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DEVELOPMENT AND ANALYSIS OF THE DESIGN OF AN INNOVATIVE HYDRAULIC CONCRETE MIXER WITH A CAPACITY OF 9 m^3

OPRACOWANIE I ANALIZA PROJEKTU INNOWACYJNEJ BETONOMIESZARKI HYDRAULICZNEJ O POJEMNOŚCI 9 m^3

Summary: *An innovative structure of a road concrete mixer with a capacity of 9 m^3, with the reduced weight, control and measurement system and an innovative modular aerodynamic cover of the front bracket was developed and analysed. The research work included the design of the structure, numerical analysis, bench tests in laboratory conditions and operational tests in real conditions.*

Keywords: *hydraulic concrete mixer truck, own bodywork, aerodynamic cover of the front bracket, control and measurement system*

Streszczenie: *Opracowano i poddano analizie innowacyjną konstrukcję betonomieszarki samochodowej o pojemności 9 m^3, o zmniejszonej masie, z układem kontrolno-pomiarowym oraz innowacyjną modułową osłoną aerodynamiczną wspornika przedniego. Prace badawcze obejmowały projekt konstrukcji, analizę numeryczną, badania stanowiskowe w warunkach laboratoryjnych oraz badania eksploatacyjne w warunkach rzeczywistych.*

Słowa kluczowe: *betonomieszarka hydrauliczna, zabudowa własna, osłona aerodynamiczna wspornika przedniego, układ kontrolno-pomiarowy*

Introduction

The publication describes the result of a complex process of research included in the project entitled "Construction of a 9 m^3 truck concrete mixer with advanced design and innovative functional solutions", with the number POIR.01.01.01-00-1738/20.

The motivation to undertake this research work was the dynamic development of the construction industry, and above all the branches of industry including the production of specialized vehicles as well as machinery and equipment employed in the construction industry, which was widely reflected in the published optimistic forecasts for the construction and investment market. Therefore, the complex process of analysing the state of the issue and inventorying the existing construction and material solutions in the area of hydraulic concrete mixers was carried out, on the basis of which the area and scope of improvement of the key functionalities of the concrete mixer's own construction was determined owing to the application of original innovative solutions.

The innovative development project was developed [1, 3, 4, 6, 7, 9] and subjected to preliminary verification by means of numerical FEM and CFD analysis [2, 11]. The results of the numerical research provided the basis for the production of test models of the bodywork, which were subjected to a complex process of bench tests in laboratory conditions using a dedicated specialized test stand.

The last stage of the research was operational tests in real conditions carried out for the prototypes of innovative mixers produced on the basis of the results of the above-mentioned research works, which were placed on the chassis of specialized vehicles rented for this purpose for hydraulic concrete mixers with a capacity of 9 m^3.

Concept, design and numerical analyses of innovative construction of concrete mixer

The analysis of the condition of the issue and the review of the materials that can be applied, including primarily sheets and profiles made of specific metal alloys, resulted in the design of innovative key elements of the bodywork, i.e. the supporting frame, brackets – front and rear, mixer drum with a mixing and unloading spiral and other necessary components. A complex exploration of CAD models according to the design assumptions was carried out in order to develop the resulting structure of the complex development. A visualization of the original solution is shown in Figure 1.

Fig. 1. Visualization of the innovative construction of the concrete mixer

The developed CAD models of the key components of the bodywork, i.e. frame, brackets and drum, were subjected to a numerical analysis of stress distribution using the finite element method (FEM) [2] – Figure 2.

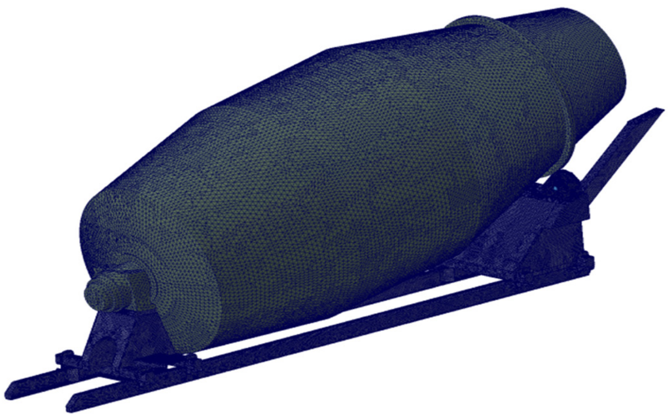

Fig. 2. FEM model of the innovative construction of concrete mixer

The results of the FEM analysis in the form of key parameters, i.e. reduced stresses, safety factor and displacement, confirmed the possibility of producing test models for bench tests according to selected construction and material variants [2].

In parallel, a previously unused modular system of an innovative aerodynamic cover for the front bracket was developed – the visualization is shown in Figure 3.

