Report:
Division of the resulting forces in biomechanics platforms

1. Objective:

This study has had as finality to evaluate the possibility of the utilization of a measurement system of the pressure distribution to determine the components of the resulting force, correspondent to each partial loading, when a double loading occurs on the biomechanics platforms.

The decomposition of the resulting force is possible, as the theoretical model described in the section 4, by the determination of the trajectories of the center of pressures (CoP) of the partial loading. The center of pressure coordinates to each instant of loading make possible the direct application of the static equations ($\sum F = 0$ and $\sum M = 0$) to determine the components of the resulting force, however the total loading can not be decomposed, because the torque Tz, applied on the platform surface, to each partial loading can not be determined by the model proposed. This limitation claims for a complementary study, to evaluate the influence of this error in the kinetics data utilized in tests of gait.

The use of a measurement system of the pressure distribution, stated on the biomechanic platform surface, allows to determine the trajectories of the centers of pressure of each loading lonely, so, it was necessary, to evaluate this project, to quantify and to compare the trajectories of the centers of pressure measured by both instruments. The tests realized in this study have esteemed the differences existent between the centers of pressure determined by the biomechanic platform and by the measurement system of the distribution pressure on a application of a single loading and variable as function of time. In these conditions, the trajectories of the center of pressure will be analogous, allowing its comparison.

If it was confirmed the viability of conjunct operation of these instruments, it will be possible to improve and simplify so much in the test protocol of gait as such in the proper project of the biomechanics platforms. The platforms fabricated by the company AMTI, for example, the center of pressure coordinates, for a generic loading, are calculated through the measuring of the moments around the axes longitudinal and transverse of the platform, by the follow equations: $Y = Mx/Fz$ and $X = -My/Fz$, where Fz is the vertical component of the total force applied (section 2.1). With the utilization of the measurement system of pressures distribution, which will measure the center of pressure coordinates, the biomechanic platform will not be necessarily equipped with instruments to measure the moments Mx and My, and so having its structure simplified. It will be possible to use only one platform, more longer, instead of two or three smaller, as such it is used now. And about the gait test, two improvements will be possible: decrease in the number of trials collected for evaluation of the kinetic movement pattern, because in all trials will be possible to decompose the resulting force measured by the biomechanic platform, to calculate the moment and the articulate power; and to chart and to quantify the distribution pressure that occur under the patients feet.

2. Used materials

2.1 Biomechanic Platform AMTI model OR6-5-1000 incorporated to the Vicon 370 system of gait analysis (Oxford Metrics Limited).

- Collect data frequency: 600 Hz.
- Platform dimensions: width = 18.25″ x length = 20″
- The origin of the coordinate system is near the geometric center of the platform and is located $\mathbf{X_0}$, $\mathbf{Y_0}$, $\mathbf{Z_0}$ from the center of the surface (figure 2.1).

For the platform used the coordinates of the origin are:

$\mathbf{X_0}$ = -1.00 mm
$\mathbf{Y_0}$ = -0.76 mm
$\mathbf{Z_0}$ = 38.00 mm

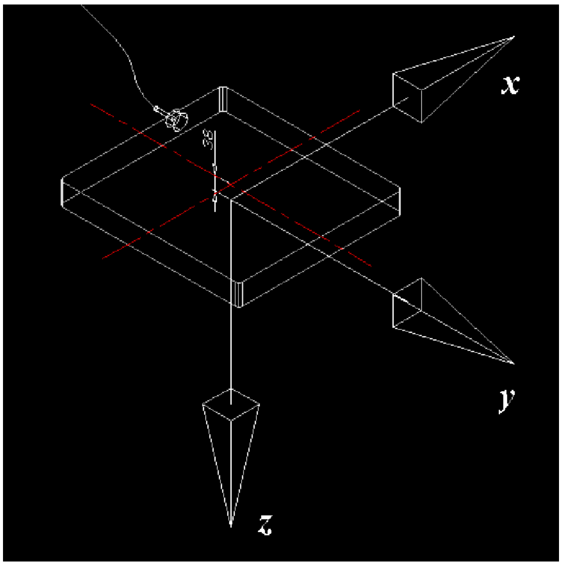


Figure 2.1

- WWW: AMTI, INC (http://www.amtiweb.com)

