Proceedings of COBEM 2003
COBEM2003 - 1072 17th International Congress of Mechanical Engineering
November 10-14, 2003, São Paulo, SP

TELEROBOTIC TROLLEY DESIGN FOR TV TRANSMISSION

Vitor Ferreira Romano
Federal University of Rio de Janeiro POLI/COPPE
Mechanical Eng. Department – Robotics Laboratory
Cidade Universitária – CT, Bloco G-204
21945-970 Rio de Janeiro - RJ - Brazil
romano@serv.com.ufrj.br
MANET – Manufacturing Automation Network

Cesar Gomes Ferreira
Digital Dinâmica Automação Ltda.
digitaldinamica@hotmail.com.br

Claudio Violante Ferreira
DSc. Candidate COPPE/UFRJ
cviolante@terra.com.br

Abstract. *In this article the mechatronical design related to the development of a telerobotic trolley project used for the 2002 Rio Carnival TV transmission is presented. The trolley system consists on a wheeled trolley that carries TV equipment and moves along a 300 meters binary linear track. A cameraperson sends command signals to an onboard microcontroller able to operate different acceleration ramps. The trolley dimensioning was based on FEM (Finite Element Method) modeling and performance tests done at the laboratory as well as on site. Other important design parameters were the space distribution of the onboard equipment and its electrical isolation to the car body. The parameters used in the FEM models of the supporting structures correspond to the existing solution implemented on site, so that data related to the stresses generated at specific points could be obtained in order to validate the system safety and reliability. The telerobot was successfully operated during the two days of the TV transmission.*

Keywords. *: mechatronics, telerobotics, mechatronical design, camera trolley, TV equipment*

1. Introduction

The “Samba school” parade in Rio de Janeiro Carnival is one of the most famous events in the world. Every year, a large amount of broadcast resources are installed on the site, so that TV transmission can obtain different and special view angles of the event. One of these resources in use for some years is a wheeled trolley that carries TV equipment onboard, such as the camera FLIR (pan-tilt remote head with a focus-zoom control and camera), transmission unit and battery packs. The trolley moves along a 300 meters binary linear track fixed on a supporting structure, Fig. (1) and Fig. (2). In the original trolley concept, DC voltage was transmitted through the binary linear track from the power supply to the motor located at the trolley, when the operator pressed a pedal. In case of danger, a break was actuated and a group of switches positioned near the track extremities guaranteed the cut of energy from the power supply when the trolley operator passed over the established travel limits. Also some modules of tracks located near the extremities were electrically isolated. The trolley velocity control was dependent on the real time operator’s ability in pressing pedals and the electrical consumption was enormous (Sampaio, 2001).

Figure 1. Operational scenario.

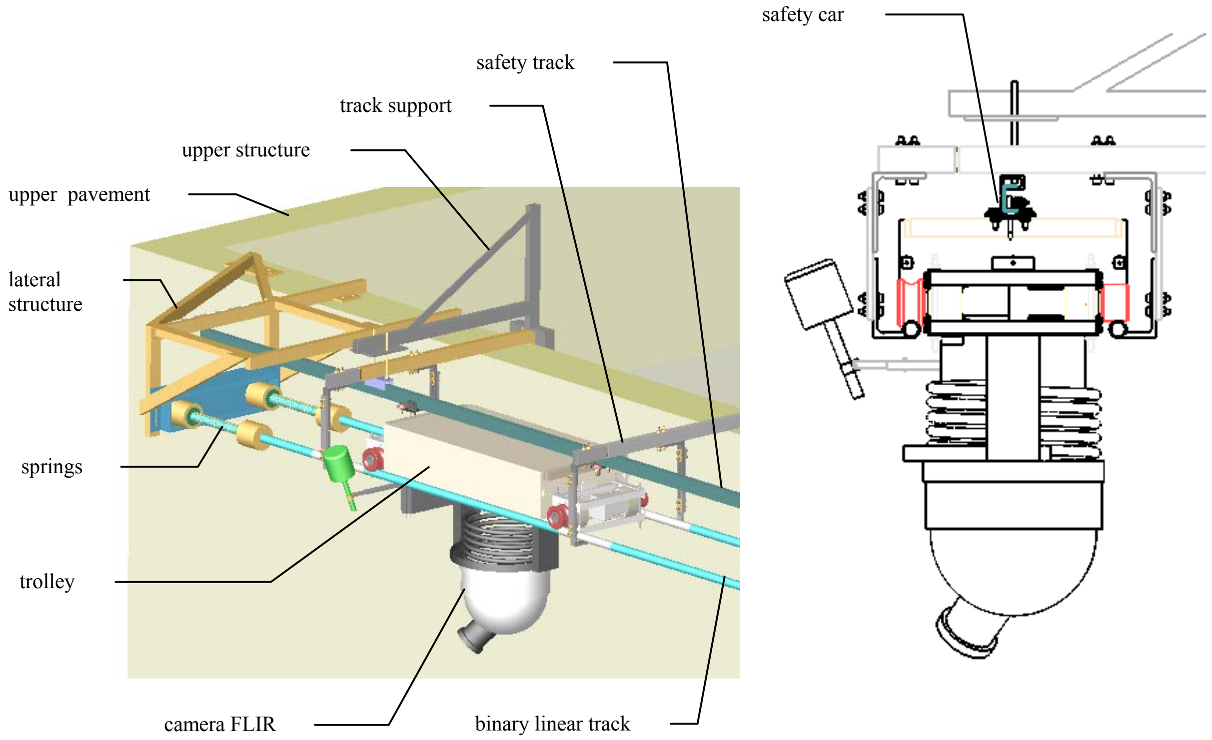
Figure 2. Details of the original structure.

