ANALYSIS OF THE EFFECT OF STANDARDIZATION OF THE MANNEQUIN ON TESTING RESULTS IN SEAT BELTS’ DYNAMIC TESTS BASED ON UN REGULATION No. 16/2020

Analisis Pengaruh Standardisasi Manekin Terhadap Hasil Eksperimen Uji Dinamis Sabuk Pengaman Berdasarkan Peraturan PBB Nomor 16 Tahun 2020

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Abstract

The research seeks to highlight problems caused by mannequins’ differences in seat belts’ dynamic tests and analyze the effect of standardization of the mannequin on testing results. It is of great importance to clarify the relationship between the type and calibration of the mannequin and the displacements of the mannequin’s chest and pelvis in dynamic tests conducted to simulate real vehicle crash accidents, for the accuracy and reliability of data collected in tests can be perceived as one of prerequisite conditions to carry out activities such as comparison between laboratories, reconstruction of road accidents, and inspections of products. A testing scheme including 8 dynamic tests was devised and conducted to verify the previous experimental findings and to explore the relationship between the standardization of the mannequin and the testing results. All the tests were set up according to the requirements and testing methods of UN Regulation No. 16. Both TNO 10 mannequin and UTAC R16 mannequin were used in the scheme, as specified in many technical standards and regulations. The trolley of acceleration type was employed to generate the qualified acceleration pulses. Based on the regulation, the effect of standardization of the mannequin on testing results was ascertained by comparison between tests using mannequins of different types or with different calibration parameters. The displacements of UTAC R10 were obviously smaller than those of TNO 10 mannequin in measurement. Besides, the changes of calibration parameters of the mannequin could also influence the testing results.

Keywords: standardization, mannequin, dynamic tests, seat belt.

Abstrak


Kata kunci: standardisasi, manekin, uji dinamis, sabuk pengaman.

1. INTRODUCTION

With the great development of economy and urbanization, the aggregate amount of vehicles increases obviously, thus bringing about lots of traffic problems such as road crashes (e.g., Sheveland et al., 2020; Teye-Kwadjo, Salia, Mensah, & Ofori, 2020; Usami, Persia, & Sgarra, 2020). As global public health problems, fatalities and injuries from road traffic crashes are drawing more and more attention. Quantities of researches have been conducted and measures have been taken to tackle the issue (Boakye, Khattak, Everett, & Nambisan, 2019; Marco et al., 2020; Shakya, Shults, Stevens, Beck, & Sleet, 2020). Especially in the process of ensuring passive safety of vehicles, seat belts are widely
used as effective means of protecting occupants, and till now the safety performance of seat belts has been improved greatly. Without the proper use of seat belts, road crash accidents could actually cause severe injuries and fatalities that should have been preventable or reduced to some extent if occupant restraint systems such as seat belts are employed and can function normally (Booker & Sung, 2017; Eluru & Bhat, 2007). Thoracic injury, lumbar spinal injury, pelvic injury, abdominal injury and many other kinds of injuries are common in road crash accidents especially between vehicles or between vehicles and barriers (Amiri, Naserkhaki, & Parnianpour, 2020; Bjurlin, Fantus, Fantus, Mellett, & Villines, 2014; Knobloch et al., 2008; Tomic et al., 2018). 3-point seat belts being one typical kind of passive safety devices, are designed to restrain the occupants' thorax and pelvis, and therefore keep displacements of the parts within the safety range. Hence, chest and pelvis displacements are often taken as the main criteria to evaluate the safety performance of seat belts in many regulations, e.g., UN Regulation No. 16, GB 14166-2013, and so on.

Mandatory legislation about seat belts and the corresponding technical standards and regulations play a significant role in improving the usage rate, and promoting the safety and standardization of seat belts. In many countries, mandatory seat belt laws have proven effective in reducing traffic-related deaths, disabilities and even injuries indeed, and with the development of passive safety technology, they also help quicken the steps of drafts, implementations, or revisions of standards and regulations concerned to some extent (e.g., Boakye & Nambisan, 2020; Harper & Strumpf, 2017; Klair & Arfan, 2014). Being the uniform provisions concerning the approval of seat belts, UN Regulation No. 16 defines the requirements and testing methods for the assessment of the safety performance. In a certain sense, the regulations provide a good reference for evaluating the overall performance of products.

