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DESIGN AND CONSTRUCTION OF DYNAMIC SIMULATOR FOR TESTING THE CHILD'S RESTRAINT SYSTEMS

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Abstract. *Design, construction and performance evaluation of impact tests simulator for child restraint systems. The constructive solution aimed to simulate an automobilistic collision to demonstrate and conviction people about the need to retain children in vehicles. This is a sled, guided and moved on rails being pulled by steel cable who crash without permanent damage against deformable barriers. The equipment was designed for easy installation in any places, whereas the floor is horizontal and flat, an induction motor pulls the cable and a system to control speed, acceleration and stop was implemented. The electronic instrumentation used in the simulator assembly allows assessment of equipment performance for speeds up to 20 km/h.*

Keywords: *Awareness, Child restraint systems in automobiles, Traffic safety and children, Dynamic tests.*

1. INTRODUCTION

In the first 50 years of motorization in the United States, Australia and Europe, the emphasis on safety car was almost exclusively in an attempt to prevent failure by individual driver's behaviour. This concept was a delay in relation to the vehicle security, because of the focus should not only be to avoid the accident but also, take precautions during and after the accident. Decades later, with the implementation of many preventive measures in other components of the occasional chain, led to a significant decrease in injuries caused by automotive accidents. (Williams, 2001)

The current rate of population growth and the growing popularity of automobiles provides a representative increase in global vehicle fleet. The Brazilian fleet in turn, accompanies this growth, but unfortunately has shown alarming numbers regarding the automotive accidents and fatalities, such accidents can occur for many reasons among them are mostly human failures, bad road condition, bad condition of the vehicle, lack of signage and the surrounding failure in vehicle components.

In order to minimize the consequences of accidents, the safety of the vehicle and its equipment security is an important design attribute, although the failures in vehicles represent one of the lowest cause accidents, severe and rigorous standards and regulations governing the running and passing the tests until the product reaches the end consumer. In Brazil equipment and parameters for testing, follow the standards defined by ABNT 14400: 1999 - Road vehicles - restraint devices for children - Safety requirements. However, according to (NCAP, 2014), "in Brazil there is a lag of independent accredited laboratories to conduct crash tests.". The Latin NCAP is an organ that performs impact tests of Brazilian cars, but for lack of reliable independent laboratories. The tests are conducted in Germany, near Munich, in the laboratory of ADAC, the German Automobile Club.

WHO - World Health Organization in 2008, pointed out that in the world, 870 children and teens die by day due to drowning, falls, burns and poisoning in their homes or in nearby areas.

As well as the SIM - Mortality Information System, administered by CENEPI - National Center for Epidemiology in cooperation with DATASUS - Department of Health System Information shows that in 2012 Brazil had 124.570 hospitalized children between 0 and 14 years old victims of injuries resulting from causes accidental external, where 14.720 due to traffic accidents, and among these there were 1.862 cases of death.

The alarming results year after year, made by private and public institutions come worrying all sectors of society. Government, people and even private companies try to find the best ways to reduce such rates. Laws and regulations on equipment children's vehicle safety are created trying to decrease such statistics, however many of the standards are based on European standards due to the limited amount of research and studies in Brazil. Two important factors that restrict research on vehicle safety in Brazil are the lack of national independent and certified laboratories that perform impact tests, and national manufacturers of dynamic testing equipment.

Then is required the development and construction of equipment made with national technology and materials for the testing child restraint systems. This equipment is useful for advancement in research and development new security technologies serve children. Another importance use of this equipment is in relation to awareness and conviction of the users of vehicles to the importance of vehicle safety equipment, with demonstrations using representative dummies, performing a comparison between using and not using the equipment security as well as correct and incorrect use, through simulation of impacts.

1.1 Dynamic Collisions

According to (Weber, n.d.), exist a number of collisions in a vehicular accident as show the Figure 1. Although the impact between the vehicle and the other object is considered the principal, there is also the impact felt by occupants who maintain the trajectory with the speed of pre-crash. Those who do not use seat belts feel a screeching halt over the deceleration experienced by the vehicle occupants while who use the device retention have this energy absorbed by the seat belt. Finally, there are collisions between internal organs of the body and the bone structure, this latter can be reduced significantly when the occupant is using a restraint system appropriate to their size and shape.