Despite the intense use of the system, the project itself as though its installations and set up procedures were not submitted to a rigid safety control. Since the binary linear track is installed in a place near the public; the TV network responsible for the trolley system decided to start a new project, taking into consideration the system safety as the mandatory criteria for the solution implementation.

2. General aspects of the new trolley concept

Basically, the new trolley should carry the same TV equipment onboard and travel along a 300 meters binary linear track, as the previous one. The main technological aspects are related to the trolley mechatronical design and a conservative reinforced supporting structure. The new system is direct driven by a high torque step motor and has onboard electronics based on programmed microcontroller able to operate different acceleration ramps, limited to a maximum velocity of 2.3 m/s. AC voltage is transmitted through the binary linear track from the power supply to the trolley. When the operator presses one of the two buttons located at a command box, a modulated DC tone corresponding to an incremental value is sent through the binary linear track to the onboard microcontroller. Then, a pre-programmed acceleration ramp converts this input data into a calculated final velocity of the trolley. The same occurs when the second button is pressed, but in this case the incremental value assumes the opposite direction. This control strategy permits the cameraperson to be concentrated on the four degrees-of-freedom movements he needs to operate (pan, tilt, focus and zoom). Electromechanical switches were installed along the supporting structure to give the absolute position of the system in relation to the control centre room (Romano, 2002).

The entire project consisted on a new conceptual trolley mechatronical design and supporting structure, CAD modeling, structural analysis, strength tests of the supporting structure, construction of mechanical and electronic components, system integration and performance tests at the laboratory as well as on site, Fig. (3a) and Fig. (3b).



(a) (b)

Figure 3 (a) and (b). CAD modeling of the telerobotic system and supporting structures.

3. Structural elements

3.1. Track support

In the original system, the track supports were the only structural elements to fix the binary linear track to the upper pavement. In order to verify its structural conditions experimental tests were performed in twenty track supports, corresponding to 10% of the total number installed on site. They were submitted to gradual increased payloads and the bending deflection was monitored by two linear variable-differential-transformers (LVDT). The load cell and LVDT data were digitally recorded at a computer, see Fig. (4).

The first three samples were submitted to plastic collapse in order to obtain its plastic bending load limit, as presented in Fig. (5). The other 17 samples were tested for bending forces limited to 80% of the plastic load obtained in the previous tests. These tests resulted in mean bending load limit values of 4,800 N for elastic deformations and 6,166 N for plastic deformations. Considering the estimated total weight of 600 N for the trolley and onboard equipments, the track supports have a static safety factor of 8 (Battista, 2001).

Figure 4. Track support test facility.

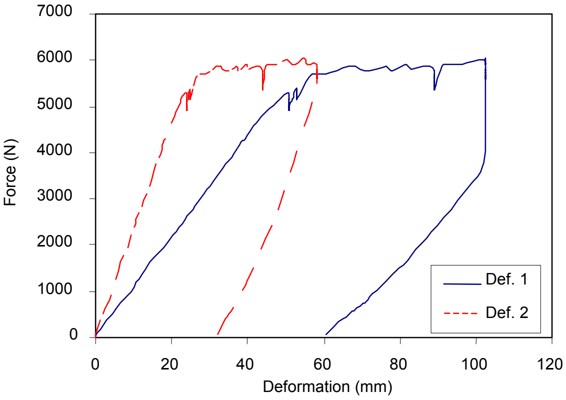


Figure 5. Force x deformation graphic (plastic deformation).

3.2. Safety tack and car

The safety track is installed above the binary tracks and is fixed at the upper structures, Fig. (3). It guides and permits the movement of a safety car connected to the trolley, so that in case of accident such as the rupture of the binary track or the derail of the trolley, the safety track and car will be the only devices avoiding the trolley to fall on the ground.

3.3. Upper structure

The upper structure connects the safety track to the upper pavement. It also operates as a redundant security structure of the support track, Fig. (3).

3.4. Lateral structure

This component is installed near the binary track extremities just to stop the trolley in case of any failure on trolley motion control, Fig. (3).

4. Conceptual design of the trolley

The design of the trolley was defined according to the onboard equipment characteristics. One of the criteria is the space layout distribution of the equipments, optimized to permit an easy mounting and dismounting of components, the access of the maintenance personnel and the elimination of any electromagnetic spurious signal. Celeron plates are used to electrically isolate the onboard equipment from the car body. Also the trolley mechanical parts were designed to provide an easy manufacture and maintenance, Fig. (6).

The trolley structural elements were calculated to permit elastic deformations in order to compensate for the inevitable track misalignments due to the lack of parallelism and planarity. The trolley structural dimensioning was based on FEM (Finite Element Method) modeling and performance tests done at the laboratory as well as on site.

In order to compensate for the lateral deviation of parallelism between tracks, the trolley had two shaped wheels to guide it along one of the binary tracks, and two normal wheels able to promote the necessary deviation adjustments in the second track.

The total mass of the trolley system including the equipment is 60 kg circa, Fig. (7).