2.2.1 Platform of measurement pressure Footscan, operating with clinic analysis program.

- Platform dimensions:
  Width = 405 mm x Length = 1000 mm x Height = 10 mm
- Collect data frequency: 166 Hz
- Linearity: 5.8 %
- Hysteresis: 19.6 %
- Accuracy: 3.3 %
- Repeatability: 0.98 %
- WWW: RsScan International (http://www.rsscan.com)

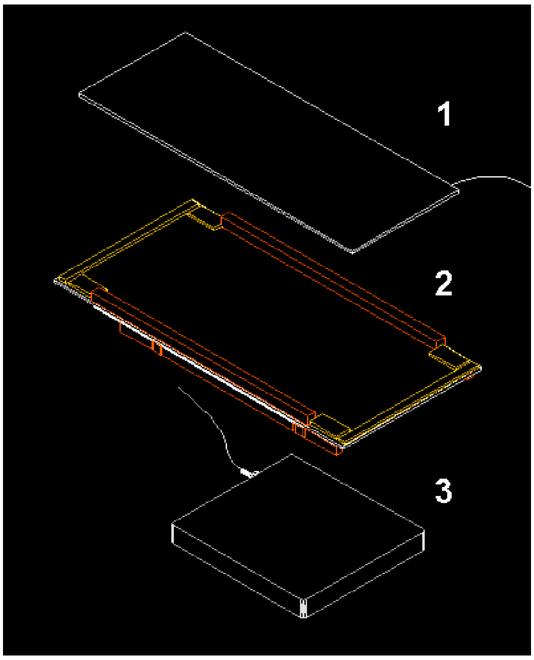
2.2.2 Trigger to synchronize the systems Footscan and Vicon 370

- WWW: RsScan International (http://www.rsscan.com)

2.3 The Program C3D Editor, Version 2.55, to edit, filter and conversion of the data begotten by the Vicon 370 system (files in C3D format)

- WWW: Motion Lab Systems (http://www.emgsrus.com)

2.4 Support in Polycarbonate and PVC (figures 2.2 and 2.3) to assembly and attachment of the Footscan platform over the AMTI platform.



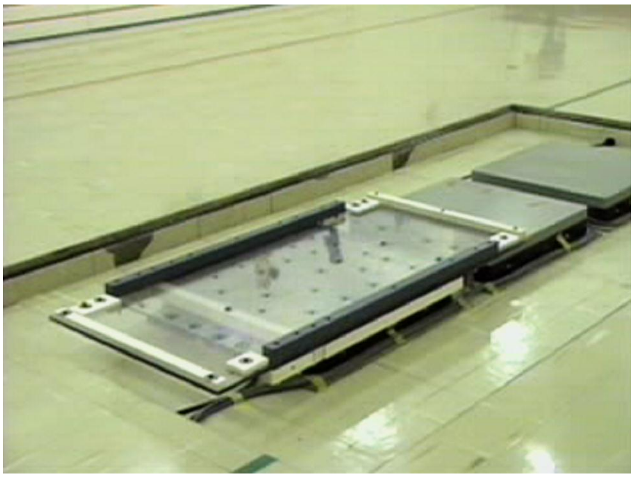


Figure 2.3

Figure 2.2 (exploded view)
1- Footscan plate
2- Support in Polycarbonate and PVC
3- AMTI Biomechanic Platform

2.5 Mathcad 2000 Pro Program to automate the calculations and to process the data collected.
WWW: http://www.mathsoft.com

