DESIGN OF NON-METAL MOBILE WORKING MACHINE CABS

Miroslav VEREŠ - Martin TANEVSKI - Ján ŠEĎO
MECHANICAL ENGINEERING FACULTY OF
SLOVAK UNIVERSITY OF TECHNOLOGY BRATISLAVA,
SLOVAKIA

HU ISSN 1418-7108: HEJ Manuscript no.: MET-090212-A

Abstract

The design of mobile working machine (MWM) cabins (cabs) is unchanged for years. First used cabins were non-structural in combination with safety frame around it. Newer designs are ”self-protective”, where the safety construction is integrated within main frame of the cabin whereas conventional mechanical engineering materials are used in their production. These materials are weldable steels with sufficient strength to meet cabin safety standard requirements, coated with paint to protect cabin body from corrosion and to give recognition character to the machine. This concept is widely used until now.

The paper deals with usage of non-conventional materials in MWM cabin building in terms of mechanical and safety-, applicable-, utility-, production-, economical- and ecological-properties, and to compare it with conventional design. The project is applied to MWM universal loader/manipulator DETVAN HON 200, being developed at PPS Group Detva (Slovakia) company in cooperation with STU's Faculty of Mechanical Engineering in Bratislava (Slovakia).

Keywords: Mobile working Machine Cab, Laminate Cab, ROPS and FOPS tests

1 Introduction

For working machines is important their power, or quality and effective running, but at last time after death accidents is still more important their safety. The most of machine accidents were roll-over's. Machines 60 years ago were without cabs or any chassis over the operator. But the requirements on safety obligated machine designers to design some chassis for safety. It is called FOPS and ROPS. FOPS are falling object protective structures while ROPS roll over protective structures. For protection opposite atmospheric exposure designers have made whole cab with FOPS/ROPS. Some cabs have got extra FOPS/ROPS chassis. But they are used on forest machinery. The development of cabs today continues mostly by material progress. Almost every year arise new modification of material or whole new material. New trends of material progress come to synthetic materials, composites especially. For cabs are considerable polymer composites - laminates. So the development focuses to laminate cabs. We develop new earthmoving machine whole-laminate cab now, applied at HON 200 wheel loader.

2 PROJECT OF UNCONVENTIONAL-MATERIAL CAB

PPS Group j.s.c. Detva in association with Faculty of Mechanical Engineering of STU Bratislava, is currently preparing the re-launch of the successful hydraulic rotary loader and manipulator DETVAN - HON in two size categories 150 and 200 (Fig.1).

At this time there are made out two masterpieces (loader and manipulator) of DETVAN HON 200 and they are going to undergo operational and safety tests. The DETVAN HON 150/200, combines the advantages of a loader and a telescopic manipulator. Thanks to its wide range of accessories, it has universal applications in civil engineering, forestry, agriculture or communal and municipal fields. The advantages of the DETVAN rotary loader are mainly in its high quality and powerful performance, ease of operation and low operating expense. The engine is characterized by its quiet operation, low consumption and emission output. The loader cab is equipped in a

Figure 1: *Mobile working machine DETVAN HON 200 - loader*

Figure 2: *3D model and the real body in white of cab*

practical and convenient way to make the operator's work easier. The hydraulic loader's operational radius and maneuverability can be increased by using the telescopic boom arm, both 4x4 controllable axes and additional equipment, interchangeable by using the hydraulically controlled quick-fixture-device.

2.1 Steel cab and its properties

Current cab metal design is made of thin-walled steel beams and steel plates, presented at Fig.2. It consists of pipe in shape supporting frame which satisfy both FOPS and ROPS strength requirements.

The steel cab chassis must also fulfill minimum value of accumulated deformation energy U requirements, to fulfill valid safety directives of ROPS, which is obtained :

$$U = 12500 \left(\frac{m}{10000}\right)^{1.25},$$

where m is the cab mass in kg.