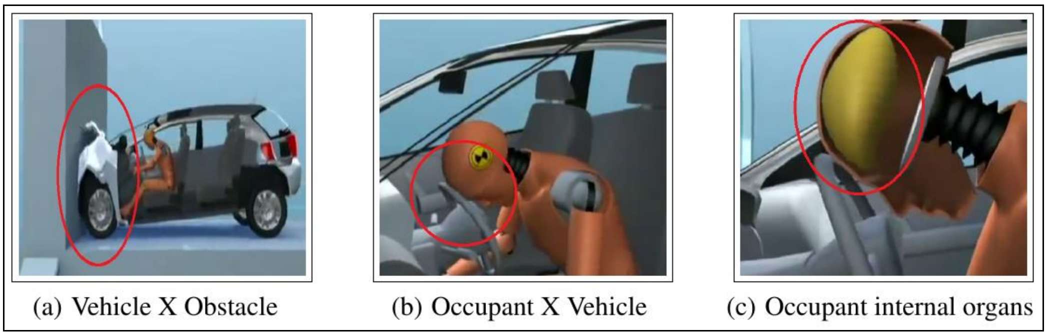

Figure 1. The three types of collisions in a vehicular accident. Source: (Chaves, F. and TAN, 2010)

The concern of reduce the number of accidents bring out the accident analysis, who cares to characterize the accident; in respect of its nature; form of occurrence; his systemic repetition; how, where and when they occur. And the need to understand the mechanisms involved in a collision originate the accidentology, which cares to analyse through mathematical models the different variables involved in accidents in order to create precautionary measures.

1.2 Security devices

The vehicle safety engineering is the area of automotive engineering who study and develops methods and mechanisms to maximum user protection. "The main components of the restraint system are the safety belts and their anchorages, banks and their anchors the dashboard, the head restraints, steering wheels (system direction), the airbags when available and child restraint systems ." (Tivelli, 2012)

The restraint device in a vehicle accident efficiency depends on the belts security are fixed to the device and the occupant, they need to be well adjusted and are suitable for each type of passenger, from children to adults, where the initial deceleration suffered for the occupation is as small as possible. Keeping under control the occupant deceleration rate not only reduces the forces acting on the surface of your body, but also the effect of collisions between internal organs and bone structure.

The vehicle safety and devices are divided into three types:

- Active vehicular safety - are devices that act in containing the accident in his imminence. Age functionally with the aim of preventing or reducing the chances of an accident occurs.
- Security passive vehicle - are devices that operate at or sudden stop, to prevent or minimize injuries to occupants of the vehicle in order to preserve the safety of the occupants. Such equipment is tested in dynamic simulation systems of car accident, known as Crash Test and Sled Test.
- Security vehicular post-crash action - are those who are employed after the collision.

1.3 Impact Test

The deep knowledge of the biomechanics response is essential when it comes to development of measures to prevent and minimize damage causes in a vehicle accident. The biomechanical analyses of the human body responses are not only crucial for understand the damage causes, but also to check and define the limits of damage tolerance. Another important factor is the biological variable, in particular the biological variation is the most relevant, becomes difficult to understand responses of many variables involved, because tests need to be done. Basically, there are five models used for testing verifying the biomechanics of the human body response: human volunteers, human cadavers, animals, mechanical human surrogates and mathematical models.

The real objective of the laboratory impact test is to conduct realistic scenario simulation in order to determine which loads a human victim suffers and define the limits of these loads during a crash. These results for the automotive industry are extensively used for improvement of retention systems as well as the development of new measures with regard to passive safety, to reduce and minimize injuries suffered in an automotive accident.

In the real world, there are various accident scenarios, but a few conditions of impacts. They are relevant for laboratory simulations impact. Such tests follow standards for their repeatability and comparison of several different categories tests. Three automotive impact tests can be distinguished, full scale test (crash test), sled test and test with components (Figure 2).

