Abstract - The important evaluation criterion of the mobile working machines is the safety of the machine operator. The initial safety standards were established for the machines used in civil engineering industry and ground shaping industry. The machines operating in the above mentioned areas are now sorted into the category of middle range machines. At the present time the frequent use of smaller scale and bigger scale machines in the various industry areas is common. Momentarily the evaluation criteria were unified for all machine types. The certification requirements are settled by following regulation and standards: 86/296/EEC, ISO 3449:1992 – Falling objects Protective Structure (FOPS) testing and ISO3471 – Roll-Over Protective Structure (ROPS) testing. The fulfilling of defined requirements by regulation and standards are the basic condition for certificating of reliability of safety frame of the mobile working machine.

The safety frames of the mobile working machines for the groundwork machines have to ensure the operator safety during the machine operation even in the difficult and extremely heavy working conditions. The working space of the machine operator is evaluated in the term of ability to protect the operator in the situation of rolling-over of the machine and in the situation when the object is falling to the safety frame of the mobile working machine. To declare the conformity with the regulations and standards requirements the laboratory measurements are provided on actual structure prepared for launch to the market. The laboratory measurements of the structure can be considered as the final stage of the design process, because after proving of safety frame reliability the mobile working machine can be operated from the operator’s safety point of view. The requirements of minimum endurance during the tests are given by the existing regulation and standards and vary according the machine type and the machine weight.

Keywords – Falling objects Protective Structure (FOPS), DLV.

I. INTRODUCTION

For the reliability of safety cabin frame testing according the FOPS test for the first category the spherical steel or cast iron object is used. Standardized object for the falling object protective structure test cannot exceed the diameter of 250mm and weight of 45 kg. After finishing of the falling object protective structure test cannot be present permanent deformations on the testing object. The energy of the falling testing object has to be 1365J. Testing object for the second category of mobile working machines can be spherical or cylinder shape with the maximum diameter of 400mm. The energy of the falling testing object for second category has to be 11600J. Falling testing object contact area must be flat circle with the diameter of 200 mm. ROPS test is simulating the roll-over of the mobile working machine by the use of quasistatical load according the following sequence:
- Side load – where horizontal load is applied to the upper part of the safety structure,
- Vertical load – where vertical load is applied to the given place of the safety structure in the same plain as the side load,
- Lateral load – where the horizontal load is applied in the lateral direction of the safety structure. The above mentioned loads have to be carried out by the safety structure without jeopardizing the safety space of the machine operator.

It is important to realize, that to fulfill the requirement of absorbed energy in the safety structure is often necessary significantly increase the loading force or to sustain on the load with the aim to achieve deformation in the area of skid limit of the material. The situation, where the requirement to increase the loading force occurred during the testing of the safety structure is presented at the fig1.1 After reaching of the load given by the regulation and standard the accumulated energy in the safety structure reached only 25% of required level. During the increasing of the loading force to fulfill the condition of the accumulated energy in the safety structure the structure after significant deformation in the area of anchoring points was broken in the anchoring points. Such result of the test
usually leads to the reinforcing of the weak points of the structure. The result of such solution is the increase of the mass of the structure and in the final stage to extremely and uselessly rigid structure. Ideal solution is such rigidity of the structure, which can guarantee the required load and accumulated energy at the same time. A protective structure for self-propelled mining and construction machines is a system of structural components arranged on the machine in a way which significantly reduces the risks to the operator. Furthermore, a protective structure can be an integral part of the operator's cabin whereby one gains such benefits as: a cost reduction, an increased operator workspace or a reduced machine height. The load-bearing structure and all the protective structure components (mounted on the machine) should be ergonomic, i.e. so designed, machined and finished that all sharp corners and edges have been eliminated. A standard laboratory test weight (for RSPS) has the form of a cylinder and it should weigh 1500–6000 kg at minimum diameter of 800 mm; dimensions d and l are arbitrary (for the minimum diameter), depending on the weight's mass. At the instant of impact the weight should have kinetic energy $E=60$ kJ (Table 1). The protected space within the protective structure's outline, called DLV (Deflection Limiting Volume — a space of limit

<table>
<thead>
<tr>
<th>Certification test parameters</th>
<th>Striking energy $E_a$ [J]</th>
<th>Mass of weight $m$ [kg]</th>
<th>Initial velocity of weight $v_0$ [m/s] (m [kg])</th>
<th>Impact surface diameter $d$ [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PN-92/G-59001 RSPS</td>
<td>60 000</td>
<td>1500–6000</td>
<td>4.472 (6000)</td>
<td>min 800</td>
</tr>
</tbody>
</table>

Deformations, a protected space), i.e. the space into which no part of the cabin or the protective frame should enter, is defined. The shape and the location of the protected space depend on the position which the operator occupies when operating the machine according to its function. Self-propelled mining and construction machines have to be equipped with ROPS and FOPS. In Poland mining machines have to be additionally equipped with RSPS. During the strength test the evaluated structure should be mounted in the same way as during the actual operation of the machine. Such components as: dismountable panels, windows or accessories which are not part of the structure (and so have no effect on its strength) should be removed. Maximum rigidity of the base to which the structure is attached should be ensured. However, no complete machine is required.