In laboratories, dynamic tests are usually carried out to simulate the real crashes by means of the equipment including but not limited to the acceleration or deceleration trolley and mannequins (e.g., Jones, Gaewsky, Weaver, & Stitzel, 2016; Peng et al., 2019; Tang, Zheng, & Hu, 2020). By conducting dynamic tests can the useful information of displacements related with the occupants be obtained. It's of importance to assess the dynamic properties of seat belts based on the information collected in dynamic tests in accordance with regulations, for ensuring that the testing results are comparable and experimental conditions are reproducible and repeatable is a necessary prerequisite for further analysis. The acceleration trolley is a perfect platform for conducting dynamic tests, since it is convenient to use and has excellent properties of repeatability and reproducibility as for generating the qualified acceleration pulses. The mannequins used widely in dynamic tests of seat belts can be classified into 2 kinds mainly, one being TNO 10 mannequin, and the other being UTAC R16 mannequin. The 2 kinds of mannequins both satisfy the requirements of UN Regulation No. 16 and therefore it's reasonable and acceptable to use them in tests. However, they have different parameters in part and their dynamic response are not the same with each other. Especially, the torsional stiffness varies between them, and the parameter influences the displacements of the mannequin's chest to some extent. In order to make testing results comparable, e.g., in laboratory comparisons, it's a must to use the same mannequin with the same calibration parameters for the same test. Otherwise, the difference between values of the results may exceed the permitted zone or the limit, thus resulting in the failure of comparison between laboratories.

Previous research mainly focuses on the application of the mannequins in different fields, the design and optimization of the passive safety systems such as seat belts, the improvement of the mannequin's materials and so on (Durrani, Lee, & Shah, 2021; Yang & Li, 2019). However, comparatively less emphasis has been put on the comparison between the mannequins used at present and how differences between them influence the dynamic response in dynamic tests. The paper seeks to highlight and analyze the differences between TNO 10 and UTAC R16 mannequins, and the effect on testing results by devising and conducting a testing scheme including certain quantities of dynamic tests. The procedure of tests is strictly performed in accordance with UN Regulation No. 16 and the requirements in the regulation are taken as the criteria for assessing whether the samples are qualified.

2. PREVIOUS EXPERIMENTAL FINDINGS

In the past 3 years, more than 1000 kinds of seat belts have been inspected in a laboratory accredited according to ISO/IEC 17025:2017, which is located in Beijing City, and the total amount of dynamic tests exceeds 2000 times. Nearly 80% of the tests conducted were oriented to 3-point seat belts, with the aim of assessing the safety performance and obtaining the information about quality of products. Patterns of regularity indicates that the safety performance of seat belts can be influenced by the mannequin used in the

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tests in some way. As shown in Figure 1, the total quantity of samples inspected using TNO 10 mannequin was 718 and 21 of them didn’t meet the requirements of the regulation, while a total of 456 samples were inspected using the UTAC R16 mannequin and 18 sets of seat belts failed in the tests. The failure rates are 2.92% and 3.95% respectively and the reason of the difference between the rates deserves deep exploration. On the one hand, it’s maybe related with the quality of seat belts, for samples with poor quality are prone to failure. On the other hand, the experimental conditions may be another possible factor that causes the difference. Since the trolley employed belongs to the acceleration type and the pulses can be generated and controlled precisely, the most obvious factor is the mannequin. Taken into consideration the fact that all the samples are provided by several large-scale factories whose quality of products is uniform and constant, the choice of mannequins remains the biggest factor.

All the tests were conducted in accordance with the requirements of acceleration curve defined in UN Regulation No. 16, and only one kind of acceleration curve was employed, and the repeatability of testing conditions such as acceleration pulses could be ensured. The obvious phenomenon was that the distances of mannequin’s chest and pelvis movement were different when the 2 kinds of mannequins were used respectively in 2 tests, with other conditions being kept almost the same.

Therefore, it’s necessary to improve the standardization of the mannequin for obtaining more reliable and accurate testing results. As is displayed in Figure 2, the mannequin is covered by a special overall, consists of head, neck, torso, hip joint, thighs, lower leg, etc., and in order to calibrate the mannequin to certain values and its total mass, the mass distribution are adjusted by the use of six correction steel masses of 1 kg each, which can be mounted at the hip joint. 6 polyurethane weights each of 1 kg mass can be mounted in the back of the torso. Meanwhile, it is also necessary to specify and control the friction at each joint, so as to achieve reproducible results. Above all, the first step to ensure mannequin’s standardization is to ascertain the effects of the intrinsic differences upon the testing results.

