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DRI DIRECT MEASURMENT DEVICE

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In case of mine detonations under a military vehicle, the occupants are loaded by shock, local structural motions/deformations, and global vehicle motion. The most significant measurement is related to the spine deflection under the vertical shock using Dynamic Response Index (DRI) criteria. DRI is measured using pelvis accelerometer of Hybrid III dummies, according to the STANAG requirement, and is a major parameter for qualification of a protected vehicle.

Since tests involving hybrid III dummies are expensive and risky for the dummies, mostly during the development phase, we have developed a mechanical low cost device which easily and instantly provides the DRI measurement. Furthermore, when more than one seat measurement is required the device can be complementary to the Hybrid III dummy.

The DRI is a dimensionless value related to the spine deflection. This deflection is the output of a mass-spring-damper system with vertical pelvis acceleration as input.

Hence, we have developed a mechanism which represents a second order model according to the standard definition of natural frequency and damping coefficient. Since the system indicates a mass-spring-damper direct deformation, we find it most practical, repeatable and accurate. Practicality is achieved by having real time results (post test raw data analysis is not required) using a standalone system, no additional external devices (power supply, cables, etc.) required.

The platform capsule vertical impulse is a major parameter for mine protected vehicle. This parameter indicates the necessity of energy absorbing seats or the type of absorbing elements required. This measurement can be implemented by attaching the compact mechanism to the vehicle side walls.

The device consists mainly of 2 parts: (a) dynamic response measuring mechanical device (b) envelope made of reinforced polyurethane (representing human body). It can be positioned on the vehicle’s seats and tightened with the original seat belts of the vehicle. The measuring device can be used also without the envelope as a measuring device for the vehicle’s vertical input impulse.

The device was tested with comparison to hybrid III and acceleration sensors on a series of blast and drop tests, and has been proven as an accurate, compact low-cost device.

INTRODUCTION

Armored vehicles are designed to protect the crew from various threats such as small arms and blast. When large blasts occur, although the vehicle absorbs the impulse the gross vehicle acceleration and deceleration are significant to the passenger's injury, especially to their spines. Blast attenuating seat is critical in the vehicles survivability system to overcome the acceleration induced from underbody blast threats.

Development of survivability systems involves large amount of experiments (drop tower, sled and blast tests). Field blast tests are usually conducted with anthropomorphic mannequins, such as Hybrid III dummies, seated on blast attenuating seats installed in the tested armored vehicle. However, such tests are expensive and hard to carry out.

The established standard [1] defines that occupant's injury criteria when subjected to underbody blast is related to the: (1) spine (2) leg, and (3) neck behavior. Herein we focused on the spine behavior that is measured in terms of DRI (Dynamic Response Index) units. The Hybrid III mannequins measure the DRI using acceleration gauges signals that are filtered and integrated twice to finally calculate the spine's contraction. However, the hazards and costs are enormous during the development phase where failure or ruptures can occur thus using the dummies at this stage is not a realistic option.

In this paper, a best value measuring device is presented using a device that can measure directly the DRI during blast scenario. The device incorporates a standalone mechanism where no power supply or cables are required. The authors believe that the use of this device during development stage and neighboring Hybrid III dummies at the final acceptance test would be cost efficient and practical.

THEORETICAL BACKGROUND

The spine is an occupant's vulnerable part when armored vehicle is subjected to underbody blast incident. Most critical is the direct impact/shock wave transmitted through the seat system to the spinal column that can cause serious injuries of the spine. Various types of injuries were observed: damage to the bone structure, ligament and muscle injuries. The spine can sustain large compressive loads, however, if the force is too great, one or more of the vertebra may break.

NATO test methodology report [2] indicates injury criteria, tolerance levels and measurement methods to assess vulnerable body regions to a blast mine strike under a vehicle. Herein, we will summarize upon the relevant issues related to the spine injury criteria and the method of its behavior measurement.