There on the Fig.3 is plotted dependence between the load and cab deformation calculated to model acc.Fig.2. This function can be formulated in form

$$F = 4 \times 10^8 \Delta^3 - 6 \times 10^7 \Delta^2 - 4 \times 10^6 \Delta - 316. \tag{1}$$

Then it is possible to calculate of formula (1) the real accumulated energy caused by cab deformation

$$U_{real} = \int_0^{\Delta_{\max}} F \Delta d\Delta. \tag{2}$$

In this particular case is $U = 3853$ J and $U_{real} = 4472$ J what means, that the accumulated energy is sufficient. The main advantage of steel cabs is just the fact that they have very good properties from strength a safety point of view.

Figure 3: *Calculated dependence between the lateral load and cab deformation*

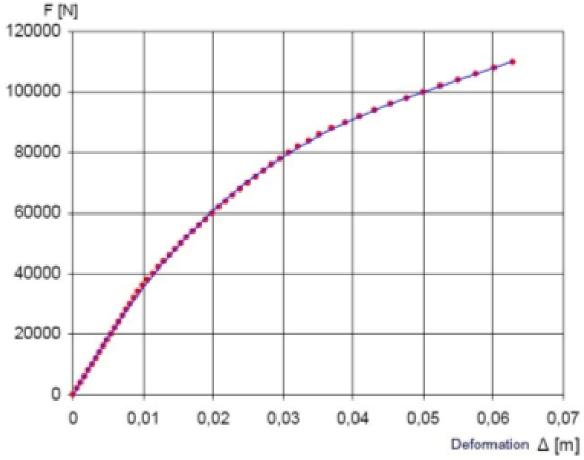
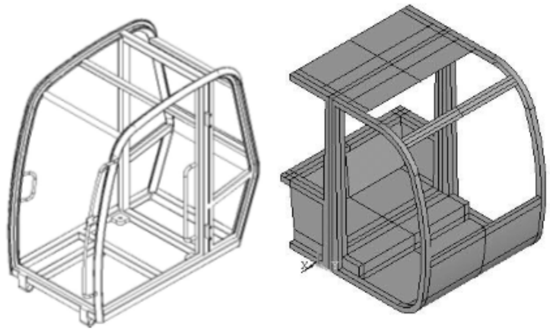


Figure 4: *Models of the laminate cab*



2.2 Preliminary Design of non-metal Cab

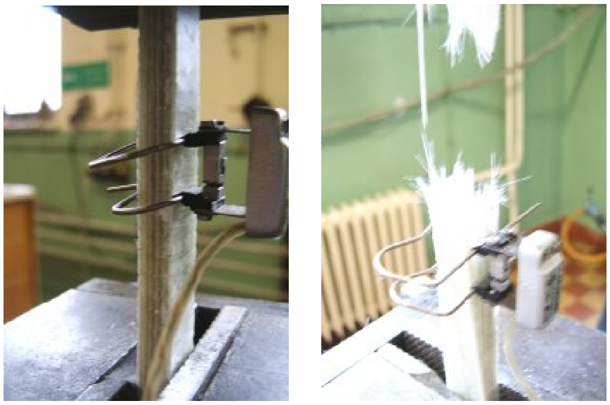
The composite material cab is to be designed in accordance with metal-cabin project. Composite cab design presented at Fig.4 was subjected to FEM computational structural analyze and modifications to meet both shape and strength security requests. For the first project approximation it is reflected one of the oldest and best known composite materials - fiberglass. Fiberglass (Glass laminate) is composite material composed of polymer matrix and glass fibers of various forms. Glass fibers are mainly combined with polymer matrices.