Figure 1. The total quantities and quantities of failure of samples in dynamic tests using 2 kinds of mannequins respectively

(a) TNO 10 (b) UTAC R16

Figure 2. Comparison of appearances between 2 kinds of mannequins

3. METHODOLOGY

3.1 Test Preparation

The vehicle undoubtedly undergoes rapid or violent deceleration in crash accidents, and in the process, the deceleration could be deemed as a function of time within stopping distance. Deceleration versus time profile could be obtained by an accelerometer mounted on the trolley. Comparability of testing results is based on consistency of acceleration or deceleration pulses for tests with the same setups and conditions. Meanwhile, enough consistency of pulses is crucial for reconstructing the crashes and ensuring the accuracy. Trolleys can be classified into 2 types according to the ways of generating pulses and of installing samples, one being the deceleration type, and the other being the acceleration type. In current research, the trolley of acceleration type as the key equipment, was employed to simulate real crashes and to generate the acceleration pulses which could replace the deceleration ones, while the same effect could be achieved with higher efficiency.

Both the TNO 10 mannequin and UTAC R16 mannequin conform to the technical regulations such as UN Regulation No. 16 and
other related technical standards including GB standards in China and JIS standards in Japan, etc., and are suitable to measure the thorax and pelvic displacements. The displacements of the 2 parts of the mannequin are also required to measure in regulations, and they’re related directly with the risks of secondary collisions which can result in occupants’ severe injuries in real crashes. So monitoring the parameters is a typical way to compare the similarities and differences between the 2 kinds of mannequins. As shown in Figure 3, the cable extension position sensor is a special device for measuring the displacements of mannequins and used widely in seat belts’ dynamic tests, for it has the advantage of accuracy and reliability, and it outweighs many other devices or means to obtain the necessary information in tests. Actually 2 cable extension position sensors can constitute the better means to measure the parameters required than other devices such as high speed camera which unavoidably induces deviations of measurement because of camera’s shooting angle. In testing scheme, the approach of using 2 sensors of the kind was adopted to measure the displacements of mannequin’s chest and pelvis movement respectively, as displayed in Figure 4.

In order to ensure the objectivity and universality, a scheme incorporating 4 groups of dynamic tests was designed, and it involved a total of 8 tests, as tabulated in Table 1. Group I and Group II employed the standard calibration method specified in the regulation for TNO 10 mannequin and UTAC R16 mannequin, while Group III and Group IV involved taking the nonstandard calibration method, in which the torques to tighten hip joint nuts were reduced by 5 Nm. Testing results of Group I and Group II were compared to validate the effect of different mannequins. Furthermore, Group I was compared with Group III, as well as Group II with Group IV, to validate the effect of different adjustments such as different calibration parameters.

In addition, the 8 3-point seat belt samples used in tests were of the same type and model, the coordinate values of each sample’s anchorages conformed to the specification of UN Regulation No. 16, and anchoring ways of samples were also identical to each other so as to reduce and eliminate the interference of factors related with samples, thus ensuring the consistency of testing conditions.

### Table 1. Testing scheme

<table>
<thead>
<tr>
<th>Group</th>
<th>mannequin</th>
<th>Calibration Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>TNO 10</td>
<td>UN Regulation No. 16</td>
</tr>
<tr>
<td>II</td>
<td>UTAC R16</td>
<td>UN Regulation No. 16</td>
</tr>
<tr>
<td>III</td>
<td>TNO 10</td>
<td>Ditto, except the torque to tighten hip joint nut (reduced by 5 Nm)</td>
</tr>
<tr>
<td>IV</td>
<td>UTAC R16</td>
<td>Ditto, except the torque to tighten hip joint nut (reduced by 5 Nm)</td>
</tr>
</tbody>
</table>

### 3.2 Test Procedure and Evaluation of Safety Performance

In dynamic tests, the R16 fixture was employed as the platform to install seat belts, and the samples could function normally and were able to restrain mannequins to the seat. Before each test and in the process of the sample’s installation, the retractor had been so installed that the retractor was able to operate correctly and stow the strap unhindered and efficiently, i.e., the manipulation did not cause any failure of retractors to function normally. For the sake of simulating the actual state, a board 25 mm thick was placed between the back of the mannequin and the seat back to cause the necessary slack.
The belt was firmly adjusted to the mannequin and the mannequin’s movement was not restrained when it was swayed or pulled gently within a narrow range. The board was then removed so that the entire length of the mannequin’s back was in enough contact with the seat back. A check was made to ensure that the mode of engagement of the two parts of the buckle would entail no risk of reducing the reliability of locking mechanism. The final states of the mannequins restrained by 3-point seat belts just before dynamic tests start are illustrated in Figure 5 and Figure 6. The procedure was repeated in each installation and preparation process to ensure the same initial state before the acceleration trolley was propelled to approach the acceleration curve defined as the object each time.