3. The methodology used to collect the data:

3.1 The instruments set assembling.

With the finality of guarantee the maximum acuity and precision possible, through of the minimizing of deadening effects, it was built a support in industrial plastic (Polycarbonate/PVC) to fix the Footscan platform to the AMTI platform. The support was projected with a conjunct of 4 lower jig, to allow its fixation to the border of AMTI platform using screws. On the superior face of the support, a conjunct of 6 adjustable lateral props fixed the Footscan platform. The base to support the Footscan platform, witch had bigger dimensions than AMTI platform (consult item 2), was built in two Polycarbonate plate, with 10 mm and 5 mm of thickness, fixed together with screws. The support's weight, without the Footscan platform, was 15 kgf approximately.

3.2 Synchronization of the systems

The synchronization between the Footscan and Vicon 370 systems was tried through a electronic trigger actuated by the application of a loading on the Footscan platform. The minimal loading to emit a signal of beginning of engraving was 1 Newton. In the Vicon 370 system the trigger was connected to the door of remote control J3 ("This connection is included to make the Vicon DataStation compatible with all previous generations of Vicon. The connector function is to allow the remote control of the data capture from external switches or photo-electric sensors"). - Vicon 370 System User and Diagnostics Manual, page 26.

After a sequence of tests, only to analyze the trigger operation, it was verified the impossibility to use a device with this characteristics to synchronize the systems. It has occurred a delay in engraving of the analogical data controlled by the Vicon 370 system and the Footscan platform, causing a loosing of data. Other trigger was built, with a drive regulator, as a try to start the engraving of the Vicon 370 system with a lower loading on the Footscan platform, but a similar result was obtained. So, we have chose, in front of the impossibility of the solution of this problem, by the drive not simultaneous of the two systems, but preserving all information volume collected. Afterwards, it was tried, through of vertical forces graphics (Fv) produced independent by Vicon and Footscan systems, the synchronization of the events. This proceeding will be detailed in section 5 (Memorial of calculus).

3.3 Type of loading

A single loading, variable as function of time, was applied to Footscan/AMTI conjunct only over the common area of the two platforms. This loading was generated through a up and down movement, by the same side, over the platforms (Figure 3.1). An adult subject, with 80 kgf weigh, exerted this action, being the backing made always over one of the feet. Instead of a progressive trajectory of the center of pressure noted in a normal gait (Figure 3.2), the trajectory produced was cyclic, having its ending near to initial contact point Fig. 3.3).