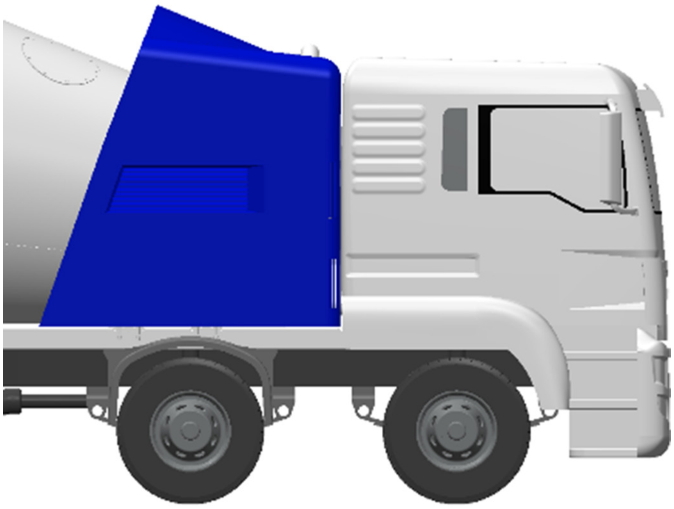

Fig. 3. Visualization of the innovative aerodynamic cover of the front bracket of the mixer body work

The new functionalities of the cover include an increase in the operational safety of the concrete mixer through adequate insulation of the area of the complex hydraulic drive system of the mixer drum, improved a aesthetics, the so-called vehicle design in line with contemporary trends, including references to the current appearance of trucks, and above all, improving the ai resistance coefficient and, consequently, reducing fuel consumption [12, 13].

The developer solution was verified during CFD numerical analysis – flow testing (Fig. 4) [11].

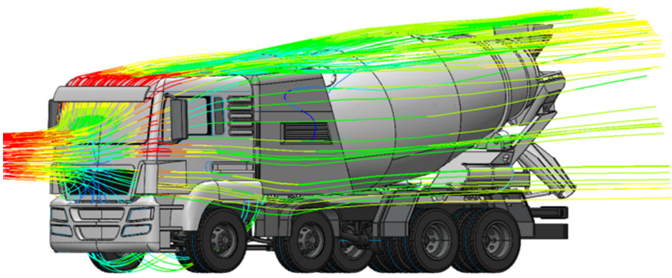

Fig. 4. Results of CFD analysis of a hydraulic road concrete mixer with a capacity of 9 m^3 with an innovative aerodynamic cover of the front bracket

The results determined by numerical CFD flow analysis showed a measurable improvement in the drag coefficient Cd in relation to the previously used standard body without the innovative aerodynamic cover of the front bracket – 0.87 for the vehicle with the cover and 0.92 for the standard body.

The results of the numerical research provided the basis for the development and production of real world research models of the innovative construction of the concrete mixer.

Stationary tests in laboratory conditions

The next stage of the work was the testing of innovative concrete mixers' construction produced on the basis of the above results on a dedicated, specialized test stand, developed for individual needs and according to the author's assumptions.

A complex series of bench tests made it possible to determine a number of individual values of functional parameters, selected at the design Assumption stage as key in the process of fatigue tests of the support frame, front bracket and rear bracket. A selected summary of results for the full t test cycle of a given body set is provided in Table 1.

Table 1. Selected summary of the results of field tests of innovative mixer construction

No.	Aggregate weight [t]	Number of Cycle Hours	Own body weight [kg]			
			strain gauge			
			1 Left front	2 Right front	3 Right rear	4 Left rear
1	0	5	977.91	1059.41	939.47	867.21
2	2	15	1473.86	1565.02	1444.64	1360.48
3	6	15	2470.35	2697.75	2440.82	2235.08
4	10	25	3397.48	3662.96	3519.31	3264.25
5	14	30	4323.58	4687.64	4594.81	4237.97
6	16	50	4657.59	5065.97	5272.75	4847.69

No.	Load [MPa]			
	strain gauge			
	1 Left front	2 Right front	3 Right rear	4 Left rear
1	9.23	9.99	8.86	8.18
2	13.90	14.76	13.63	12.83
3	23.31	25.45	23.03	21.09
4	32.05	34.56	33.20	30.79
5	40.79	44.22	43.35	39.98
6	43.94	47.79	49.74	45.73

No.	Axial run out [mm] Sensor position-tracking	Radial run out [mm]				Vibration level
		Sensor position				
		1 Anterior cone	2 Centre band	3 Neck cone	4 Mouth cone	
1	1.13	0.75	0.80	0.77	0.74	1.39
2	1.14	1.00	1.12	1.03	0.97	1.41
3	1.15	1.20	1.47	1.24	1.16	1.50
4	1.2	1.49	1.77	1.55	1.46	1.40
5	1.26	1.71	1.93	1.74	1.70	1.51
6	1.3	1.92	2.20	1.95	1.89	1.53