Polymer matrices are generally relatively low strength and stiff visco-elastic materials. These properties are getting worse with rising temperature, while the temperature of glass transition is the main denominator of polymer thermal resistance. Polymers are furthermore moisture sensitive materials, what means they are trying to balance moisture volume difference between them and environment they are in. Glass fibers are very thin fibers made out of glass used mainly to reinforce polymers. Their diameters are 0.003 mm - to 0.020 mm. Main engineering glass fibers are Electro technical (E-glass) and High strength (HS-glass). E-glass fibers were originally developed for electro-insulation applications. They are the oldest and the most widely used of all fibrous reinforcements, because of their low cost and good knowledge. Glass fibers are produced as multifilament bundles. E-glass fibers have relatively low elastic modulus compared to other reinforcements. In addition E-glass fibers are susceptible to creep and creep (stress) rupture. HS-glass fibers are stiffer, stronger and more resistant to fatigue and creep than E-glass fibers. Thermal and electrical conductivity and thermal expansion of glass fibers are low, compared to most metals. The most efficient composite reinforcement form is continuous fibers. Because of the low transverse strengths of unidirectional laminates, they are rarely used in structural applications. Laminates with layers in several directions (quasi-isotropic) are used for this purpose to meet requirements for strength, stiffness, buckling and so on. Laminates are quasi-isotropic when they have the same percentage of layers every $180/n$ degrees,

Table 1: *Strengths of E-Glass fiber (60%) reinforced Epoxy composites at room temperature*

MATERIAL SYSTEM	TENSILE STRENGTH		COMPRESSIVE STRENGTH		SHEAR STRENGTH
	MPa		MPa		MPa
	AXIAL	TRANSVERSAL	AXIAL	TRANSVERSAL	IN-PLANE
Unidirectional	1020	40	620	140	70
Qasiisotropic	550	550	330	330	250

Figure 5: *Multiaxial composite specimen testing*



where n is number of layers and $n \geq 3$. The most common quasi-isotropic laminates have layers which repeat every $30°$, $45°$ or $60°$. However, these laminates have not exactly isotropic in-plane properties, although they tend to become more uniform as the angle of repetition becomes smaller. In most applications, the laminate geometry is such, that maximal axial modulus and tensile and compressive strengths fall somewhere between axial unidirectional and quasi-isotropic values. Mechanical properties of Epoxy composite reinforced by continuous E-glass fibers, with unidirectional or polydirectional (quasi-isotropic) fiber configuration with volume fraction 60%, at room temperature are shown in Tab. 1.

Strength characteristics of laminate profiles were also estimated by experimental way at department laboratories (Fig.5) during anticipation at *APVT 20-007602* project solution. Partial result of this project was design and proposition of optimized profile parameters, which should be compared with non-optimized cabin structural profile and used to build up of alternative cabin

Results of these tests (Fig.6) approve, that accordingly chosen laminate has comparative strength properties as ordinary steel quality 37 acc. DIN standard. In addition, this material has very good shape memory, even under high stress does not show any plastic deformation. However, this means that such structure has not deformation energy absorption ability by irreversible manner, under external loads. In spite of legislative demands, this relative limitation should not be disadvantage for MWM cabs, because irreversible absorption of deformation energy is necessary under dynamic loads (for example impact or hit at high speed), which does not occur at MWM's. But this conclusion is only author's position and it will be yet the complicated way to the future to try change the up the present valid directives.

Real laminate cab made according the previous theoretically obtained results is shown on the Fig.7.

2.3 FEM Simulations of Cab safety tests

For comparative and production reasons, there were done structural analyses of metal and laminate cabs at FEM system COSMOS. ROPS test was simulated by vertical-downward, horizontal-lateral and horizontal-longitudal loading.

Figure 6: *Experimentally obtained multiaxial composite stress-strain curves*

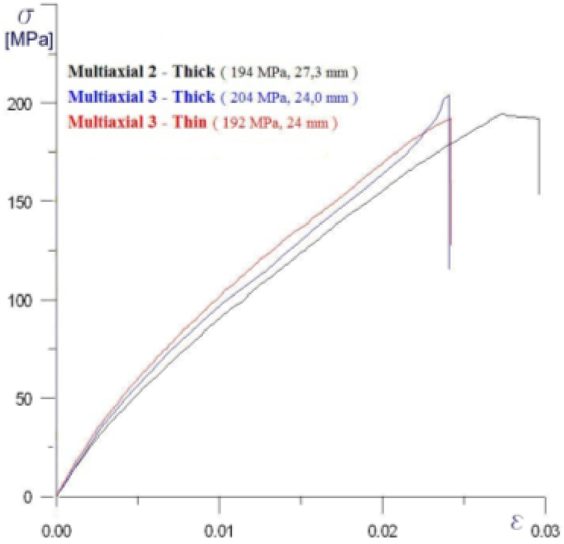


Figure 7: *Real laminate cab made from Epoxy composite reinforced by continuous E-glass fibers*