The overall objective of this investigation was therefore to determine the (mass) range of small vehicles that can be accommodated within current FOPS performance testing criteria and the potential (lower mass) extrapolation limit(s) of the current test criteria; thereby enabling appropriate design criteria and tests procedures to be specified where a FOPS is required on a mining rigs, and determine where alternatives to current FOPS may have to be considered.

The majority of recognized FOPS performance testing standards does not encompass smaller vehicles, particularly below 600 kg mass. Certain of the industry suspects that the FOPS test performance criteria intended for larger (> 800 kg) vehicles are inappropriate for smaller / lighter examples. Consequently, at present, manufacturers of small vehicles who wish to design and install appropriate FOPS upon their machines are unable to refer to recognized performance criteria for these structures.

II. LITERATURE REVIEW

2.1 History:

Currently protective structures for construction and mining machines are required to provide safety in case of a rollover during engineering work (ROPS – Rollover Protective Structure – ISO 3471, EN 13510:2004) and protect construction machines against falling objects (FOPS – Falling Object Protective Structures – ISO 3449, EN 13627:2002). In the case of mining machines safety at much higher impact energies than the ones specified by ISO 3449 must be ensured. This is dictated by the operating conditions and the danger of rock slides. In Poland standard PN-92/G-59001: ‘Rock slide protective structures (RSPS). Requirements and tests.’ is binding for mining machines.

- [Jacek Karliniski, Eugeniusz Rusinski, Tadeusz Smolnicki-2008] [1] Depending on the needs, the cabin may have adjustable height, which facilitates transport and increases the field of view of the machine operator when drilling...
blast holes. However, such structures also cause a number of problems in adjusting the cabin to the safety requirements outlined in normative acts. The mass of such machines reaches up to 30,000 kg and when the vehicle rolls over the structure must protect the residual space defined by the DLV model. This paper presents the methodology of conducting simulation tests for such units with the application of finite element [J.Karlinśki, M.Ptak, P.Działalak 2013.] [2]. Accidents which involve a fall over object on structure are often fatal for the worker operating the mining machines. Fall over are the leading cause of work-related death in USA, where only about 70% of mining machines sold were equipped with fall over protective structures (FOPSs) (Freeman, 1999) Each year, about 250 people are killed in mining accidents in USA (NIOSH, 2004), constituting more than one-third of all production mining-related fatalities (Murphy & Yoder, 1998). The majority of fatal accidents involved mining machines without protective structures (Arana et al., 2002). Myers and Pana-Cryan (2000[4]) compared three strategies to prevent injuries incurred as a result of mining machines overturns. The strategies were ‘do nothing’, ‘install FOPS, and ‘replace machines cabin’. They concluded that the preferred strategy in terms of cost-effectiveness was to ‘install FOPS’ on mining machines for which FOPS were available. FOPS in combination with a seat belt can prevent nearly all mining machine fall over objects protection. [J. Mangado; J.I. Arana; C. Jaren; S. Arazuri; P. Arnal][3]

2.2 Review of Papers:-

A general problem in designing a falling object protective structure system is to find out the actual demands of the load, since in most cases the load is neither known nor can it be measured. This problem also occurs in the application considered in this paper where the load not only is unknown but may also change in a very fast manner by impacting on protective structure. In order to deal with this fact, the nonlinear control strategy has to be augmented by a load estimator. This is a challenging task since it is well known that the separation principle of the control of potential energy & measure or calculate kinetic energy and the estimator design does not hold for nonlinear systems. In this contribution, the stability of the deformation in protective structure design consisting of the nonlinear controller, the nonlinear load estimator and the plant model is proven by means of theory & FEA analysis.

2.3 Comments:-

1. To fulfill the demands to sale equipment in European countries, FOPS (fall over protection) to operator cabin of any earth moving equipment is mandatory & its legal requirement.
2. Whereas design of protecting structure against FOPS is dependent upon weight of falling object & potential energy of falling object on protective structure. During impact the amount of energy get absorbed by protective structure with deformation of structure.
3. By weight consideration of falling object, the test standard & load carrying capacity of FOPS varies from equipment to equipment depend upon cabin rigidity structure provided during design of cabin.
4. If test standard & load carrying capacity of FOPS different from equipment to equipment because of weight of falling object, then design of protecting structure for operator cabin against FOPS is not similar from certain category of machine group.
5. We will see all above parameter how it affect in current operator cabin by design point of view & then what to be required to modify in current design to fulfill EU standard in problem identification.