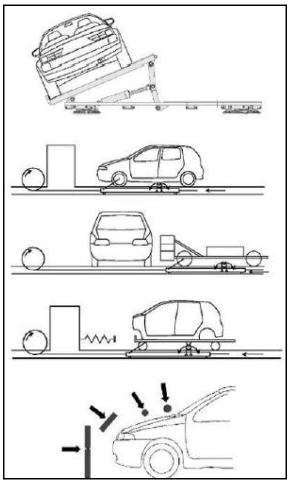

Figure 2. Different impact tests respectively: crash test (rollover test, impact front and side), and sled test different impactors used in the safety tests for pedestrians the front of a car. Source: (Schmitt, K.-U et al., 2010)

In full scale test (crash test), the vehicle will against a fixed object or another vehicle or is hit by a moving object that comes to meet him. Devices of anthropomorphic tests (dummies), represent the occupants of the vehicle, mechanical data and cinematic are collected during the impact test. The complete crash tests are also used for no biomechanical testing, e.g. deformation tests of the vehicle or braking system.

But the sled test is a test performed to evaluate equipment or isolated security situations simulating the impact in a traffic accident, different from crash test, which can damage the vehicle, make it unable to new tests, and the sled test is designed to achievements of different tests with different safety devices.

According to (Cardoso, E. and Oliveira, 2010), the sled tests, in car bodies are very common in developing of restraint systems. Where the car bodies are fixed on a sled impact by a controlled deceleration system (hydraulic, pneumatic or by deformation of metal structures), provides similar components deceleration to those occurring in real collisions.

2. DESIGN OF DYNAMIC SIMULATOR

The aim of this paper is to design, develop and test a system for dynamic simulations of automobile collisions, for demonstrations and testing of children's retention equipment.

For the simulations, the speed cannot be too high because it prevents view as occurred in normal tests*, not too low because one of the dummies should be catapulted into front, demonstrating the risks of non-use of child car safety equipment. After each presentation, only part of the deformable barrier impact will need to be reset, that occur with very low cost due to use of deformable barriers analysed by (Tivelli, 2012), allowing several statements in a single day.

* In Brazil, according to ABNT (1999), the test speed is 50^{0}_{-2} (Km/h).

For the creation of mobile simulator of impacts, were taken into consideration to start of proposals, patents as (Marvin, S. and JOHN, 1969); (Cerny, 1997); (Song, S.-J. and Miller, 1997); (Stein, D. J. and Peters, 1999) and projects of the leading manufacturers of sled tests as the German "*messring*" European "*aries*" and American "*hyge*", "*Calspan*" and "*Seattle safety*". Existing models offered by sled test manufacturers, are always fixed and with high cost infrastructure, to illustrate the complexity of the project we have below a model similar to this present work, but is fixed, where according (Evans, 2014), such a model is a partnership of three (3) years between China and UK institutes to test seats Children's produced in China. The space required for the facilities was 30x12m2, and the cost was approximately $ 1 million.

Therefore, the major difference between these models and proposed in this paper, beyond the cost, is the fact that mobile can be mounted virtually anywhere, provided you have a flat surface.

Figure 3. Chinese Sled test, for children's car seats tests. Source: (Evans, 2014)

2.1 Design evolution

All components of this project, include products and services existing in the Brazilian market today, allowing the reproduction of the same in Brazil. Another factor taken into account are the costs of materials and production of this simulator of impacts, the idea was to reduce the maximum amount of custom parts to reduce the cost of production, if necessary customize a part, making its production as simple as possible and can thus be made in the anyone mechanic laboratory.

During planning, many impact simulators were developed, the first idea was to improve a simulation rail (Figure 4), existing on Biomechanical laboratory at FEM/UNICAMP - mechanical engineering college had alignment problems, restricted mobility with high mass of the components and the propulsion system was not simulated what really happens during a crash. It has been seen that solve these problems of design, may would be unfeasible technically and financially, being better to design a new model.

The second option was a model where the sled would slide on 2 (two) parallel tubes, with 4 (four) shoes, each one composed by three wheels 180° out of phase; they would have the function of guide, supporting and do not let the sled go out of the track, the trigger would be done by existing pneumatic piston in the biomechanics laboratory FEM/UNICAMP.

This model was discarded due to the difficulty of alignment between the tubes, high production cost of the rail that support the tubes how need be produced with laser technology, shoes and the most important factor was on trigger piston, the acceleration simulation of a car, would be impossible, because of the piston starts at the maximum speed which the simulator could achieved, and an initial jolt would be suffered by the test dummies, simulating a unreal situation on the frontal collision case.