When short duration load is applied (in terms of milliseconds) injury risk model must consider the dynamic behavior of the spine. Therefore, the assessment criterion depends on a dynamic function. Dynamic Response Index (DRI) model was introduced by Latham [3] to describe the impact of ejection seats to the human body, and was evaluated by Stech and Payne [4], was recommended since it considers this requirement and fits the best for the injury assessment.

DRI model simulates the biomechanical response due to human body dynamics, in the vertical to the ground axis, by using a single mass-spring-damper system (Figure 1).

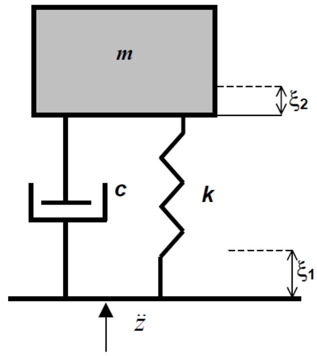

Figure 1 - DRIz Model [Stech, 1969]

Consider δ is the relative displacement of the system with $\delta = \xi_1 - \xi_2$ ($\delta > 0$, i.e. compression), ω_n is the natural frequency with $\omega_n = \sqrt{k/m}$, and ξ is the damping coefficient with $\xi = c/(2 \cdot m \cdot \omega_n)$. The mathematical equation of motion that describes this model is:

$$\ddot{z}(t) = \ddot{\delta} + 2 \cdot \xi \cdot \omega_n \cdot \dot{\delta} + \omega_n^2 \cdot \delta \quad (1)$$

Where $\ddot{z}(t)$ is the acceleration in the vertical direction measured from the initiation point.

The DRIz is calculated by the maximum relative displacement δ_{max}, ω_n and the gravity acceleration g:

$$DRIz = \frac{\omega_n \cdot \delta_{max}}{g} \quad (2)$$

For the spinal direction (vertical compression of the spine) Stech and Payne [4] selected the values of $\zeta=0.224$ and $\omega_n=52.9$ radians/sec, as values for a representative Air Force pilot with a mean age of 27.9 years. The values were based on research on compressive individual vertebral strength [5] and on load-deflection curves [6]. Brinkley and Shaffer [7] introduced the function of spinal injury risk due to compressive loads versus DRIz values as shown in Figure 2.

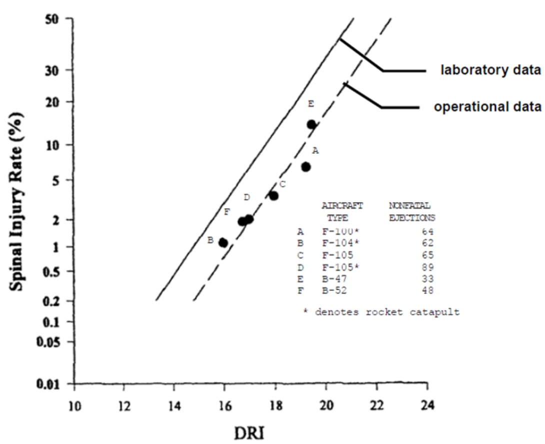

Figure 2 - Spinal Injury Risk Calculated form Laboratory and Operational Data [7].

The DRIz model is at this point the best available model for spine injury assessment. It was decided to only assess spine injuries in the vertical (z) direction and that the DRIz is to be calculated with the pelvis Anthropomorphic Test Dummy (ATD) vertical acceleration. Furthermore, the NATO group [2] decided to use the more conservative risk curve derived from laboratory data. Using this curve the tolerance level of 17.7 for DRIz refers to a 10% risk of AIS (Abbreviated Injury Scale) 2+ injuries (i.e. moderate+ injury).

DEVICE TECHNICAL DESCRIPTION

As mentioned above the DRIz model simulates the biomechanical response of the spine by using a mass-spring-damper system.. The proposed mechanical device keeps the damping coefficient and natural frequency values $\zeta=0.224$ and $\omega_n=52.9$ radians/sec respectively, by using a combination of mass-spring-damper ratio as required by the standard, and measures the maximum displacement δ_{max}. Thus, the DRIz is obtained directly. The structure of the device is shown in figure 2.