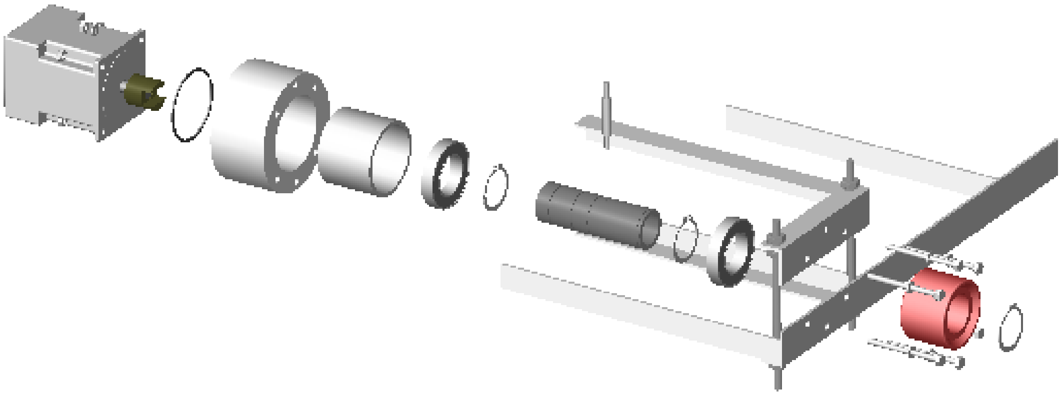


Figure 6. Mechanical parts of the actuator module.

Figure 7. Trolley with onboard equipments on site.

5. Control and power units

The binary linear track is used to transmit both energy to move the trolley motor and command signals to control the velocity module and direction. Brushes are used to obtain AC voltage from the binary track to the trolley. The AC power supply is located at the upper pavement.

The command box is the interface between the operator and the trolley system. By pressing one of the two buttons located at the command box, a modulated DC tone corresponding to an incremental value is sent through the binary linear track to the onboard microcontroller. Then, a preprogrammed acceleration ramp converts this input data into a calculated final velocity of the trolley. The same occurs when the second button is pressed, but in this case the incremental value assumes the opposite direction. Each button has independent DC tone generators, so that frequency interference problems are avoided. In Fig. (9) it is presented the command box functional scheme.

The control unit is located onboard and contains the electronic circuits needed to actuate the step motor. It has two PLL detection blocks synchronized at the same frequencies generated by the command box. The signals go to the microcontroller as input data to the preprogrammed acceleration ramp. Then, the microcontroller sends the correspondent step and direction parameters to the motor driver. The control unit functional scheme is shown in Fig. (10).

Extensive tests were done at an 8 meters long binary track test facility located at the Robotics Laboratory COPPE/UFRJ, Fig. (8), and on site, so that the integrated system formed by the mechatronical parts were properly adjusted.

Figure 8. Test facilities at LabRob COPPE/UFRJ.

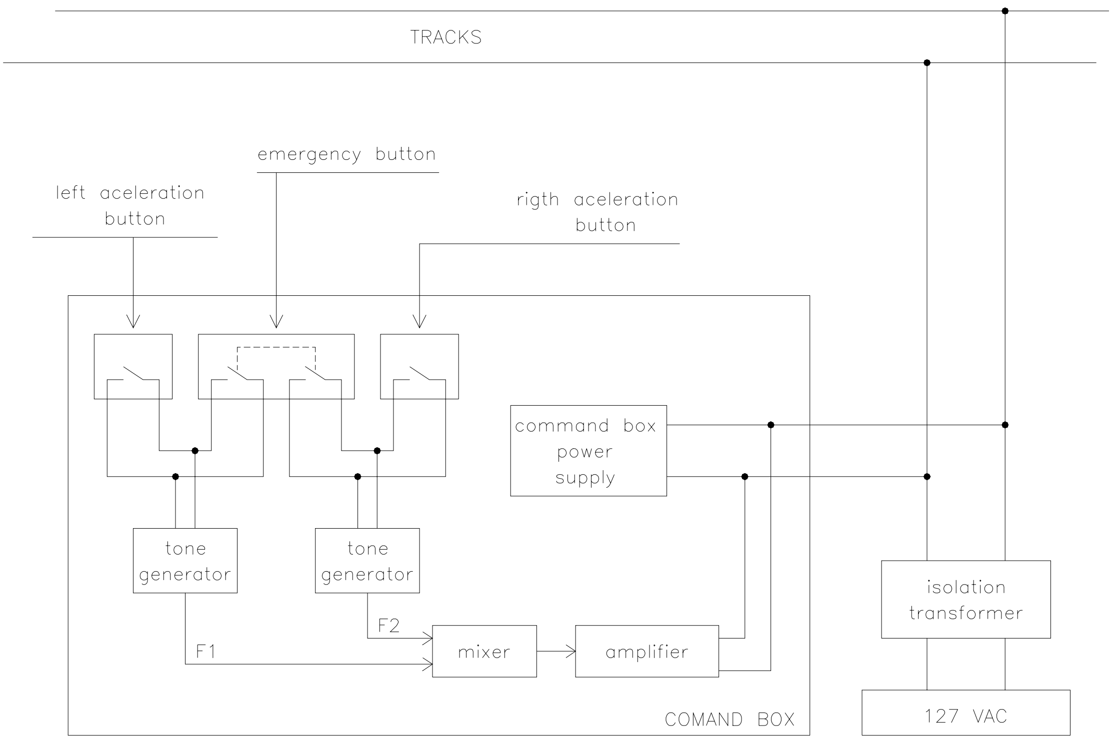


Figure 9. Command box functional scheme.

