Frontal collision simulation in laboratory conditions

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Abstract: The article presents the displacement of individual body parts of volunteers during a controlled crash test at low speed. The crash test stand used is equipped with a vehicle seat with standard seat belts, which moves along the ramp rails. The stand enables both front, side and rear crash tests. The stand enables crash tests from 5 km/h to 20 km/h. The aim of the research is to compare the displacements of individual parts of the volunteers' body, taking into account the division into sex. A study carried out on 130 volunteers (80 men and 50 women), at a collision speed of 15 km/h, showed slight differences in the trajectory of the volunteers' head movement. Before the study, the volunteers were measured and weighed, and then assigned to the appropriate population percentile. Volunteers were classified into a given percentile group on the basis of the mean of 15 anthropometric dimensions of individual body parts. The obtained results are the basis for building a physical model of a dummy.

Keywords: automotive safety, crash test, anthropometric dummy

1. Introduction

Research issues concerning the protection of the driver and passengers of passenger vehicles against the consequences of road collisions has been constantly developed since the creation of passenger vehicles. In an accident at a speed of 50 km/h, a person mass over 2 tons. It is compared this kind of impact with a fall from 3-4 stories. The consequences of such a collision are, in fact, internal injuries, broken bones and serious injuries, which can be fatal. Since the creation of the first Carl Benz vehicle in 1886, the problem of safety has been considered by many scientists around the world [1-6]. Undoubtedly, in order to prevent the tragic consequences of events during vehicle accidents, vehicle manufacturers around the world are working on more and more modern safety measures. Current passenger protection systems play a key role in preventing the serious consequences of road accidents. Newly built vehicles are becoming safer and the safety requirements are becoming more and more stringent. Despite the better and better road infrastructure and more perfect safety systems installed in vehicles, accidents still happen. In the European Union alone, there are over a million accidents each year, with both injured and killed [6-10].

The complicated nature of the loads acting on the driver and passengers during a road accident contributes to the development of safety systems, in particular the model test of the introduced or improved passive safety systems of the vehicle. There are two types of model analyzes [11, 12, 13]:

- Computer simulation studies, with the use of specialized simulation programs using virtual models reflecting real models of anthropometric dummies,
- Crash-test experimental studies that use material models and anthropometric dummies that reflect human shapes and behavior during collisions.
Experimental research is characterized by high testing costs. Moreover, this type of research reduces the frequency of tests. It is especially visible during crash tests, where a large amount of data should be collected during one test and a repetition cannot be expected because it involves additional costs [14, 15, 16]. Therefore, nowadays simulation tests are becoming more and more popular. It is characterized by low costs of building simulation models and great ease of carrying out research on virtual models. This type of research does not put such pressure on the research team, as each attempt can be repeated without additional costs and long preparations. Despite the great advantages, simulation studies also have disadvantages. Their main importance is accuracy. The simulation model must undergo validation, which is based on comparing the results of simulation studies with experimental studies [17,18,19].

The crash test dummy models used consist of assemblies and elements resembling the human body. An ideal crash test dummy should have a simple structure that does not require frequent calibration and, at the same time, be highly durable and repeatable results [20, 21]. Currently, in the case of frontal collisions, with the most advanced Hybrid III and THOR dummy. The Hybrid III dummies have a high rate of compatibility with the human body. Research on the behavior of dummies during crash tests led to the evaluation of head, face, chest, abdomen, lower and upper limb injuries, which are used by all countries around the world [21, 22].

2. Experimental research
Experimental tests with the use of volunteers were carried out on a test stand designed for low-speed crash tests and for measuring the force in seat belts during a collision. An experimental crash test was carried out in the laboratory of motor vehicles and tractors at the Kielce University of Technology. The stand consists of a 10m long track along which a vehicle seat moves. At the end of the track, where are shock absorbers that simulate a collision with a stationary obstacle. The speed of the collision depends on the length of the road and the gradient of the tracks. The vehicle seat is on rollers that allow it to move freely along the tracks of the test stand. The measurement takes place when the electro valve is released, which keeps the chair with the dummy or the volunteer at a given height. Measurements on the experimental stand were recorded with a high-speed Phantom camera with a speed of 2500 frames/second.

![Test stand for crash tests at low speed](image)

Figure 1. Test stand for crash tests at low speed

People aged 18 to 45 participated in the experimental studies. A total of 130 people took part in the crash tests - including 80 men and 50 women. Before the measurement test, all people were measured and weighed, and then allocated in the given percentile of the population. Volunteers were classified into a given percentile group on the basis of the mean of 15 anthropometric dimensions of individual body parts. Examples of anthropometric dimensions for a 5-percentile woman and a 50-percentile male are presented in Table 1.
Table 1. Volunteer anthropometric dimensions

| Dimensions                          | Woman   | Man     |
|-------------------------------------|---------|---------|
| body height, cm                     | 165     | 183     |
| mass, kg                            | 62      | 91      |
| knee height, cm                     | 42      | 50      |
| shoulder width, cm                  | 41      | 45      |
| upper limb length, cm               | 64      | 85      |
| length elbow axis of the handle, cm | 32      | 43      |
| hand length (forearm), cm           | 17.5    | 18.5    |
| hand length, cm                     | 10.5    | 11      |
| crotch height (lower limb length), cm| 88      | 96      |
| thigh length (buttock knee), cm     | 59.5    | 59      |
| medial height of the foot, cm       | 7.8     | 9       |
| arm length, cm                      | 33      | 37      |
| head circumference, cm              | 56      | 57.5    |
| head height, cm                     | 21.5    | 21.5    |
| chest circumference, cm             | 96      | 90      |