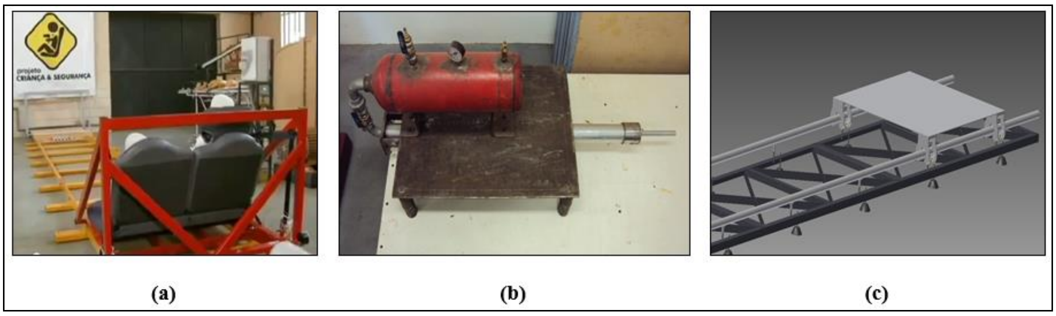

Figure 4. (a) Sled test on railway the model; (b) Trigger system; (Sacconi, 2012) (c) Parallel tubes design. (Author)

Then, it was designed a sled test with one single central tube and a shoe with four (4) wheels just to guide the sled straight and prevent the sled leave rail during the impact. Thus, eliminating the alignment problems of the model tubes earlier, the sled would be supported by a structure in H available in biomechanics laboratory FEM/UNICAMP, which served as a runway, and four (4) wheels of skates would be placed in the sled structure to support and skidding. The cost was reduced and the designed shoes model was manufactured easily in UNICAMP laboratories. The acceleration gradual simulator was still a problem, so it was designed a driven motor by an inverter frequency to control the sled acceleration ramp for the speed to have a characteristic increase damped. Thus, preventing the initial jerk, a spool connected to the motor shaft has the function of winding the cable, so as to pull the sled up to the moment of impact, the time to drive and engine stop would be automated through motion sensors.

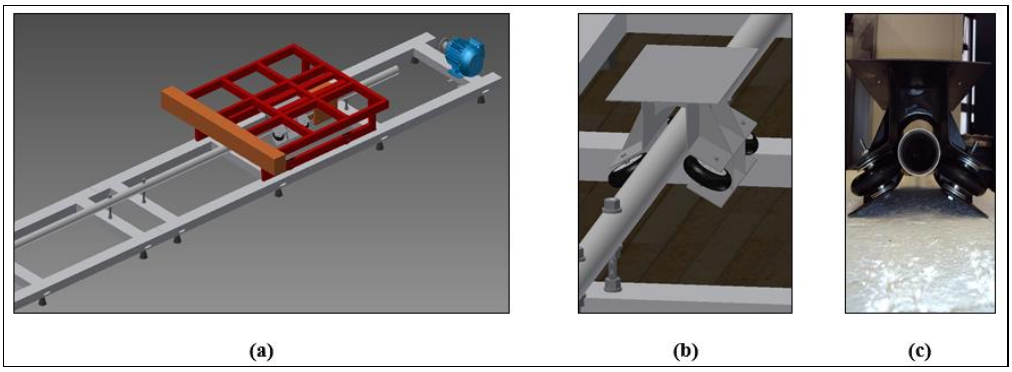

Figure 5. (a) Sled test design with central tube on CAD; (b) Shoe on CAD; (b) Picture of Shoe. Source: Author

It was used an average mass of 100kg to dimensioned the motor, cables, wheels, frequency inverter and diameter of the motor pulley, taking in account the mass of the seat with two seats and two children attending the use of an ambulance stretcher that has less mass and an effective size rail of 11 m[**], in order to reach a final speed of 20km/h.

2.2 Speed measurement system

To measure the speed was thought a simple system consisting of two pairs of infrared sensors (transmitter and receiver), a microcontroller *arduino one*, two radio frequency modules, an adapter (*XBee Shield*) for coupling the radio module in one *arduino* and a USB adapter (*USB XBee Explorer*) for communication between another radio module to the computer. The sensor measures the average speed of fourteen (14) anchoring points between the tube and the structure H, when the sled pass through them.