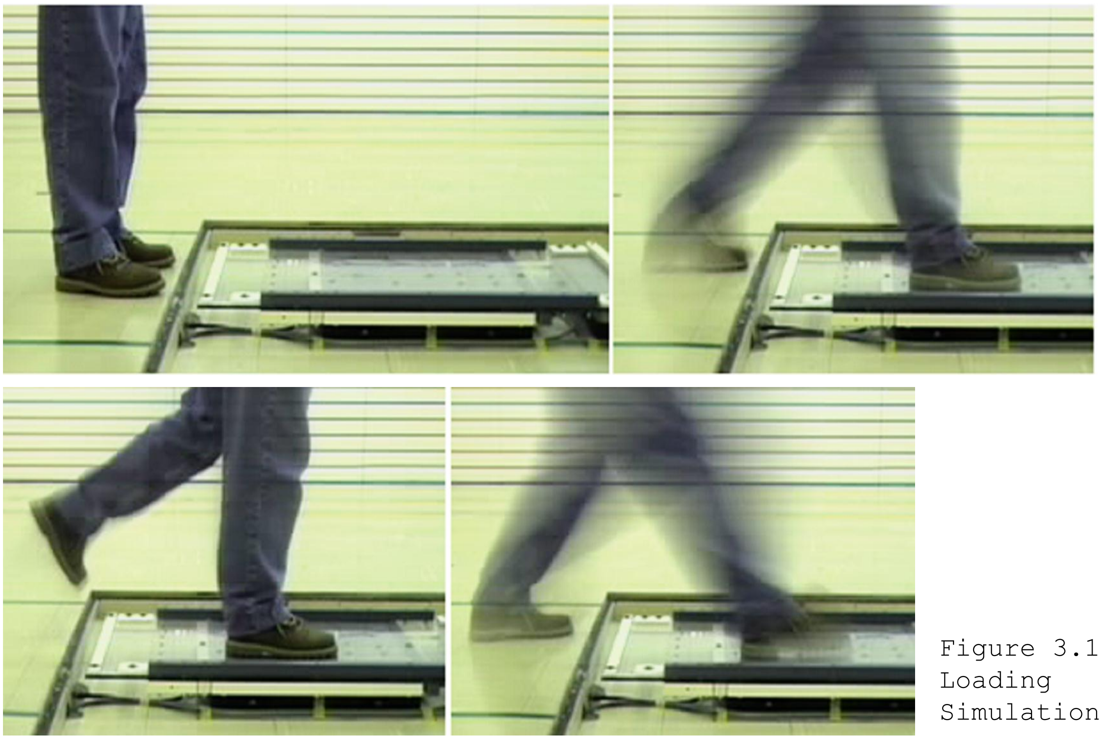


Figure 3.1 Loading Simulation

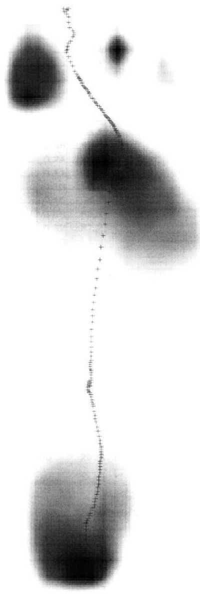


Figure 3.2

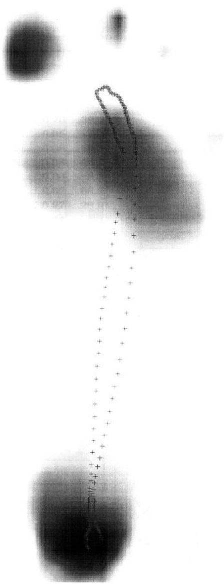


Figure 3.3

4. Theoretical Model of Calculation

Two loading F1 (Fx1, Fy1, Fz1, Tz1) e F2 (Fx2, Fy2, Fz2, Tz2) (Figure 4.1) are applied on a biomechanic platform on the points (x1, y1) and (x2, y2) respectively, producing a resulting force F (Fx, Fy, Fz) and the moment Tz in the coordinates (x, y) (Figure 4.2), measured by the platform.

<u>Simulation:</u> Platform with double loading

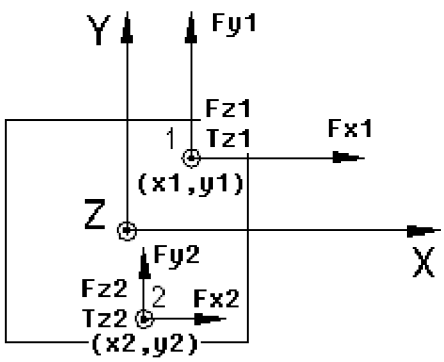


Figure 4.1

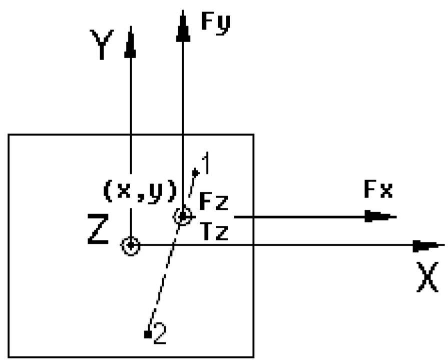


Figure 4.2

<u>Note:</u> The axes X, Y and Z were just built for effect of the demonstration of this method, the real axes of the platform are positioned in a different form.