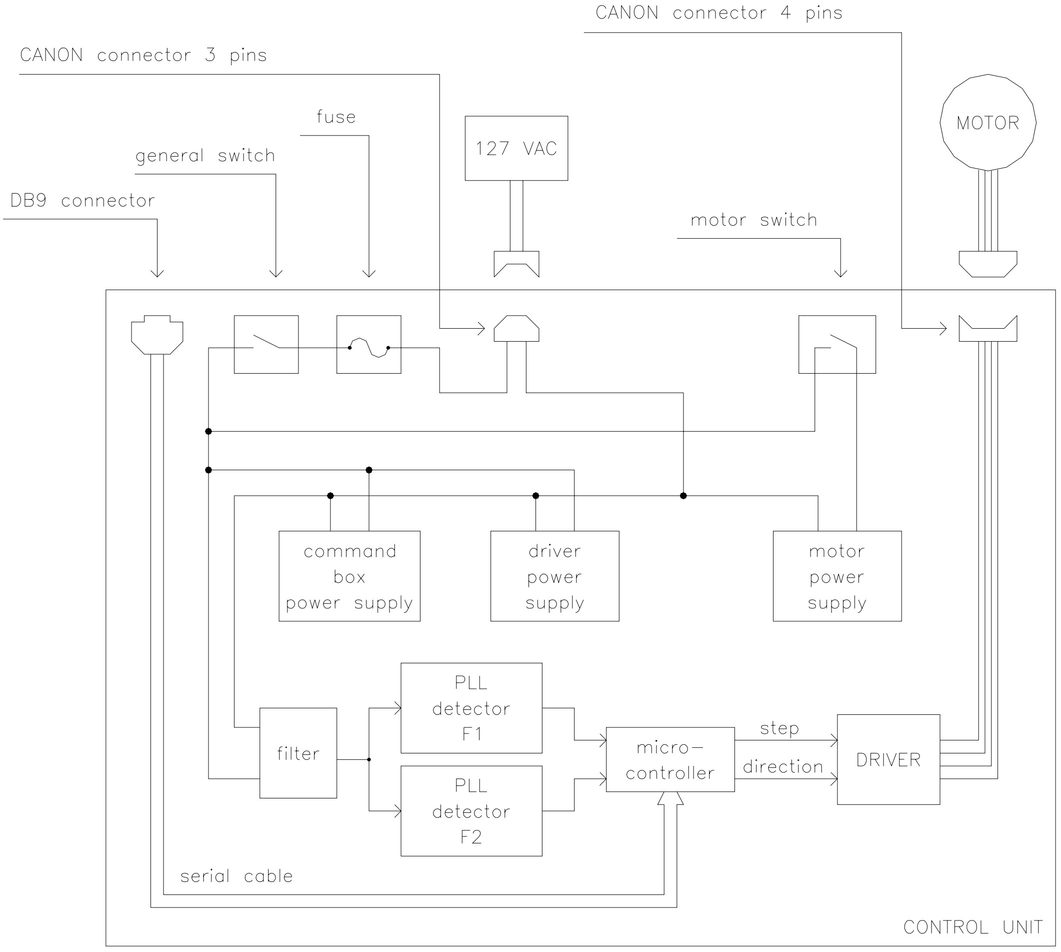


Figure 10. Control unit functional scheme.

6. Structural analysis of the supporting structure

6.1. General aspects

The trolley moves back and forth along the tracks, therefore its alternate motion may induce dynamic payload conditions on the supporting structures. The maximum controlled trolley velocity obtained at the site is 2.3 m/s, for a distance of 300 m, generating a low frequency excitation on the supporting structures. Tests with the integrated system performed at the laboratory, where an 8 m binary track was built, and on site showed that, in order to analyze the behavior of the supporting structures, consideration of the static payloads only was enough in the finite element method (FEM) modeling. The main components of the binary tracks are commercial tubes that are successively connected to the track supports. During summer the temperature of the tracks can change from 20^oC to 50^oC, therefore a special fixture device was conceived to separate appropriately the tube and track support interfaces, so that the necessary thermal expansion could occur. Each time the trolley passed through the interfaces, a perturbation was generated for the TV image, due to a local vertical impulse created at the trolley. This phenomenon was eliminated by extensive tests combining design factors, such as the distribution mass inside the trolley, the choice of the material hardness for the wheels and the application of absorber materials. Finally, the use of the camera FLIR, which is a gyrostabilizer platform, contributed to the achievement of the right image quality. A commercial FEM program, ANSYS® 5.4, was used in the analysis of the trolley and supporting structures. The element “3-D Elastic Beam” (ANSYS-PC, 1991) was used to model the components, since it can support tension, compression, torsion and bending. This element also has six degrees-of-freedom in each node (three translations and rotations referred to X, Y and Z axis). The most relevant data for the optimal design process resulting from the FEM analysis were the tensions and deformations of the elements at some specific locations, such as lateral structures, binary tracks, track supports, upper structures and safety tracks.