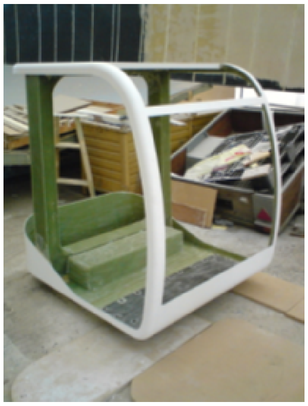
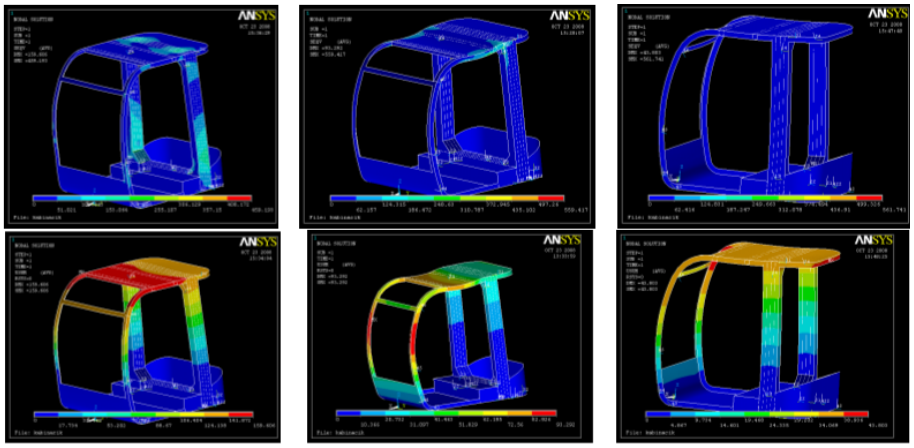


Table 2: *ROPS test cab forces*

Testing direction	Testing load	Standard load	Testing force F [N]
Vertical	downward	$F = 19,61 \cdot m \cdot g$	78440
Horizontal	lateral	$F = 6 \cdot m \cdot g$	2400
	longitudinal	$F = 4,8 \cdot m \cdot g$	19241

Figure 8: *Laminate cab strength and stiffness analysis results*



horizontal – lateral load **vertical – downward load** **horizontal – longitudinal load**

For MWM's of mass category $700m < 10000$ [kg], standard structural test of cabin requires to load cabin structure under:

1. Vertical-downward loading, by 19,61-fold of machine gravity
2. Horizontal-lateral loading, by 6-fold of machine gravity
3. Horizontal-longitudinal loading, by 4,8-fold of machine gravity

As materials were chosen:

1. Isotropic material - steel type - simulating current used cab structure material
2. Unisotropic material - multiaxial composite type - simulating preliminary composite cab design with
   a) non-optimized profile
   b) optimized profile

Normal stresses and deformations were computed by COSMOS and ANSYS software FEM algorithms for all material and loading combinations of considered cabin. Graphical software outputs are iso-areas of normal stresses respectively deformations. Maximum normal stresses are obtained in multiaxial non-optimized profile composite, stressed by horizontal lateral loading, while maximum deformations are observed in multiaxial optimized profile, stressed by horizontal lateral loading. Both most inconvenient material-loading combinations for models plotted at Fig.4 are presented at Fig.8.

3 CONCLUSION

By comparison of results we can say, that normal stresses are not considerably material dependent, however it is apparent that deformations are markedly material dependent. This behavior is due to great difference between elastic modulus of steel and multiaxial composite. We can conclude of received results, that multi-axial-composite cab match to maximum deformation, since this does not interfere into the deformation limiting space. The optimized profile cabin maximum normal stresses are about $3 - 18\%$ lower, than those at non-optimized profile cabin, even though deformations are slightly higher. Hence we can advise using of optimized profiles. While interpreting of FEM results it must be considered, that computation does not respect machine frame deformation nor clearances in cab's seating, as well success of real cab test results depends on its final design and its individual parts manufacturing quality.