Variables measured by the platform:

- Resultant Force in X (longitudinal) = Fx
- Resultant Force in Y (transverse) = Fy
- Resultant Force in Z (vertical) = Fz
- Moment in X = Mx
- Moment in Y = My
- Moment in Z = Mz

Variables calculated by the platform (AMTI):

– Coordinates of the resulting force = (x, y)
<u>OR6-5 Manual - page 2:</u>

$$Mx = Fz * y \quad \text{thus:} \quad y = Mx / Fz$$
$$My = - Fz * x \quad \text{thus:} \quad x = - My / Fz$$

– Moment Tz
<u>OR6-5 Manual - page 2:</u>

$$Mz = - Fx * y + Fy * x + Tz \quad \text{thus:} \quad Tz = Mz + Fx * y - Fy * x$$

Note: It is not possible to decompose the moment Tz.

Variables measured by the mesh Foot Scan:

– Vertical Force in the point 1 = Fz1
– Coordinates of the center of pressure of the point 1 = (x1, y1)
– Vertical Force in the point 2 = Fz2
– Coordinates of the center of pressure of the point 2 = (x2, y2)

System of equations for determination of the values Fx1, Fy1, Fx2 and Fy2:

(1) $Fx = Fx1 + Fx2$
(2) $Fy = Fy1 + Fy2$
(3) $Mz = - Fx * y + Fy * x + Tz$
However:
(4) $- Fx * y = - Fx1 * y1 + Fx2 * y2$ (equivalent moments)
(5) $Fy * x = Fy1 * x1 + Fy2 * x2$ (equivalent moments)
Thus:
(3.1) $Mz = (- Fx1 * y1 + Fx2 * y2) + Fy * x + Tz$
(3.2) $Mz = - Fx * y + (Fy1 * x1 + Fy2 * x2) + Tz$

System of equations:

(1) $Fx = Fx1 + Fx2$
(2) $Fy = Fy1 + Fy2$
(3.1) $Mz = (- Fx1 * y1 + Fx2 * y2) + Fy * x + Tz$
(3.2) $Mz = - Fx * y + (Fy1 * x1 + Fy2 * x2) + Tz$

5. Memorial of Calculus.

The complete sequence of calculations, used for determination and comparison of the trajectories of the center of pressure, are detailed in this section. It were used the programs C3D Editor for filtration, to edit and export the data generated by the Vicon 370 system, and the Mathcad 2000 Pro to the automatization of the calculation.

On the following items, to aid the understanding of methodology, it was used as example the trial nr. seg_03 (section 7).

5.1 Filtering of the analogical data of the AMTI platform:

It was applied to the same analogicals channels a filter type FIR-Low Pass with order (n) = 20 and cutting frequency = 75 Hz, to eliminate the noises of larger intensity (figures 5.1.1 and 5.1.2).

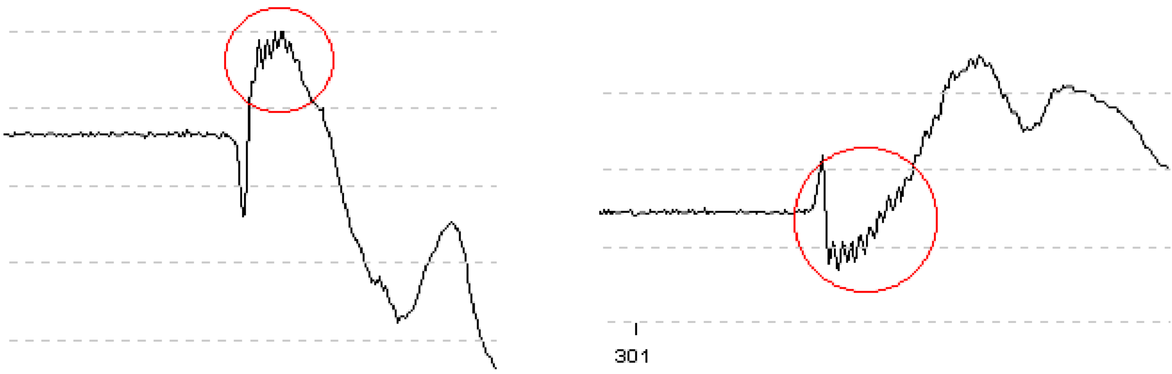


Figure 5.1.1 (Noises - Channels Fx and Mz - Start of the loading)

