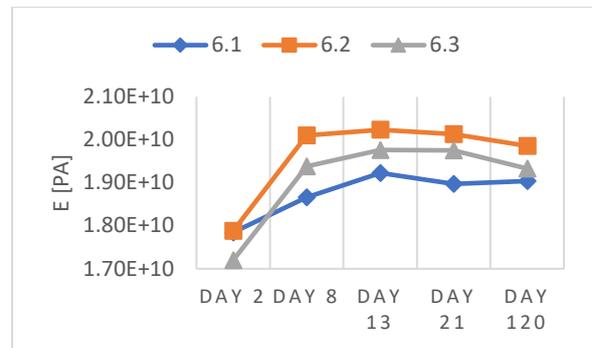


Fig. 11. Results of the modulus by longitudinal vibrations.

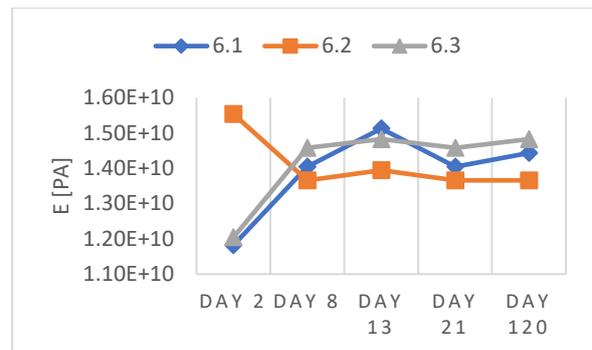


Fig. 12. The results of the modulus by flexural vibrations.

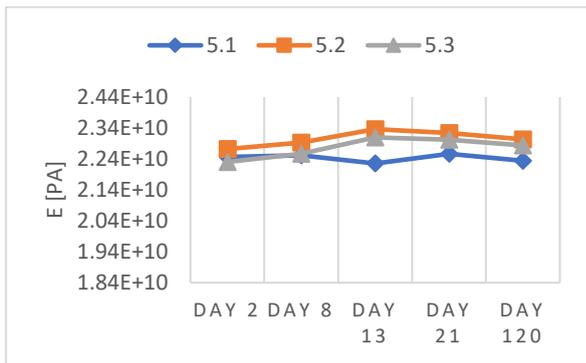


Fig. 13. The results of the modulus by longitudinal vibrations.

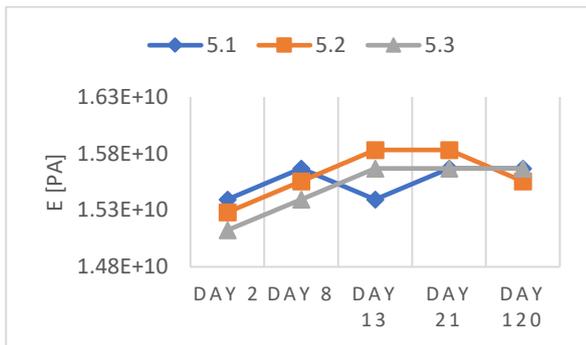


Fig. 14. The results of the modulus by flexural vibrations.

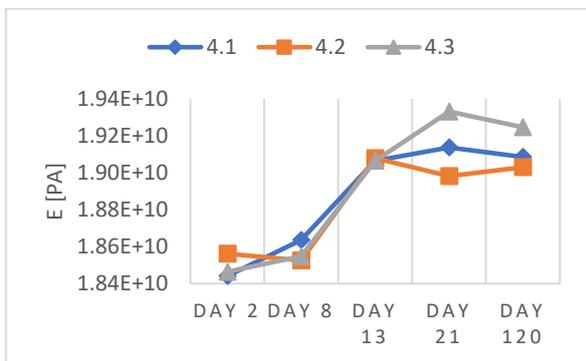


Fig. 15. The results of the modulus by longitudinal vibrations.

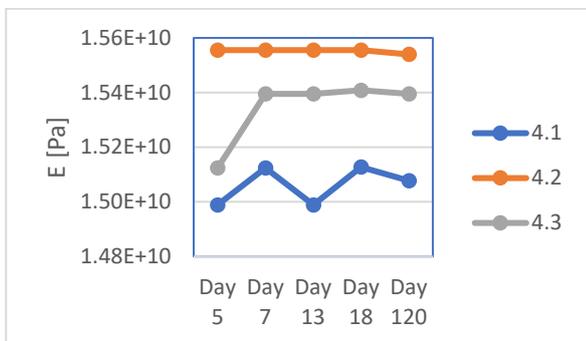


Fig. 16. The results of the modulus by flexural vibrations.

Using the Minitab software, the influence of the fibers used for reinforcement on the modulus of linear deformations was analyzed. The obtained results of the analysis are presented below.