Acknowledgement

The article was written within the solution of the project APVT 20-007602 and APVV-0100-06 with financial grant of Slovak APVV agency.

References

[1] BARQUAWI, P., *Navrhovanie kabín stavebných strojov*, diploma paper, STU Bratislava 2006, 79 p.

[2] JANČO, R., *Modelovanie konštrukčných prvkov z kompozitných materiálov využívaných v dopravnej technike*, dissertation, STU Bratislava 2004, 117 p.

[3] BUKOVECZKY, J.- GULAN, L.: *An effective approach to the development of mobile building machines-platform creation.* X. Országos Gépész Találkozó. Gépezet és informatika, Kiadó: Erdélyi Magyar Műszaki Tudományos Társaság - EMT, Kolozsvár 2002, ISSN - 1454-0746, p.78-79

[4] GULAN, L.: *Modulárne projektovanie mobilných pracovných strojov*, monograph, STU Bratislava 2000, ISBN 80-227-1397-X, 98 p.

[5] GULAN, L. - BUKOVECZKY, J.: *Systematic Approach to Design of Modular Mobile Manipulators.* Járművek, 9/1999, p. 52-54, GTE Győr, HU ISSN 1585-0676, p. 52-54

[6] GULAN, L. - BUKOVECZKY, J. - ZAJACOVÁ, ź.: *The platform of machine assemblies of mobile workong machines*, In: Monograph on the occasion of 47th anniversary of the Faculty of Technical Sciences, UNS FTS Novi Sad 2007, ISBN 978-86-7892-038-7, 185 - 186 p.

[7] GULAN, L. - ZAJACOVÁ, ź.: *Architectonic structure of flexible constructions of mobile working machines.* In: Machine Design : On the occasion of 48th anniversary of the Faculty of Technical Sciences: 1960-2008. - Novi Sad, University of Novi Sad, 2008. - ISBN 978-86-7892-105-6. - S. 105-108

[8] VEREŠ, M. - BOŠANSKÝ, M.: *Vývoj výrobku a moderné konštruovanie - State of the Art*, Zborník XXXIX. konferencie kateder částí a mechnizmů strojů, Liberec 1998, p.339-342,

[9] VEREŠ, M. BOŠANSKÝ, M.: *CAx technológie v strojárenskom priemysle, Strojárstvo v hodpodár-stve a priemysle*, ISSN 1335-2938, 12/1999, p.44-46

[10] VEREŠ, M. BOŠANSKÝ, M.: *Nové metódy vývoja pol'nohospodárskych strojov a ich význam pre prax*, Zorník vedeckého seminára s medzinárodnou účast'ou "Nové trendy v konštruovaní a exploatovaní pol'nohospodárskej techniky", Nitra 1999, p.9-14.

[11] VEREŠ, M. BOŠANSKÝ, M.: *CAx technológie v automobilovom návrhárstve*, Zborník referátov XL. medzinárodnej konferencie katedier častí a mechanizmov strojov, Žilina 1999, p.317-320.

[12] VEREŠ, M. - ŠIMKOVIČ, M - BOŠANSKÝ, M. - JANČO, R. - NEMČEKOVÁ, M: *Moderné kompo-zitné a hybridné materiály pri navrhovaní pol'no-hospodárskych strojov*. In: Nové trendy v konštru-ovaní a v tvorbe technickej dokumentácie 2005, ISBN 80-8069-517-2, Medzinárodná vedecká konfe-rencia Nitra 2005

[13] VEREŠ, M. - BOŠANSKÝ, M. - NEMČEKOVÁ, M. - ŠIMKOVIČ, M.: *Hybridné konštrukcie v konštrukciách strojov*. Sborník mezinárodní XLVI. Kon-ference kateder částí a mechanismů strojů, Sedmihorky, ČR, 2005, p.357-360