Coupling the sensor on the sled test simulator and the objects has been fixed, such as the anchorages between the tube and the track, it can be seen the average speed at these points using two radio frequency transmitter modules using the standard *ZigBee IEEE 802.15.4 the MaxStream®* manufacturer, to send speed sensor readings to another installed in a computer.

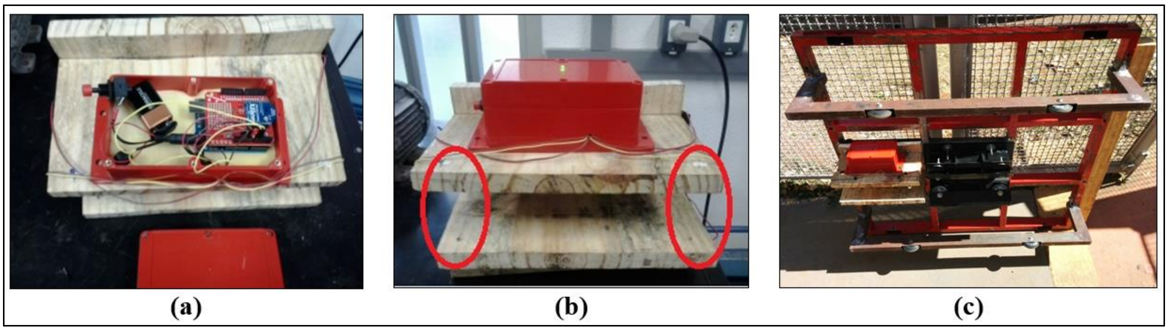

Figure 6. (a) Sensor assembly; (b) Featured sensor positioning; (c) Sensor positioning on the sled. Source: Author

[**] Although the track has 12m of length, the space that the sled really runs until the moment of impact is 11m are due to sled have 1m of length.

3. RESULTS AND DISCUSSIONS

Initial tests were conducted in order to verify that the mechanical structure, electrical and automatic of the project would achieve the desired expectations. It was used foam of polyurethane in the impact barrier as shock absorption systems to reduce the chances of causing damage to the sled structure. The tests were first performed with the minimum frequency of the frequency inverter allows is 3 (Hz), thereafter was raised to 10 (Hz) and then to 15 (Hz) as show at Table 1.

After the initial tests demonstrated the effectiveness of the system, tests were carried using 20 (Hz) Table 2, this is the frequency needed to reach the final speed of 20 (km/h) in order to check if it was possible to achieve speed and the mechanical structure of the simulator would endure to testing.

Table 1. Tests performed with engine on 3 (Hz), 10 (Hz) and 15 (Hz). Source: Author

Sled Test Speed with engine on 3Hz, 10Hz and 15Hz														
Speed measuring point	1	2	3	4	5	6	7	8	9	10	11	12	13	14
3Hz (Km/h)	2.6	2.75	2.66	2.64	2.58	2.65	2.78	2.8	2.81	2.77	2.79	2.71	2.57	2.72
10Hz (Km/h)	4.35	4.61	6.39	7.18	8.97	9.89	10.22	10.4	10.5	10.4	10.49	10.24	10.2	10.57
15Hz (Km/h)	4.7	7.81	10.03	10.6	12.45	13.9	14.77	15.05	15.51	15.97	15.71	15.71	15.93	15.9

Table 2. Tests performed with engine on 20 (Hz). Source: Author

Sled Test Speed (20Hz)														
Speed measuring point	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Reference (Km/h)	1.496	3.179	3.74	5.423	7.106	8.789	9.35	11.033	12.716	14.399	14.96	16.643	18.326	20.009
Test 1 (Km/h)	4.28	5.11	8.05	8.5	10.69	12.61	14.13	14.71	16.09	17.15	18.21	19.4	19.8	20.14
Test 2 (Km/h)	4.1	5.72	7.74	8.42	10.99	12.95	14.63	15.2	16.79	17.03	18.42	18.57	19.48	20.2
Test 3 (Km/h)	3.55	4.25	5.86	6.74	9.18	12.13	13.92	14.63	16.23	17.1	18.32	18.33	19.64	20.14