The results of the experiment using volunteers were obtained with the help of the TEMA program [23]. This program allows you to analyze the movement of objects recorded with the camera. The program included the trajectory of the volunteers' head movement in individual percentile groups. The head displacements of volunteers in relation to the X axis are presented in Figures 2 to 7. The head displacement in the case of women and men representing the 5th percentile in the first phase of impact (0.05 s) ranges from 0.45 m to 0.57 m. In the second phase of impact (0.125 s), it ranges from 0.55 m to 0.62 m. In the case of people representing the 50th percentile of the male population in the first phase of the impact, the displacement of the head in the direction of the X axis ranges from 0.57 m to 0.75 m, in the case of women from 0.59 m to 0.72 m. The displacement of the head in relation to the X axis in the second phase of impact for volunteers representing the 50th percentile of the male population ranges from 0.55 m to 0.62 m, and for volunteers representing the 50th percentile of the female population from 0.55 m to 0.60 m. The head displacement for women and men representing the 95 percentile in the first phase of the impact ranges from 0.65 m to 0.82 m, and in the second phase from 0.70 m to 0.77 m. In the case of in the case of male volunteers, it ranges from 0.65 m to 0.85 m in the first phase of the impact, and in the range from 0.71 m to 0.77 m in the second phase.

Figure 2. Displacement of the head along the X axis of volunteers representing the 5th percentile of the male population

Figure 3. Displacement of the head along the X axis of volunteers representing the 5th percentile of the female population
Figure 4. Displacement of the head along the X axis of volunteers representing the 50th percentile of the male population

Figure 5. Displacement of the head along the X axis of volunteers representing the 50th percentile of the female population

Figure 6. Displacement of the head along the X axis of volunteers representing the 95th percentile of the male population

Figure 7. Displacement of the head along the X axis of volunteers representing the 95th percentile of the female population

The head displacements of volunteers in relation to the Y axis are presented in Figures 8 to 13. The head displacement in the case of women and men representing the 5th percentile in relation to the Y axis in the first phase of the impact ranges from 0.31 m to 0.4 m, and in the second phase in the range from 0.52 m to 0.62 m. In the case of volunteers representing the 50 percentile of the population, the head displacement in relation to the Y axis for men in the first phase of the impact ranges from 0.32 m to 0.45 m, and in the second phase from 0.55 m to 0.70 m. For women, the displacement of the head relative to the Y axis in the first phase ranges from 0.37 m to 0.50 m, and in the second phase from 0.56 m to 0.70 m.
Figure 8. Displacement of the head along the Y axis of volunteers representing the 5th percentile of the male population

Figure 9. Displacement of the head along the Y axis of volunteers representing the 5th percentile of the female population

Figure 10. Displacement of the head along the Y axis of volunteers representing the 50th percentile of the male population

Figure 11. Displacement of the head along the Y axis of volunteers representing the 50th percentile of the female population

Figure 12. Displacement of the head along the Y axis of volunteers representing the 95th percentile of the male population

Figure 13. Displacement of the head along the Y axis of volunteers representing the 95th percentile of the female population
3. Conclusions

More than 70 years have passed since the first mannequin was created (Sierra Sam Dummy), and there is still a need to design new joints and the structure of the individual body parts of the anthropometric dummy to be similar to the human body. Modern crash test dummies are modeled on the human body and use more than 200 sensors to record data. Their measuring points are distributed over the entire surface of the manikin. In the case of low speed crash tests, there is no need to use such extensive models of anthropometric dummies to correctly identify the behavior of individual parts of the human body [23-24].

In the case of crash tests aimed at increasing the level of passive safety of passenger vehicles, simulation programs are of great importance. Computer simulation in the simplest way is to recreate the phenomena that take place in the real world using mathematical models. They are defined and also operated using computer programs. In the case of crash tests, experimental tests are associated with high costs. On the other hand, simulation tests are much cheaper than experimental tests because they do not require a test stand. Contemporary simulation programs such as Dytran, Madymo or ADAMS are geared towards crash test simulations and data validation using experimental tests.

On the basis of the volunteers' head displacement in relation to the X and Y axes, it can be noticed that there are differences of 5% between men and women. Therefore, it should be noted that anthropometric dummies should not be divided into sex during a collision with a low speed of 5 to 20 km/h.

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