2.4 Design and test standard:-

1. Design and test requirement as per ISO 3449:2005(E)
   i. This test procedure is generally destructive of the FOPS assembly, as permanent deformation will occur to the structure.
   ii. Structure, and might not reproduce structural deformations, owing to variation in the actual impact of the falling objects.
   iii. Two levels of performance criteria are specified for impact protection, based on the machine end use.
      a) Level 1: protection against the impact of a round test object dropped from a height sufficient to develop an energy of 1 365 J. See Figures 2.1
b) Level II: protection against the impact of a cylindrical test object dropped from a height sufficient to develop an energy of 11600 J. See Figures 2.2.

iv. The drop height of the test object is defined as a function of its mass, as shown in below Figure 2.3 & 2.4
2. Current operator cabin condition against FOPS standard

FEA Simulation of Falling Object Protection structure test (FOPS) was carried out on current cabin using nonlinear explicit solver LS Dyna. A mass with Potential energy 11600J (level II) was dropped on the operator cabin roof at relatively weaker location. Deflection Limit Volume (DLV) simulating the operator body maximum boundaries as per ISO3164:2008 was placed inside the cabin and the cabin part intrusions in the DLV were checked. Please ref. fig 4 & 5 for out come of FEA analysis on current cabin problem.
III. EXPERIMENT AND RESULT

FEA to analyze the operator cabin’s performance under falling object protection test specifications as per ISO 3449:2008 FOPS test. The mass with potential energy specified in the standards is to be dropped at structurally weak locations on the roof and penetration of the structure in the DLV is to be predicted.

FEA Simulation of Falling Object Protection structure test (FOPS) was carried out using nonlinear explicit solver LS Dyna. A mass with Potential energy 11600J (level II) was dropped on the operator cabin roof at three different relatively weaker locations. Deflection Limit Volume (DLV) simulating the operator body maximum...
boundaries as per ISO3164:2008 was placed inside the cabin and the cabin part intrusions inside the DLV were checked.

It was observed that in all three impact cases there were no penetrations inside the DLV. The energy of the drop mass was completely absorbed by the operator cabin roof structure and the drop mass was elastically rebounded back. This implies that operator cabin is safe under ISO 3449:2008 FOPS test loading condition.

3.1 Inputs required for FEA analysis:
- Pro/E Model of the Cabin Structure

3.2 Units:
- Length – Meter
- Force – Newton
- Mass – Kg
- Mass Density – Kg/m³
- Stress – Pa
- Energy – Joules

3.3 Glossary of Terms:
- Falling Object protective structure : FOPS
- deflection-limiting volume : DLV
- boundary plane : BP

5.4 Displacement plot (for assembly): Dropping Object
From figure 4.5 it clearly indicate, the outcome of FEA analysis related to displacement after impact on protective structure of cabin the displacement is observed:-
Max displacement = 0.2357 m (235.7 mm)

- Refer to the figure (3.1) for DLV and cab structure.
- As per the standards, the cab structure should not deform more than allowable distance between cab and DLV.
- Clearance between unreformed cabin top and DLV = 0.32868 m (328.68 mm)

3.5 DS/EN ISO 3449:2008 standard:

- DS/EN ISO 3449:2008 defines two acceptance level for FOPS:
  - Level I acceptance –
    - Level I acceptance is intended for protection from falling bricks, small concrete Block, hand tool etc.
    - Dropping mass of 46 kg (round shape = hemispherical + cylindrical) producing 1,365 J energy.
  - Level II acceptance –
    - Level II acceptance is intended for protection from falling trees, rocks, overhead demolition.
    - Dropping mass of 227 kg (499.4 lb) is dropped from a height of 5.22 m (205.51 in) on a FOPS structure to produce 11,600 J (102575 lbf-in) energy.
- FE Analysis is done to meet Level II acceptance criteria

3.6 After test parameter as per ISO 3449:

Result conclusion from displacement FEA analysis:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max displacement in Y-direction</td>
<td>0.23620 m (235.30 mm) at t = 0.040 sec</td>
</tr>
<tr>
<td>Clearance b/w cabin top and DLV</td>
<td>0.09338 m (93.38 mm)</td>
</tr>
</tbody>
</table>

Refer figure 3.3.
IV. CONCLUSION

1. Maximum displacement during Drop Test is found to be 0.2357 m near first drop object load hitting area compared to 0.1252 m second drop object load hitting area.
2. There are few plastic deformations during the loading. However, these plastic deformations are local and can be neglected.
3. Results obtained from analytical method give an in-depth understanding of the structural behavior under machine FOPS situation.
4. Numerical analysis of FOPS model is studied using explicit finite element analysis.

The high stress points and plastic strain regions have been evaluated with respect to the guide line values provided. Based on the calculations of the True stress and true strain at failures, these appear to be below the guide line values to analyze the worst case material properties. However, since these calculations are based on certain assumptions, especially beyond the engineering ultimate stress, these results should be considered only as indicative.

<table>
<thead>
<tr>
<th>Sr. no</th>
<th>Theoretical calculation</th>
<th>Calculation by FEA analysis</th>
<th>Experimental result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>263.84</td>
<td>235.7</td>
<td>236.2</td>
</tr>
</tbody>
</table>

Basis FE Analysis / Simulation & experimental test carried out with ref to ISO 3449 (level I or II). Minimum performance requirements of ISO 3449 (level I or II) were met in this FE simulation & experimental test. The operator Cab Structure with the mounting system passes / meets the requirement.

REFERENCES