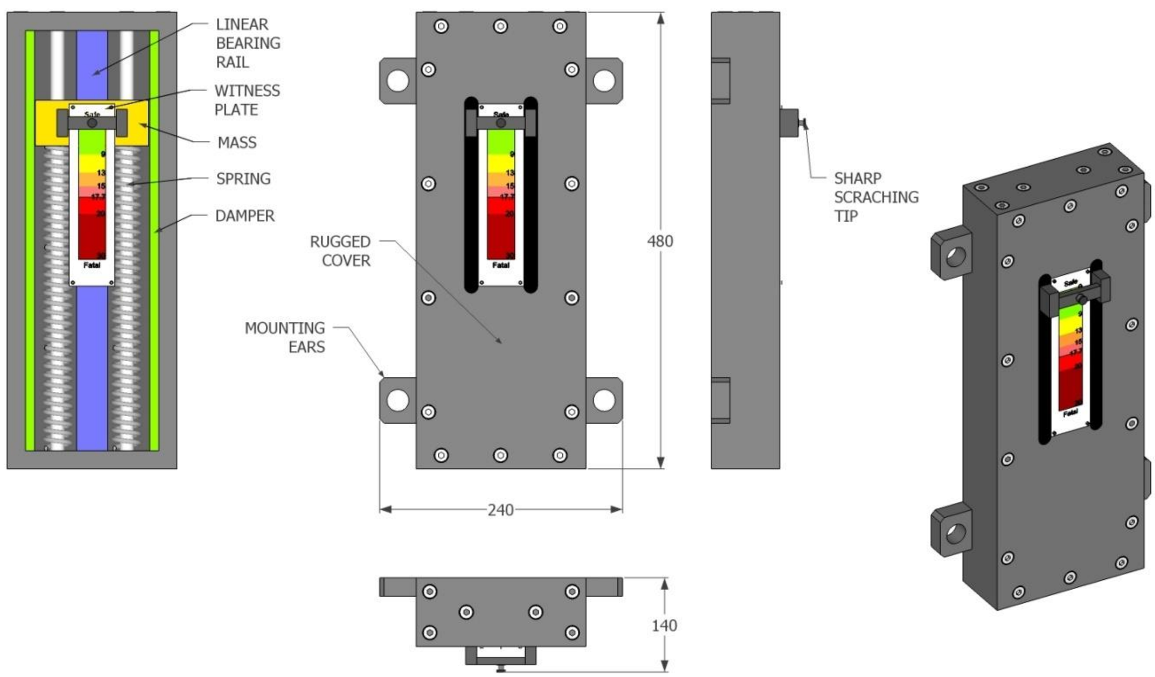

Figure 3 – Schematic drawing of the DRIz measurment device

The difficulty was to obtain accurate spring and damper coefficients. While the spring can be manufactured to a certain acceptable accuracy, finding viscous damper that provides force to velocity linear ratio during the relevant velocities and durations was impossible. Consequently, we have developed a magnetic damper that provides the desirable force to velocity linear ratio.

The measurement of the maximum displacement is achieved by using a sharp tip scratching a plastic witness plate.

The device consists mainly of 2 parts: rugged mass-spring-damper mechanism, and reinforced envelope polyurethane humanlike (optional), or metal weights keeping the same center of gravity, as shown in figure 4. The device can be positioned on the vehicle's seats and tightened with the original seat belts of the vehicle. The measuring device can be used also without body envelope as a measuring device for the vehicle's input impulse to assess if attenuating seats are required (to be discussed later).