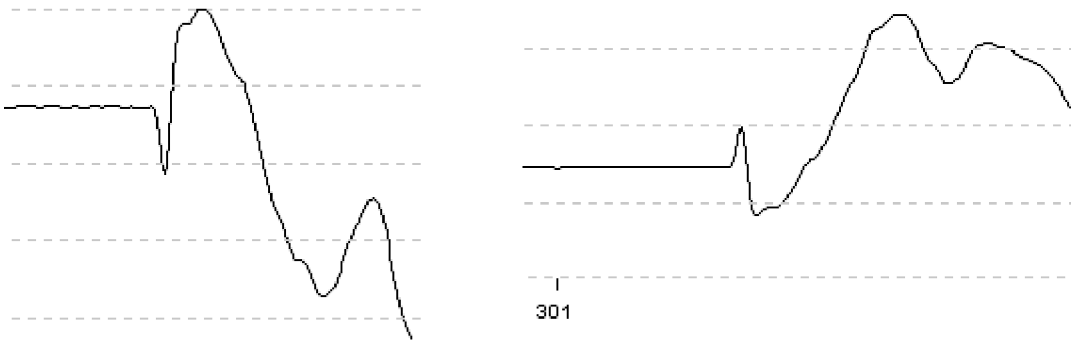


Figure 5.1.2 (Channels Fx and Mz filtered)

5.2 Setting in "Zero" the AMTI Platform:

Due the weights of the fixation's support, of the Footscan platform and calibration's error (bridge balance), the channels of the AMTI platform, mainly Fz, Mx and My, have accused overloading (Figure 5.2.1). The correction of these deviations was done, through a recourse of C3D Editor software, by the subtraction of the values measured in each analogical channel of Force and Moment by the medium value of the one sample of the ten firsths "samples" of the respective channels (Figures 5.2.1 and 5.2.2).

Figure 5.2.1 (Channel Fz overloading)

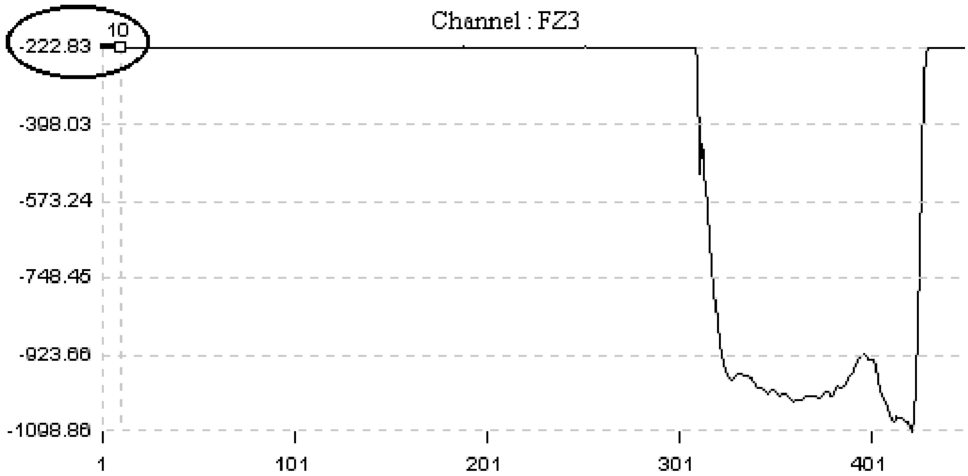
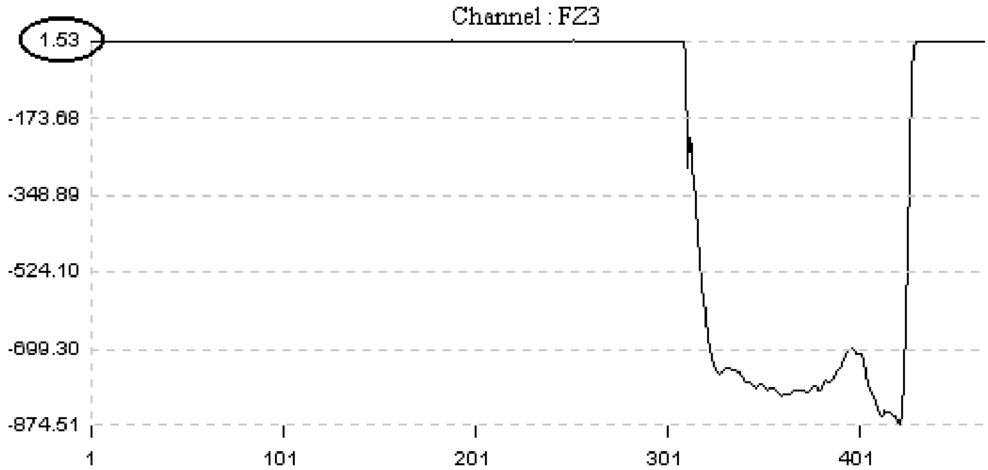