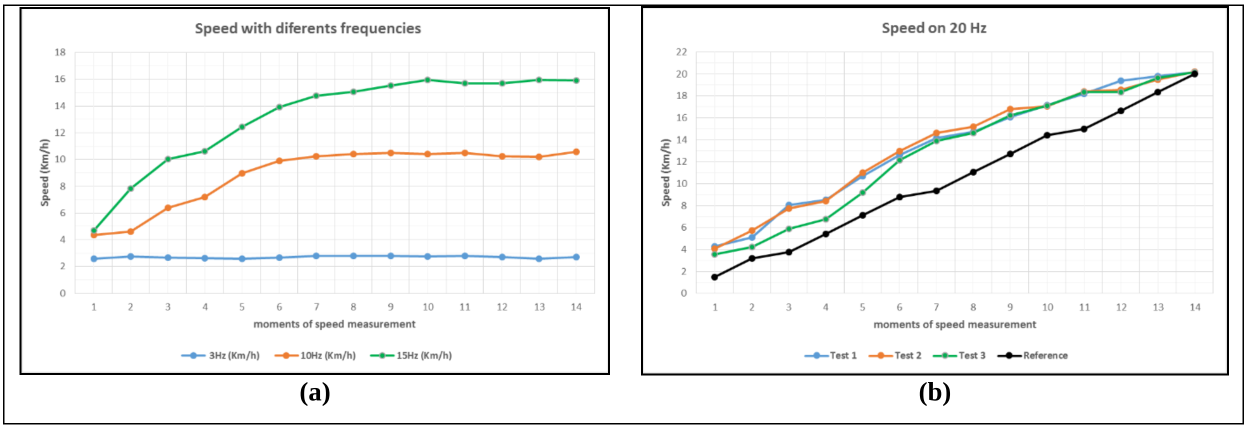

Figure 7. (a) Speed with engine on 3(Hz), 10(Hz) and 15(Hz); (b) Speed with engine on 20(Hz). Source: Author

It was seen that the final speed of 20 (km/h), can be reached and has a gradual increase until the moment of impact. Then we verified the variance, standard deviation and relative error values of the three tests as show on Table 3 and Table 4.

Table 3. Average, variance and standard deviation of sensor readings. Source: Author

Speed measuring point 20(Hz)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Average (Km/h)	3.976667	5.026667	7.216667	7.886667	10.28667	12.56333	14.22667	14.84667	16.37	17.09333	18.31667	18.76667	19.64	20.16
Variance	0.096422	0.363622	0.936289	0.658489	0.627356	0.113156	0.088689	0.063489	0.091467	0.002422	0.007356	0.210156	0.017067	0.0008
Standard deviation	0.310519	0.603011	0.96762	0.811473	0.792058	0.336386	0.297807	0.25197	0.302435	0.049216	0.085765	0.458427	0.130639	0.028284

Table 4. Relative error between reference ramp and real increase the speed. Source: Author

Speed measuring point 20(Hz)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Relative error 1 (%)	65.04673	37.78865	53.54037	36.2	33.52666	30.30135	33.82873	24.9966	20.96955	16.04082	17.84734	14.21134	7.444444	0.650447
Relative error 2 (%)	63.5122	44.42308	51.67959	35.59382	35.34122	32.13127	36.09023	27.41447	24.26444	15.44921	18.78393	10.37695	5.924025	0.945545
Relative error 3 (%)	57.85915	25.2	36.17747	19.54006	22.59259	27.54328	32.83046	24.58647	21.65126	15.79532	18.34061	9.203492	6.690428	0.650447
Average of relative error	62.13936	35.80391	47.13248	30.44463	30.48682	29.99197	34.24981	25.66585	22.29508	15.76178	18.32396	11.26393	6.686299	0.748813

From the data collected in the test, was concluded that the measurement of the speed was satisfactory, as the highest value of the standard deviation was not higher than 1 (Km/h). Higher error was expected because of it is an open loop system without feedback from the sensors to the engine and factors like the motor slip and friction. Such error does not influence the valuation of the impact therefore the graph of velocities (

Figure **7**.b) has a similar characteristic to a ramp, softening the initial acceleration of the simulator, eliminating the jolt on the systems to be tested.