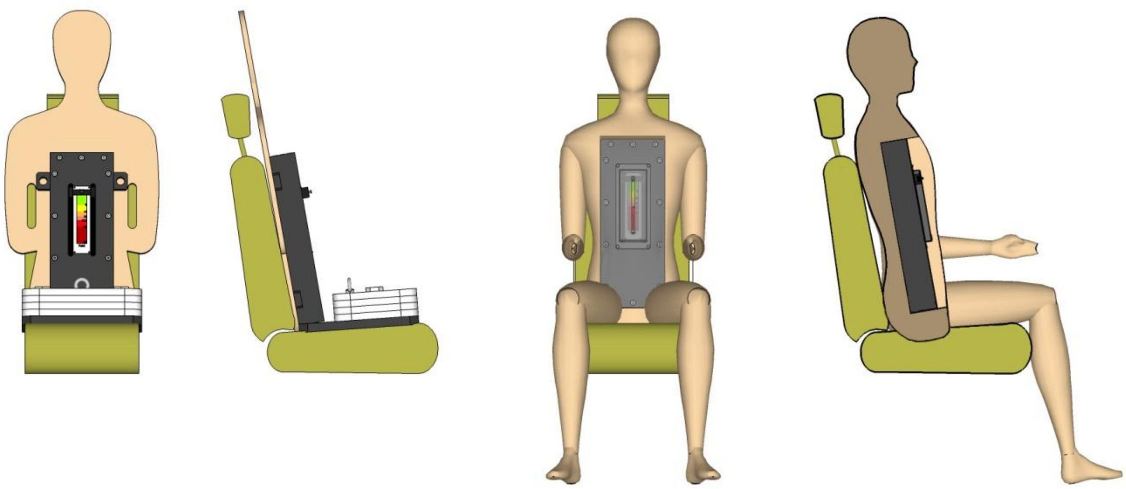

Figure 4 – Two optional envelopes for the device: on the left, metal weights, and on the right humanlike polyurethane

DROP TOWER TEST

Prior to the use of the device, calibration was required. The method of calibrating was drop tower tests from different heights and absorbing cushions. While the scratching sharp tip marked the witness plate, accelerometers were located on the device and cradle to record the signals during the shock test (see figure 5). The accelerometers sensitivity was 1 mV/g. Each accelerometer recorded the z direction. The sampling frequency was 20 kHz. The recorded acceleration signals in each drop test were processed and the DRIz was calculated using three different methods:

- Method 1 – Signal filtering according to standard using low pass and high pass filters.
- Method 2 – Solving the differential equation of motion using the recorded data as input.
- Method 3 – Finite element analysis.

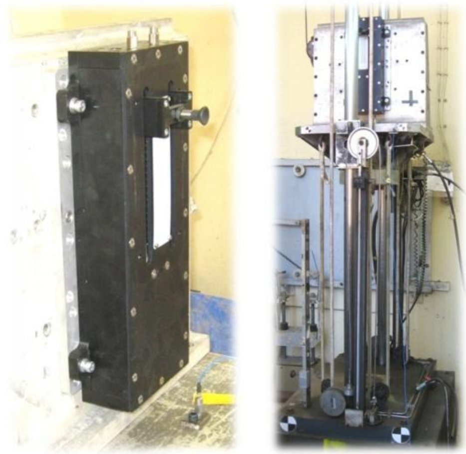

Figure 5 – Drop test tower setup

BLAST TEST

Additional calibration was required to evaluate the accuracy of the device during blast scenarios. The method was to compare Hybrid III dummy signals to the DRI device results under similar blast conditions. Two similar rigid seats were mounted on a blast test rig 1.5 tons total weight. High explosive charges, up to 6 kg-TNT, were initiated under the structure, as shown schematically in figure 6. The recorded acceleration signals from the Hybrid III dummy were compared after each explosion test to the DRI device scratched witness plate. These tests were conducted by the IDF Tests and Evaluation Unit at their proving ground. Note, that while the hybrid III dummy is sensitive and in some cases the measurement signals were not recorded, the DRI device kept supplying repeatable results.