6.2. Characteristics of the models

The supporting structures were modeled for both normal operation and impact modes (Romano et all, 2003). In the normal operation mode, the trolley static payloads transmitted to the supporting structures were considered for a conservative value of 130 kg and the analysis performed in three situations: at central position, at the extremity and by a sequence of eleven positions simulating the passage of the trolley near a support track. In the impact mode the crash of the trolley is simulated at the speed of 2.3 m/s with deceleration time of 0.1s at the lateral structure and at the central position of the track structures. The following types of FEM models were considered: type 1 – track support (a) and binary track (b); type 2 – lateral structure (c), track support and binary track; type 3 – safety track (d) and upper structure (e). The displacement constraints at each of the FEM models free extremities admitted only 3 degrees-of-freedom for angular displacements. Gravity effect is included. In “table 1” some characteristics of FEM models defined previously are presented. From Fig. (11) to Fig. (14) some models and its correspondent nodal displacement graphs are indicated.

Table 1. FEM models for supporting structures.

Payload Conditions	Type 1	Type 2	Type 3
Normal operation			
✓ at central position	X	X	X (trolley derail)
✓ at the extremity	X	X	-
✓ sequence	X	-	X (trolley derail)
Impact			
✓ at central position	X	X	-
✓ at the extremity	X	X	-
Types of elements per module	2 (a), 2 (b)	2 (c), 2 (a), 2 (b)	2 (d), 4 (e)
Number of elements per module	5 (a), 8 (b)	13(c), 5 (a), 8 (b)	3 (d), 6 (e)
Number of modules	15 (a), 15 (b)	1 (c), 15 (a), 15 (b)	10 (d), 10 (e)
Displacement constraints	Fixed at upper pavement (a)	Fixed at upper pavement (c) Fixed at upper pavement (a)	Fixed at upper pavement (e)

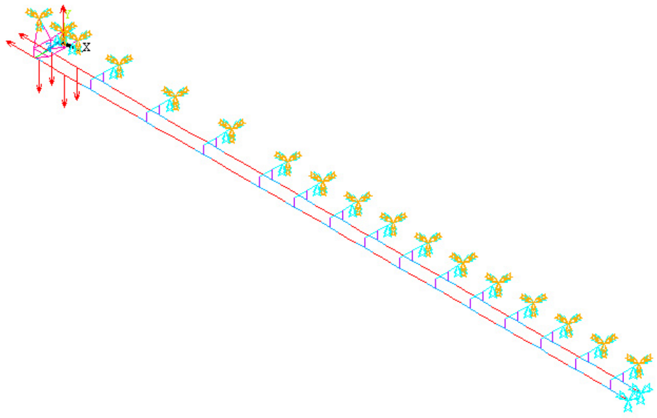


Figure 11. Type 2 FEM model with impact at the extremity.

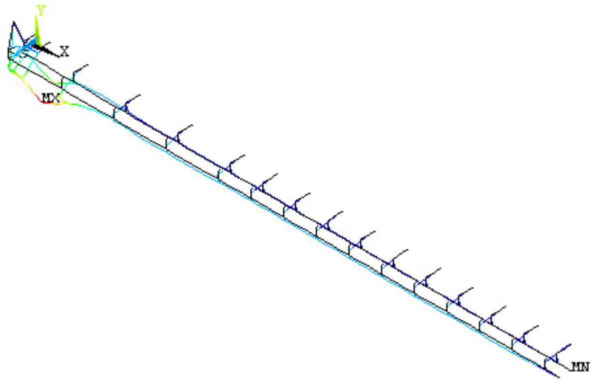


Figure 12. Nodal displacements of the Fig. (11).

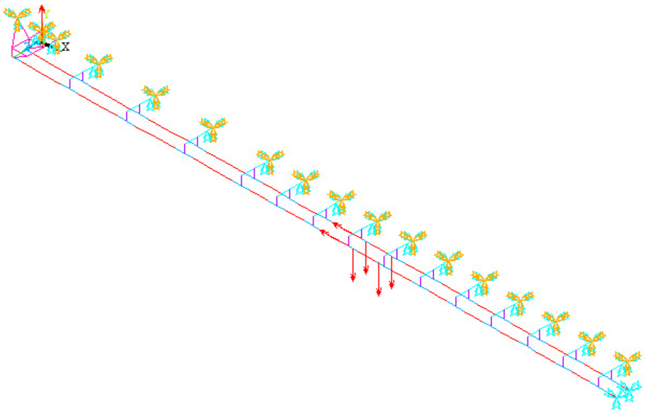


Figure 13. Type 2 FEM model with central impact

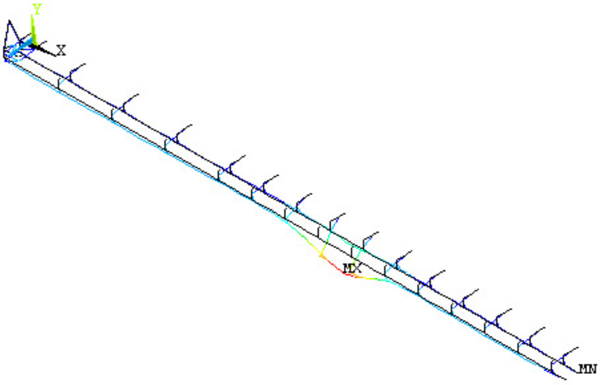


Figure 14. Nodal displacements of the Fig. (13).

The "3-D Elastic Beam" elements and nodes for the central position module of the type 1 FEM model are shown in Fig. (15). A module for the type 3 FEM model is presented in Fig. (16).