In addition, the accelerometer was mounted directly at the bottom of the trolley and had been calibrated. As the device to monitor the trolley’s acceleration, it collected the essential data and then the acceleration pulses were obtained in the tests. Cable extension position sensors were mounted behind the mannequin and the heights were equal to those of the mannequin’s chest and pelvis measuring positions respectively. Similarly, the displacement pulses of mannequins were captured and served as the input information for analysis of the effect of standardization of the mannequin on testing results. The displacements of mannequin’s chest and pelvis are required to measure in dynamic tests in accordance with UN Regulation No. 16.

The acceleration trolley was propelled to the acceleration strictly according to the target curve set previously. After the tests, all the results including the trolley’s accelerations, and the mannequins’ displacements were acquired through human-machine interface.

In accordance with UN Regulation No. 16, the forward displacement shall be between 80 and 200 mm at pelvic level and between 100 and 300 mm at chest level, as for 3-point seat belts. Displacements exceeding the limits could bring about severe injuries and fatalities to occupants in real crash accidents, while in dynamic tests, it is a kind of non-conformance with the technical regulation. Therefore, the chest and pelvis displacements can be taken as the criteria to evaluate the safety performance of seat belts and be used to assess the differences between mannequins of the 2 kinds in dynamic tests.

4. RESULT AND DISCUSSION

The displacements of mannequins’ chest and pelvis movements, along with the trolley’s acceleration and velocity pulses were collected when the testing scheme had been conducted, as shown in Figures from Figure 7 to Figure 14. The numerical results of mannequins’ displacements were all displayed in Table 2.

As illustrated in Figure 7 and Figure 8, the acceleration pulses are all within the area specified in UN Regulation No. 16 and conform to the regulation, and the velocities also satisfy the requirements. The trolley remained horizontal during the acceleration and had been so propelled that its total velocity change was from 51 km/h to 53 km/h. The start of the impact (T0) was defined according to ISO 17 373 (2005) for a level of acceleration of 0.5 g. Due to capability and
accuracy of the trolley of acceleration type, the repeatability and consistency of experimental conditions could be ensured strictly. Additionally, the samples’ types, models and installations were the same with each other. Any potential interference to data acquisition in the process was excluded. Therefore, comparability between testing results of different groups can be ensured and comparison between them become feasible.

In accordance with the characteristics and trends of displacement pulses displayed in Figure 9 and Figure 10, it can be inferred that using different mannequins can influence testing results, although the mannequins undergo the same calibration procedure and both fulfil the requirements about dynamic tests for seat belts in the regulation. The upper torso’s torsional rigidity of UTAC R16 mannequin appears bigger than that of TNO 10 mannequin, which will inevitably result in the smaller displacements of chest and pelvis of UTAC R16 mannequin in tests even under the same testing conditions. The extent to which choosing and using mannequins influence chest displacements is obviously greater than that to which they influence pelvis displacements. Actually, the mannequin slides forward firstly the moment the trolley is propelled, then the upper torso has the tendency of toppling forward in a very short period of time and stops leaning forward when seat belt functions. In the process, the mannequin’s torsional rigidity has a negative correlation with chest displacement. Hence, it is a prerequisite for seat belts’ safety assessment to use a proper mannequin in dynamic tests. The effect of standardization of mannequins upon testing results cannot be ignored and it should be taken into consideration in laboratories’ inspection activities.