Figure 5.2.2 (Channel Fz with overloading subtraction - complete rectification of the data)



After the execution of these two rectification's process, all the data were exported, in files format *.CSV, to continue the calculations in the programs MS Excel 97 and Mathcad 2000 Pro.

5.3 Duration estimate of the loading time

It was used Visual Basic routine, inner to the MS Excel, to determine the instant of start and end of the loading. The Vertical Force was used as unique parameter of evaluation. It is showed in the Figures 5.3.1 and 5.3.2 a part of the data planking and the two instants determined. As reference, all channels were setting in "zero" on the initial and final.

Figure 5.3.1 (Loading start. Sample: 3082)

Sample	FX3	FY3	FZ3	MX3	MY3	MZ3
3079	0.178	0.18	0	0	0	0
3080	0	0.18	0	0	0	0
3081	0	0.18	0	0	0	0
3082	0	0	0	0	0	0
3083	0	0	-2.289	-285.96	0	0
3084	0	0	-3.052	-476.6	0	45.39
3085	0	-0.18	-4.579	-762.56	95.09	45.39
3086	0	-0.36	-6.868	-1143.84	95.09	45.39
3087	0	-0.36	-10.683	-1620.44	190.18	45.39
3088	0	-0.54	-13.736	-2097.04	190.18	45.39
3089	0	-0.72	-17.551	-2764.28	285.27	0
3090	0.178	-0.9	-24.419	-3622.16	285.27	0
3091	0	-1.081	-32.813	-5147.28	380.36	45.39
3092	-0.356	-0.9	-45.786	-7816.24	665.63	90.78
3093	-1.246	-0.18	-67.916	-12200.96	1141.08	226.95
3094	-2.67	1.081	-99.203	-18396.76	1711.62	453.9
3095	-4.45	3.062	-148.805	-26213	2472.34	726.24

Figure 5.3.2 (Loading end. Sample: 4287)