The tensions (mN/mm^2) at the most relevant structural elements for the sequence simulating the passage of the trolley (complete sequence) are represented in Fig. (17) and its nodal displacements (mm) are indicated in Fig. (18).

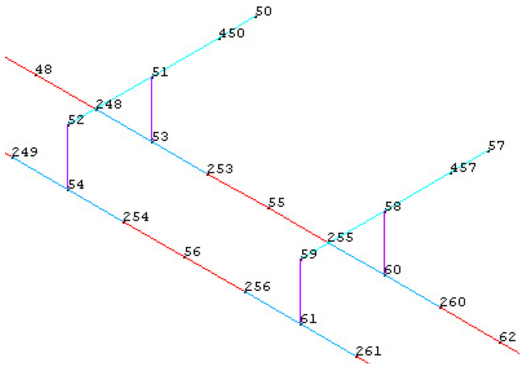


Figure 15. Module of Type 1 FEM model.

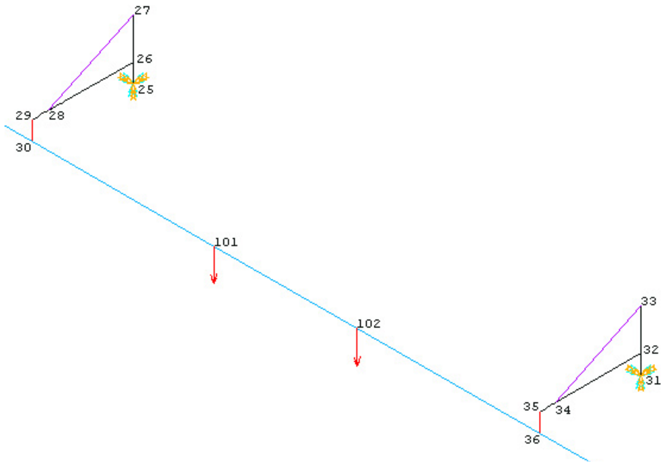


Figure 16. Module of Type 3 FEM model.