Even for the same mannequin, it can influence testing results if the calibration parameters are different. In the current research, torques for tightening the mannequin’s hip joint nuts being one of the most possible factors that may be related to mannequins’ displacements, are given priority and taken into consideration. In group III and group IV, the mannequins were calibrated according to the standard calibration procedure defined in the regulation except the parameter, i.e., the torque to tighten hip joint nut was reduced by 5 Nm in each test. As shown in Figure 11, Figure 12, Figure 13 and Figure 14, the effect of the adjustment is obvious, and it leads to the changes of displacement pulses’ peak values and the time to peak. By reducing the torques, mannequins are more prone to greater freedom of movement and the change will undoubtedly be reflected in chest and pelvis displacements. The lower the torque value is, the higher risks of secondary collision will be brought about. Chest and pelvis displacements exceeding the limits is part and parcel of secondary collision, and in real crash accidents, it will cause occupants’ severe injuries or fatalities. It is necessary to adopt standardized calibration methods and to promote standardization in every aspect so as to ensure the objectivity, accuracy, and comparability of testing results.
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Figure 10. Differences of pelvis displacements between the mannequins of the 2 types

Figure 11. Differences of chest displacements between conditions of the standard and nonstandard calibrations of TNO 10 mannequin

Figure 12. Differences of pelvis displacements between conditions of the standard and nonstandard calibrations of TNO 10 mannequin

Figure 13. Differences of chest displacements between conditions of the standard and nonstandard calibrations of UTAC R16 mannequin

Figure 14. Differences of pelvis displacements between conditions of the standard and nonstandard calibrations of UTAC R16 mannequin

Table 2. Testing results

<table>
<thead>
<tr>
<th>Group</th>
<th>Chest Displacement</th>
<th>Pelvis Displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1  241 mm</td>
<td>143 mm</td>
</tr>
<tr>
<td></td>
<td>2  238 mm</td>
<td>146 mm</td>
</tr>
<tr>
<td>II</td>
<td>3  203 mm</td>
<td>134 mm</td>
</tr>
<tr>
<td></td>
<td>4  207 mm</td>
<td>136 mm</td>
</tr>
<tr>
<td>III</td>
<td>5  249 mm</td>
<td>153 mm</td>
</tr>
<tr>
<td></td>
<td>6  251 mm</td>
<td>157 mm</td>
</tr>
<tr>
<td>IV</td>
<td>7  214 mm</td>
<td>139 mm</td>
</tr>
<tr>
<td></td>
<td>8  217 mm</td>
<td>141 mm</td>
</tr>
</tbody>
</table>

5. CONCLUSION

The research seeks to clarify and validate the effect of standardization of mannequins on testing results in seat belts’ dynamic tests, and the goal is achieved by devising and conducting the testing scheme. Although TNO 10 mannequin and UTAC R16 mannequin both meet the requirements of UN Regulation No. 16, they are different in some aspects, e.g., the torsional rigidity of the torso, and the testing results show that displacement values appear smaller when the tests are conducted using UTAC R16 mannequin. Moreover, it is validated that adjustment of calibration parameters such as torques to tighten hip joint nut can also result in alterations of the mannequin’s displacements in dynamic tests. So the proper mannequin and the suitable calibration method play an important role in dynamic tests, and their standardization is crucial. In addition to the factors influencing testing results directly, the auxiliary instrument, calibration interval, installation locations of sensors, and even temperature can lead to changes or fluctuation of testing results.
actually. Therefore, standardization is essential for conducting dynamic tests. The current research focuses on distinguishing the differences between 2 kinds of mannequins in dynamic tests and analyzing the effect of calibration parameters, since it is often perceived normal to replace one mannequin with the other of a different kind in dynamic tests for seat belt, and the calibration parameters should also be adjusted in accordance with the usage situation and abrasion state of mannequins. The objective has been achieved by carrying out the testing scheme.

How to choose a mannequin for a dynamic test depends upon various factors and an important one is the type of inspection. As to the normal inspection in a laboratory, TNO 10 mannequin and UTAC R16 mannequin can both be chosen for conducting dynamic tests, while it is better to choose TNO 10 mannequin to finish the tightened inspection considering its lower torsional rigidity. In China, there are more TNO 10 mannequins used in seat belt inspection laboratories than UTAC R16 mannequins, with the aim of evaluating the safety performance more strictly and improving the product quality by means of third-party inspection.

The effect of mannequins’ standardization on testing results has been ascertained, so further research can be conducted to explore the optimization of mannequins and calibration methods as well as standardization of major factors based on this research.

ACKNOWLEDGEMENT

Thanks are due to A. Hardianti, F. M. Yusuf, and K. L. Zheng for assistance with the translation and revision.

REFERENCES