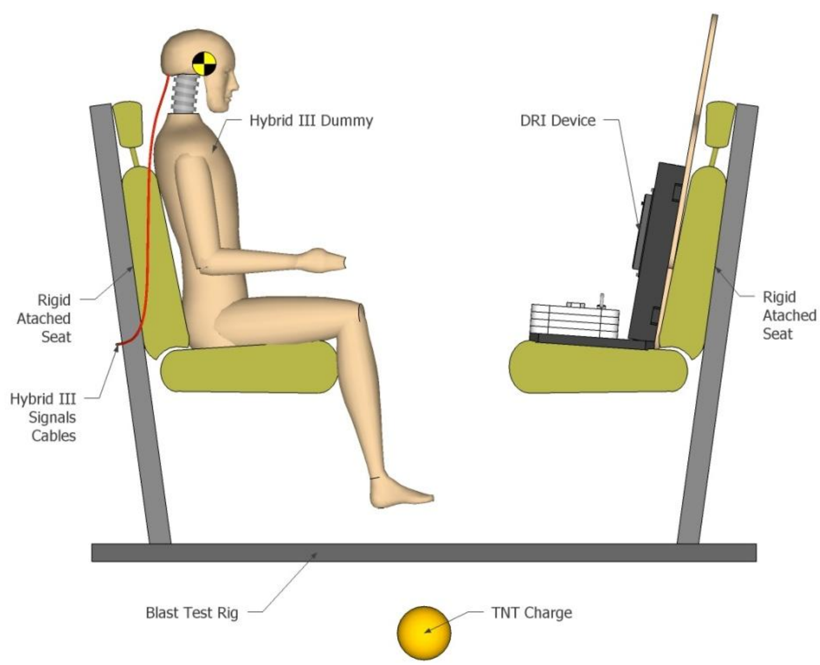

Figure 6 - Blast tests setup; Comparing Hybrid III Dummy to DRI Device

FINITE ELEMENTS SIMULATIONS

A single degree-of-freedom system was modeled in finite element analysis (FEA). In this case ANSYS software was used. The FEA was conducted on a model representing Stich DRIz model [4] shown in figure 1. The model included: Two joined masses connected by longitudinal stiffness (spring) element and longitudinal damper. The stiffness and damping were calculated according to the values Stech and Payne [4] selected for $\zeta=0.224$ and $\omega_n=52.9$ radians/sec. The lower mass was two times stiffer than the upper mass. A body to ground joint was defined on the lower face of the lower mass. All its rotations and the axial and lateral translations were constrained. The recorded acceleration signal was defined as input to the body to ground joint. For the DRIz calculation, transient analysis was performed for each test with its recorded acceleration signal (and not a filtered signal) as an input. The maximum displacement used for calculating DRIz was the relative displacement between the two masses.

RESULTS

Figure 7 presents in a graph comparison between finite elements DRIz results, accelerometer signal processing and the DRI device results.