Regression Analysis: E_l versus Filler

Regression Equation

$$E_l = 2.2767 - 0.2933 \text{ Filler} + 0.05083 \text{ Filler*Filler}$$

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	2.2767	0.0180	126.83	0.000	
Filler	-0.2933	0.0229	-12.82	0.000	13.00
Filler*Filler	0.05083	0.00550	9.25	0.000	13.00

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0310913	97.95%	97.27%	95.39%

Analysis of Variance

Source	DF	Seq SS	Seq MS	F-Value	P-Value
Regression	2	0.277089	0.138544	143.32	0.000
Filler	1	0.194400	0.194400	201.10	0.000
Filler*Filler	1	0.082689	0.082689	85.54	0.000
Error	6	0.005800	0.000967		
Total	8	0.282889			

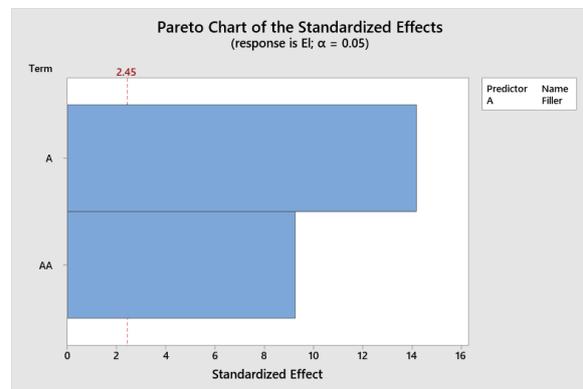


Fig. 17. Influence of fibres on a modulus during bending vibrations.

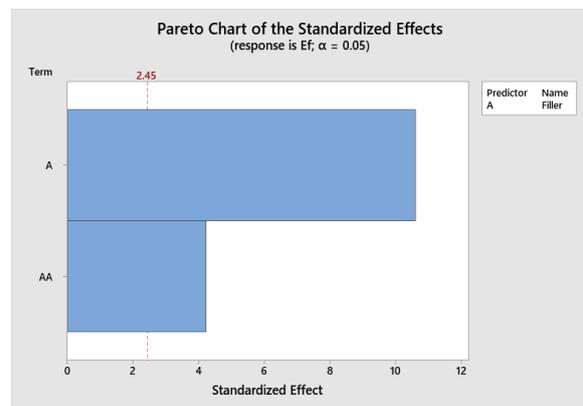


Fig. 18. Influence of fibres on the modulus by flexural vibrations.

Regression Analysis: E_f versus Filler

Regression Equation

$$E_f = 1.5567 + 0.0142 \text{ Filler} - 0.01292 \text{ Filler*Filler}$$

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	1.5567	0.0100	155.67	0.000	
Filler	0.0142	0.0127	1.11	0.309	13.00
Filler*Filler	-0.01292	0.00306	-4.22	0.006	13.00

Model Summary			
S	R-sq	R-sq(adj)	R-sq(pred)
0.0173205	95.60%	94.13%	90.10%

Analysis of Variance					
Source	DF	Seq SS	Seq MS	F-Value	P-Value
Regression	2	0.039089	0.019544	65.15	0.000
Filler	1	0.033750	0.033750	112.50	0.000
Filler*Filler	1	0.005339	0.005339	17.80	0.006
Error	6	0.001800	0.000300		
Total	8	0.040889			

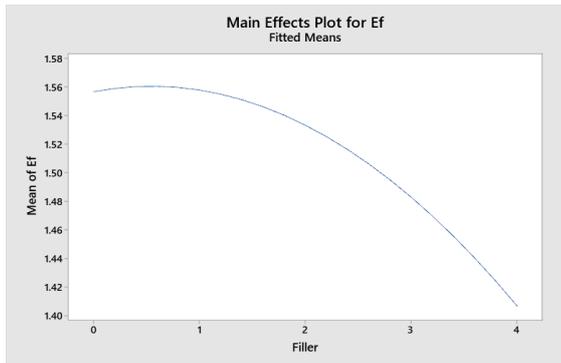


Fig. 19. Influence of fibres on the modulus by flexural vibrations.

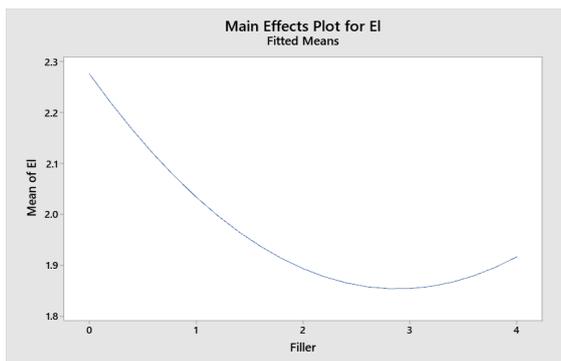


Fig. 20. Influence of fibres on the modulus by longitudinal vibrations.

IV. CONCLUSIONS

The results of the present work are as follow:

- A standard methodology was used for the quantitative determination of the modulus of linear deformations of PB compositions.
- A laboratory equipment that ensures the research has been designed and manufactured
- Based on the obtained experimental results from the reports and the performed analysis, it was established that as the number of fibres increases, the dynamic modulus decreases.

An analysis of the experimental results shows a change in the values of the modulus during curing change as follows:

- Composition 4 with 2g of fibers for reinforcement – 3,8 - 4,7%.
- Composition 5 with 0g fiber for reinforcement – 1-3%.

- Composition 6 with 4g fiber for reinforcement - 12-21.5%.

The dynamic modulus of elasticity during curing of polymer concrete has not been studied in the literature. Modulus of elasticity in other investigations is in the range $10 \div 40 \text{ GPa}$, [13]-[21].

During the curing of PB composition 4 and 5, it may be assumed that the modulus remains constant and deviation of 1 - 3% - is a measurement error.

The possibilities of obtaining reliable information about the modules for this type of composites with the proposed methodology and measuring equipment are real and adequate.

V. ACKNOWLEDGMENTS

The scientific research, the results of which are presented in the paper, was financed by project BG05M2OP001-1.002-0023 - Competence Center "Intelligent Mechatronic, Eco- and Energy-Saving Systems and Technologies" of Technical University of Sofia, branch Plovdiv.

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