4. CONCLUSIONS AND FUTURE WORK

The design and construction of a simulator vehicle collisions in order to convince viewers about the need to use save seats in automobiles, had base on patents of sled tests used by research and development centers in vehicle safety. The main difference between it and the equipment with high costs (about R$ 2.500.000,00) and made just outside Brazil, is the use of a central tube which was designed from models used in "roller coasters".

The engineering challenges were focused on search a practical, low cost and effective solution to build a collisions simulator, transportable, with a total length less than twenty meters and capacity support to the installation of an ambulance stretcher or two-seater with retractable belts to withstand impact at a speed of up to 20 (km/h) against a deformable barrier.

Built to simulate frontal impacts, the requests of low-cost project (about R$ 10.000,00), easy transportation and quick installation (about 1 hour and 30 minutes) were achieved. Meets the basic requirement to achieve speeds that allow easy viewing from the time of match until the final collision. It allows the use of one of the bank places to secure a seat with a dummy by it retained and another dummy without retention, basic condition of the project aiming to permit the viewer to conclude the need to use restraint devices for children in cars. It fulfils the requests to provide an impact with enough kinetic energy to throw the dummy not retained, at enough distance and altitude to educate viewers about the danger, linked on no use of safe seats.

It has low weight structure and sufficiently rigid to keep steady, it may be used for several demonstrations on the same day. They are divided into modules facilitating transport, requiring only two (2) people to mount it. The base (track): It is divided into 4 modules of 3 meters long and 80 cm wide, with approximate mass of 14 (Kg) each, The two tubes, one with 6 meters and a mass of about 15 (kg) and one with 5.3 meters and an approximate mass of 13 (kg). The sled with an approximate mass of 25 (kg). The chair system for two places with an approximate mass of 55 (kg). An induction motor 3 (cv) with an approximate mass of (19 kg) and 1 frequency inverter with a mass of 1.8 (kg), total about 185 (Kg).

The approximately speed of 20 (km/h) was achieved using the propulsion model with a three-phase induction engine 3 (cv), which controlled by a frequency inverter with capacity to 10 (A), programmed to make a linear ramp acceleration with 5 seconds, pulls gradually 11 meters of steel cable attached with the test sled. The system with a single central tube fixed to the base (track) with a single central shoe attached to the sled, equipped with two pairs of wheels, placed parallel in the bottom of the tube, where the wheels of each pair are 120 ° out of phase each other, it is used to maintain the rectilinear trajectory for sled during testing, without the possibility of locking and without leave the track all the way and impact.

The sled by parameter and constructive design enforcement, impact reaches the barrier during simulation, without being pulled by the engine due to the automatic system shutdown, which is done through the presence sensor positioned in front of the track, turn off the engine when the distance from impact barrier is 5mm. The automated measurement system speed, made and used in the simulator, has a low standard deviation with averaging 0.38 (km/h).

Improvements with regard to the types of bearings and automation of the sled return to initial position can be discussed from now, in order to make this more practical model and simple as possible to handle. Concerning to speed test, although there is a possibility of increasing the frequency of the engine to its limits 60 (Hz), this will not increase final speed of the sled acceleration because of the space is not enough, limiting the sled test at 20 (km/h). The final speed of the simulator can be significantly higher in two ways. The first is the use of an induction engine with higher power, with a frequency inverter at high current capacity. The second, simpler way, would increase the size of the base (track), because with a larger path is possible increase acceleration time, thus final speed too.

In both solutions, there are limiting factors. In the first case, the frequency inverter and the engine used hinder mobility and assembly of simulator due to the sizes and weights, plus the higher cost of such equipment. In the latter case, a larger track requires larger areas to be installed. Although this limiting factor, this way become more appropriate to increase the final speed test if needed.

This project encourages and enables new research dynamic tests with national child safety products for car, as the study of child restraint systems on stretchers ambulances, closures systems, retentive strips, children's car seats, among others. An interestingly study could be realized is the impact absorption systems with deformation of metallic structures, depending on the deceleration curve of the results obtained by the model and if the rail speed is raised to values defined in the Brazilian standard, the simulator can turn out to be a model of validation tests for children's vehicle safety equipment.

5. ACKNOWLEDGEMENTS

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