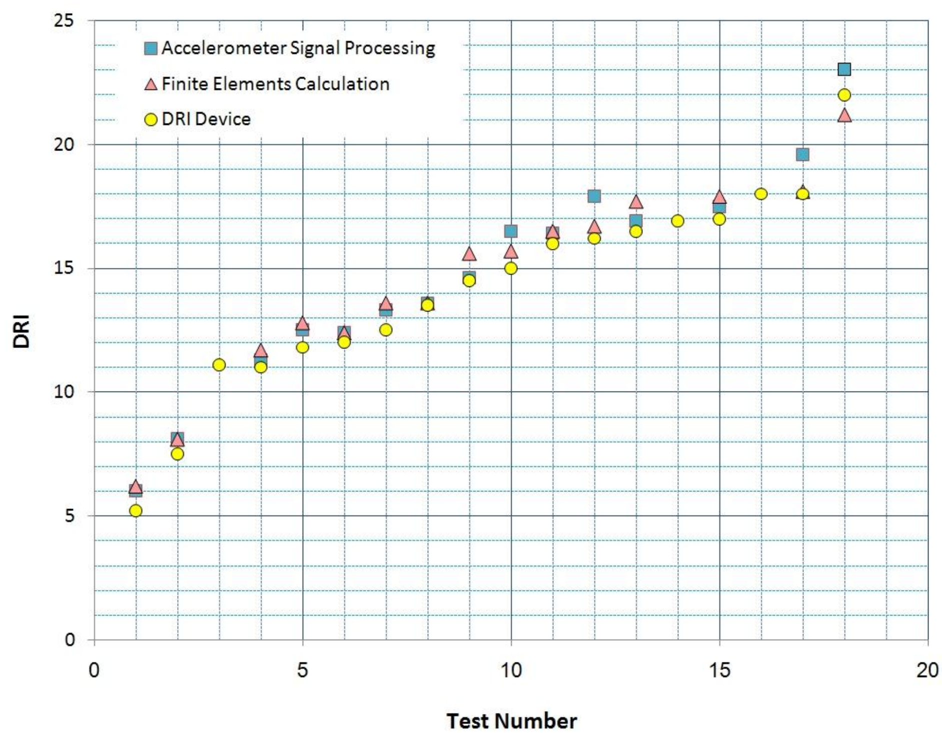

Figure 7 – Compared DRI results by processing signals from Hybrid III dummy or attached accelerometers, finite elements calculations when accelerometer signal is used as input, and DRI measurment device.

An overall excellent agreement can be noted between the three methods. One should note that in test numbers 3, 14, and 16 the only obtained result was from the DRI device due to fault in the accelerometers measurement. It should be emphasized that the following tests 4, 15, 17 were conducted with identical conditions as the previous fault tests. By comparing these results it can be concluded that the device provides repeatable results.

After calibration was finalized the device was used in an armored vehicle acceptance test. Since the number of available hybrid III dummies was limited, it was decided to measure six more seats using the DRIz device as presented in figure 8. The results have proven the efficiency of the device for collecting as much as possible data during one blast test and reasonable budget.

(A) (B) (C)

Figure 8 – Armored vehicle field test: (A) Two DRIz devices on passangers seats (B) Hybrid III dummy on one seat and a device on the following seat (C) View from the back of two symetric locations in the vehicle, on the left seat Hybrid III dummy and on the right seat DRIz device.

DISSCUSSION

This paper addresses a solution of DRIz measurement using a pure mechanical device. The device was used to evaluate attenuating seats performance under given underbelly blast conditions. In some cases we ask ourselves the question: Are energy absorbing seats are needed for the given conditions? Suppose the device was attached rigidly to the side walls of the vehicle, a direct answer is given whether the input conditions are hazardous or not. Thus, it can be used as an input gauge in terms of DRI units.

SUMMARY

A mechanical device for DRIz measurement was developed. The device represents a second order model according to the standard definition of natural frequency and damping coefficient. By conducting a series of tests at different shock conditions, calibration of the device was obtained. The DRIz device was also used in true armored vehicle acceptance test as an assisting measurement device to the hybrid III dummy for collecting maximum data during a blast test. The device was found to be most practical, repeatable and accurate. Practicality was achieved by having real time results (post test raw data analysis was not required) using a standalone device, without additional external devices (power supply, cables, etc.) required.

The platform capsule vertical impulse is a major parameter for mine protected vehicle. This parameter indicates the necessity of energy absorbing seats or the type of absorbing elements required. The developed device, when attached rigidly to the side walls of the vehicle, can obtain the input shock to the vehicle in terms of the effect upon the crew, i.e. DRIz units.

The device consists mainly of 2 parts: (a) mechanical device (b) envelope. It can be positioned on the vehicle's seats and tightened with the original seat belts of the vehicle. It was tested with comparison to hybrid III and acceleration sensors on a series of blast and drop tests, and has been proven as an accurate, compact low-cost device.

AKNOLEDGMENTS

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