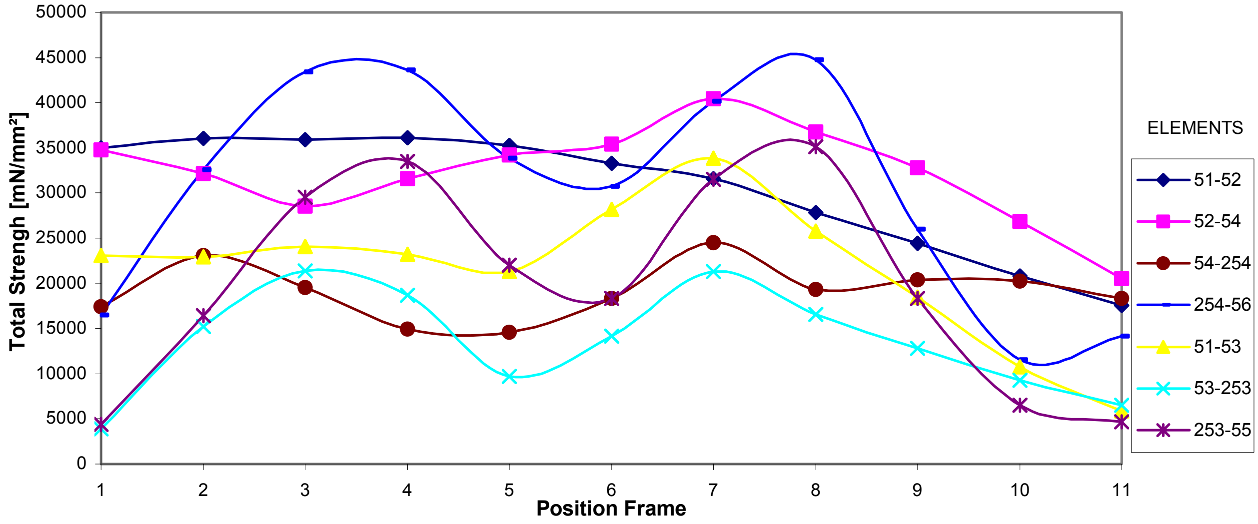


Figure 17. Tensions at elements of type 1 FEM model - complete sequence

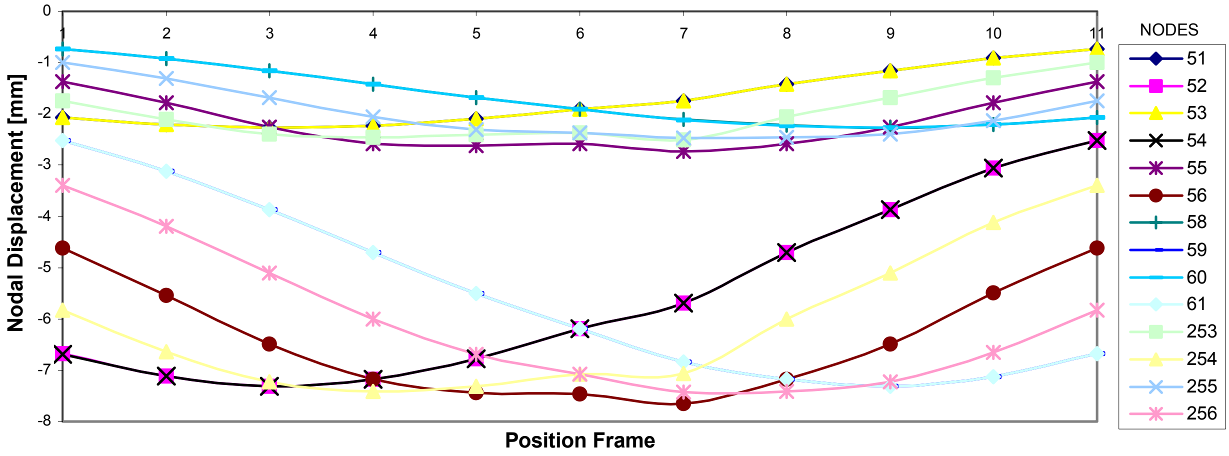


Figure 18. Nodal displacements for the type 1 FEM model - complete sequence

The type 3 FEM model with loads simulating the derail of the trolley at the central position can be noted in Fig. (19). Its correspondent nodal displacements are presented in Fig. (20) and the tensions (mN/mm^2) at some structural elements, see Fig. (16), for the complete sequence of eleven derail positions are indicated in Fig. (21).

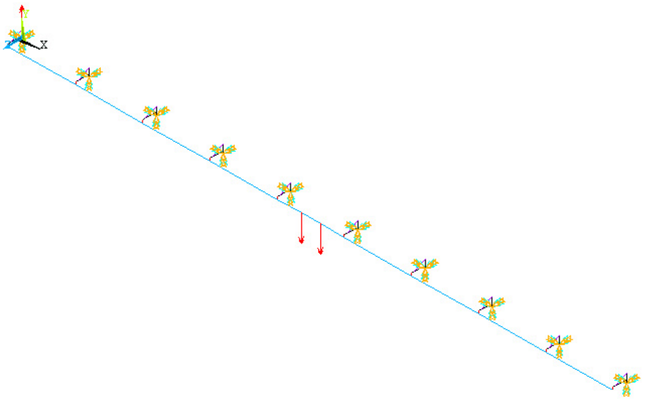


Figure 19. Type 3 FEM model with the trolley at central position.

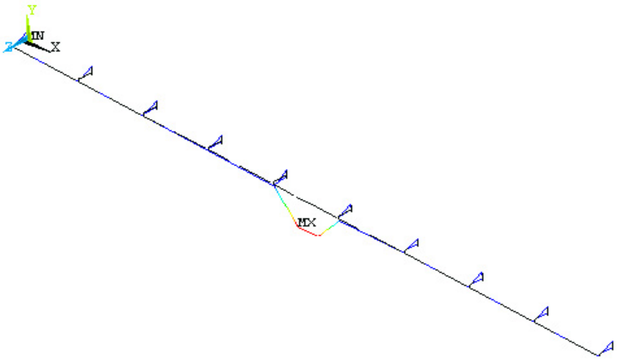


Figure 20. Nodal displacements of the Fig. (19).

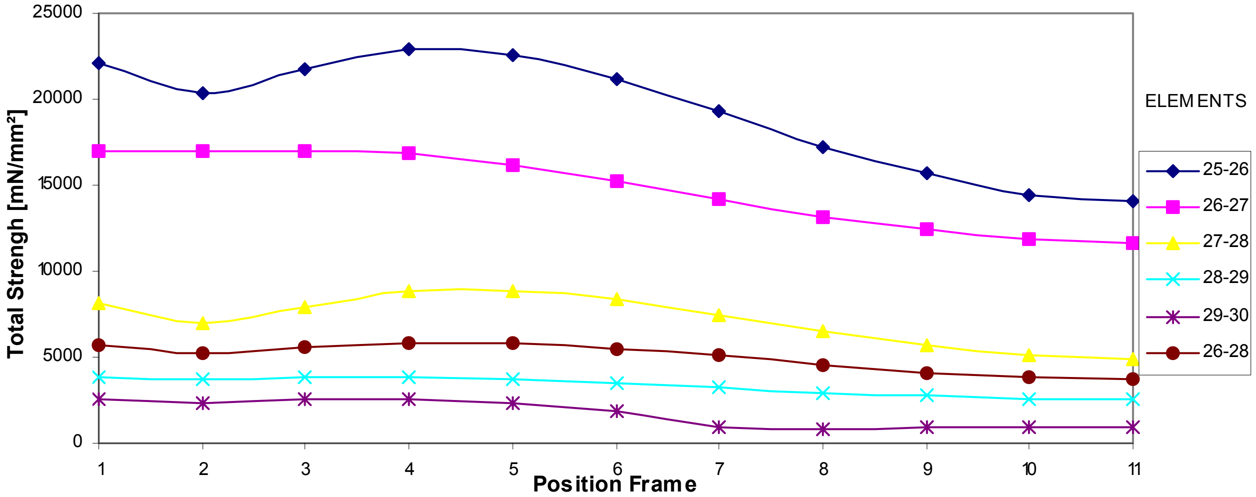


Figure 21. Tensions at elements for the type 3 FEM model - complete sequence

7. Structural analysis of the trolley

The trolley chassis was modeled for both normal operation and impact modes. In the normal operation mode, the onboard equipments transmit static payloads (approximately 400 N) to the trolley chassis, due to gravity acceleration. In the impact mode the trolley chassis model simulates the crash of the trolley at the speed of 2.3 m/s with deceleration time of 0.1s, as considered in the supporting structure modeling. The impact forces were estimated for a total mass of 130 Kg and an elastic collision.