No.	Deflection [mm]			
	Sensor position			
	1 Anterior cone	2 Centre band	3 Neck cone	4 Mouth cone
1	0.00	0.00	0.00	0.00
2	1.40	1.60	1.49	1.33
3	2.42	2.77	2.58	2.30
4	3.70	4.23	3.94	3.52
5	5.13	5.86	5.46	4.87
6	6.15	7.03	6.55	5.84

Fig. 5. An example of the welded joint analysis process

The analysis of the results of the bench tests showed the improvement of the determined values of individual parameters in relation to the standard body subject to verification as part of the previous own works during the implementation of the commissioned service tasks. This includes radial run-out, axial run-out, and deflection, which can be determined in a standard service procedure. Many of the currently operated concrete mixer bodies subjected to the analysis were characterized by up to a dozen percent increase in the parameters in question. Therefore, it was found that the developed structural and material solutions of the body elements show, *inter alia*, an increase in mechanical strength and the associated extended service life.

During the bench tests, an advanced verification of the welded weld was also carried out in characteristic areas – stress concentrations determined by numerical FEM analysis – with the use of specialized equipment. No damage was found after the bench fatigue testing process, which also confirms the key assumptions of the project. An example of a weld seam analysis process is shown in Figure 5.

Bench tests in laboratory conditions – the determined results confirming the key assumptions of the project – resulted in a decision to carry out the last stage of work, i.e. the manufacturing and assembly of prototypes of innovative mixer bodies on the chassis of special vehicles in order to carry out a comprehensive series of operational tests in real conditions.

Operational tests in real conditions

Prototypes of the innovative own body were installed according to a standard procedure in a dedicated area of chassis of specialized vehicles – hydraulic concrete mixers trucks – Figure 6.

Fig. 6. Vehicle for operational testing of an innovative self-built mixer body work

The comprehensive operational tests in real conditions included the acquisition and analysis of the results of the tests in question based on the data from the test vehicle work cards, records from the installed measurement/control system and comments of the operators of the vehicles, as well as physical verification and assessment of the degree of wear in real conditions' operation.

The tests in the real conditions were carried out according to the assumed schedule, including, first of all, a specific number of man-hours for the selected concrete mixers, including the number of trips in full loading conditions, the number of loading/unloading processes, the type of transported material and its weight. It was assumed that the test vehicles should carry out their standard cycle of transporting the concrete mass, namely loading under the concrete plant, transport to the target construction site, unloading the concrete and returning to the base. At the same time, a minimum working time of 100 hours was determined in real conditions for each of the concrete mixers with innovative mixers.

The culmination of the operational tests were the final tests of the mixer prototypes on a specialized test stand in laboratory conditions – a detailed analysis of the degree of wear, including the measurements under the assumed load.

The results confirmed the achievement of the assumed objectives and provided the basis for the development of final conclusions.

Final conclusions

The implementation of a comprehensive test procedure for the innovative construction of the own hydraulic concrete mixer truck with a capacity of 9 m^3 made it possible to determine the key results, which unambiguously confirm the achievement of new functionalities *via* the application of construction and material solutions that have not been used so far in the area before the subject.

The developer solution showed a reduction in weight and material consumption for the key components of the body, i.e. the support frame, front bracket and rear bracket at the level of 10.596% compared to the previously used standard body design. In addition, in the process of numerical analysis of the FEM stress distribution as well as bench and operational tests, an increase in the service life of the innovative development at the level of 18.8% was shown.

The last parameter, according to the project's assumptions, was the reduction of fuel consumption. Owing to the above-mentioned reduction of the curb weight of the body and the application of an innovative aerodynamic cover of the front bracket confirmed by the numerical CFD analysis, the level of reduction of fuel consumption by a specialized vehicle – a hydraulic concrete mixer equipped with an innovative bodywork at the level of 7.37% was achieved, which was finally confirmed in standard operating cycles carried out as a part of tests in real conditions.

Summary

The selected results of the research work prepared for the purposes of this publication, including the design and analysis of the structure of an innovative construction of an innovative hydraulic concrete mixer truck with a capacity of 9m^3, confirm the achievement of key parameters of milestones provided for the implemented project.

An innovative product has been developed with new functionalities resulting directly from the application of previously unused proprietary solutions in the field of building one's own concrete mixer. The above men-tioned parameters achieved in the course of the work are of key importance in both ecological and economic aspects for market recipients. Moreover, it should be emphasized that the application of the innovative aerodynamic cover of the front bracket measurably improves the aesthetics of the vehicle, bringing its external design closer to modern trucks.

Acknowledgements

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