In Fig. (22) the elements and the external forces applied to the trolley are presented for the impact mode, and in Fig. (23) the resulting nodal displacements of the trolley are shown.

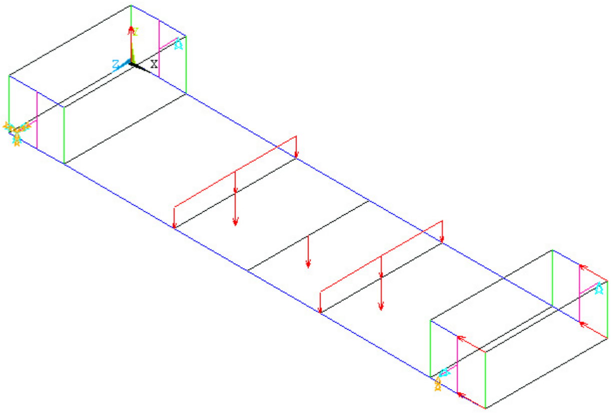


Figure 22. FEM of the trolley with external forces.

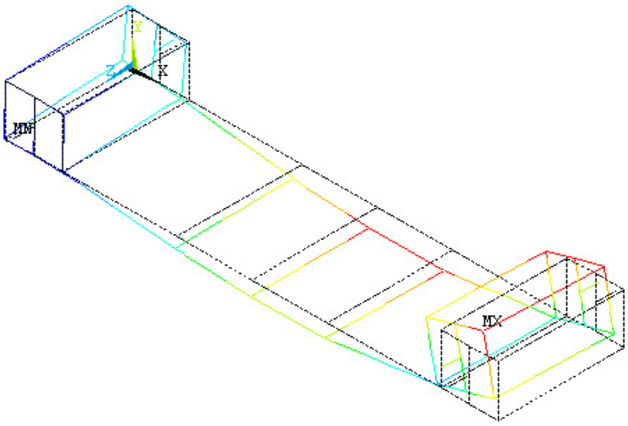


Figure 23. Trolley nodal displacements of Fig. (22).

8. Safety aspects

The system safety reliability was the main condition to be considered during the project implementation.

Some efficient measures were taken, such as the existence of electric isolated binary tracks at the extremities, and the maximum velocity limited by software and hardware. There are also springs touching the lateral structure, which are able to decelerate the trolley within the calculated course of 600 mm.

A crash test was done with the trolley colliding with a wooden stick located over the binary track, resulting in the fracture of the stick. For safety purposes a test was made with a metal stick placed at the same location, resulting in a short-circuit and consequently the automatic interruption of energy from the power supply.

The probability of existing undesirable obstacles on the track was reduced, because only authorized personnel could access the upper pavement, and a strict surveillance during the event was enforced.

9. Conclusions

The dimensioning procedure based on FEM was essential for the development of the telerobotic trolley system, since the design, construction and set-up of the entire system (including hardware and control) were done within 105 days. The system performance at the laboratory and on site is an evidence that the modeling, design and construction of the trolley system were indeed correctly carried out.

The mechanical tensions calculated at the elements were below the elastic limits of the materials (Beitz et all, 1994), except for the safety track where plastic deformations would occur in case of derail of the trolley. In this case the tension is safely below the rupture tension and the element damaged could be quickly substituted by a simple maintenance procedure.

The telerobotic trolley was operated without interruption during the two days of the “samba schools” parade in Rio de Janeiro with a successful performance.

In Fig. (24) a photo taken on the first operational day of the telerobotic trolley is presented.

In may 2002 a crash test was made with the trolley and the springs located at the lateral structure, in order to verify the efficiency of the springs under the maximum payload and the eventual malfunction of the hardware after the impact.

The safety system formed by the springs was proved to be effective and the trolley system worked properly.

Figure 24. Photo of the telerobotic trolley in operation.

Acknowledgements

The authors thank Eng. João Paulo Pinto Pereira of the Tecnoflex Engenharia Ltda., Eng. Luiz Eduardo Demenicis, and Prof. Ronaldo Carvalho Battista for their valuable and active participation on the project. The authors also thank MSc. Gilson Vaz Sampaio and the team from TV Globo Ltda. CGE-DEMEM SMECJAC for the logistics.

References

ANSYS Inc., 1992, “ANSYS 5.4 Reference Manual”, EUA.

Battista, R. C., 2001, “Technical Report COPPETEC PEC-3070 – Structural Verification of the Camera-trolley Track Supports”, Civil Engineering Department COPPE/UFRJ, (in portuguese), 23 p.

Beitz, W. and Küttner K.-H., Editors, 1994, “Dubbel Handbook of Mechanical Engineering”, Springer-Verlag, Germany, appendix C6, table 12.

Romano, V. F., 2002, “Technical Report COPPETEC PEM-2671 - Revision, Analisys and Validation of the Camera-trolley System and Tracks", Mechanical Engineering Department COPPE/UFRJ, (in portuguese), 172 p.

Romano, V.F., and Ferreira, C.V., 2003 , “Static Structural Analysis of a Telerobotic Trolley for the TV Transmission”, Proceedings of the X DINAME-International Symposium on Dynamic Problems of Mechanics, Vol. 1, pp. 71 - 76, march 2003, Ubatuba, São Paulo, Brazil.

Sampaio, G.V., 2001, “TV Globo Technical Report RE.047.01”, (in portuguese), 5 p.