Sample	FX3	FY3	FZ3	MX3	MY3	MZ3
4274	4.45	-0.18	-41.207	-7625.6	190.18	-862.41
4275	4.984	-2.521	-35.103	-6481.76	0	-953.19
4276	5.34	-4.322	-28.235	-5623.88	-95.09	-1043.97
4277	5.162	-5.223	-23.656	-4861.32	-190.18	-1043.97
4278	4.628	-5.403	-19.078	-4194.08	-190.18	-907.8
4279	3.738	-4.863	-16.025	-3622.16	-190.18	-771.63
4280	2.67	-3.962	-13.736	-2954.92	-190.18	-544.68
4281	1.78	-2.882	-9.92	-2478.32	-285.27	-408.51
4282	1.246	-1.981	-9.157	-2001.72	-285.27	-272.34
4283	0.89	-1.261	-6.868	-1525.12	-285.27	-226.95
4284	0.712	-0.72	-5.342	-1239.16	-285.27	-181.56
4285	0.534	-0.36	-4.579	-857.88	-285.27	-181.56
4286	0.534	-0.18	-3.052	-667.24	-285.27	-136.17
4287	0	0	0	0	0	0
4288	0.356	0.18	-2.289	-285.96	-285.27	-90.78
4289	0.178	0.36	-0.763	-190.64	-285.27	-45.39
4290	0.178	0.54	-0.763	-190.64	-190.18	-45.39

– Loading duration on the AMTI platform

Frequency of conversion analogical/digital used by the Vicon 370 system = 600 Hz.

Total time:

Start Sample = 3082
End Sample = 4287

Total time of loading (AMTI) = (4287 - 3082) / 600 = 2.0083 seconds

- Loading duration on the Footscan platform (value measured directly by the own system):

Total time of loading (Footscan) = 1.973 seconds

Time difference between the systems = 0.0353 seconds

Note:
It was verified, as in this example, that the time calculated to the AMTI platform were superior than those measured by the Footscan platform, in all the trials processed.

5.4 Comparison between the values of Vertical Force of the Footscan system and AMTI platform (Figure 5.4):

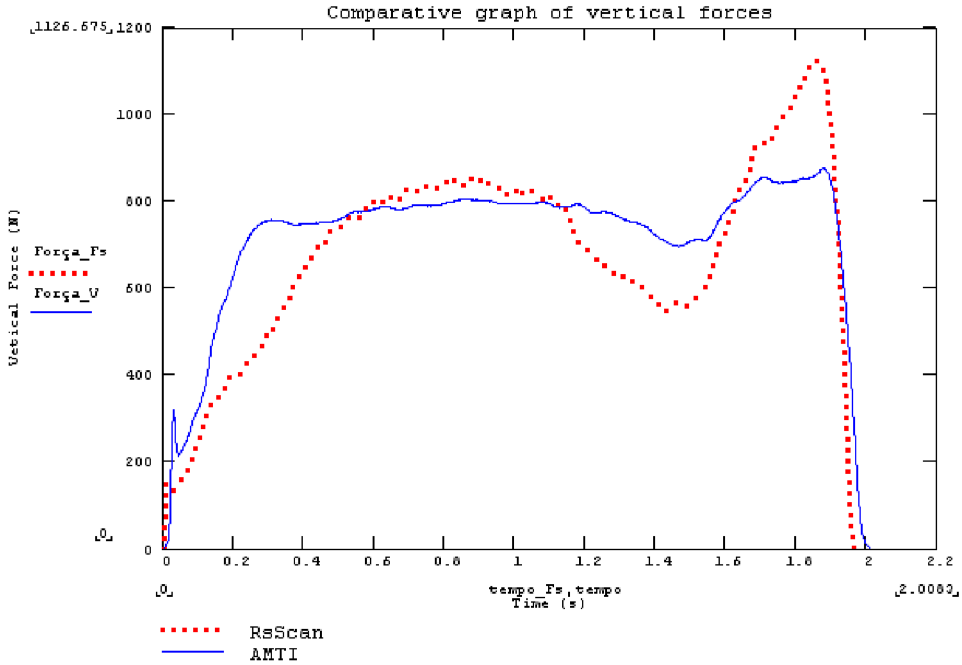


Figure 5.4

Note:
The differences between the profiles of the graphics of Vertical Force were constants, even proceeding the recalibration of the Footscan system.

5.5 Coordinates determination of the center of pressure for the AMTI platform

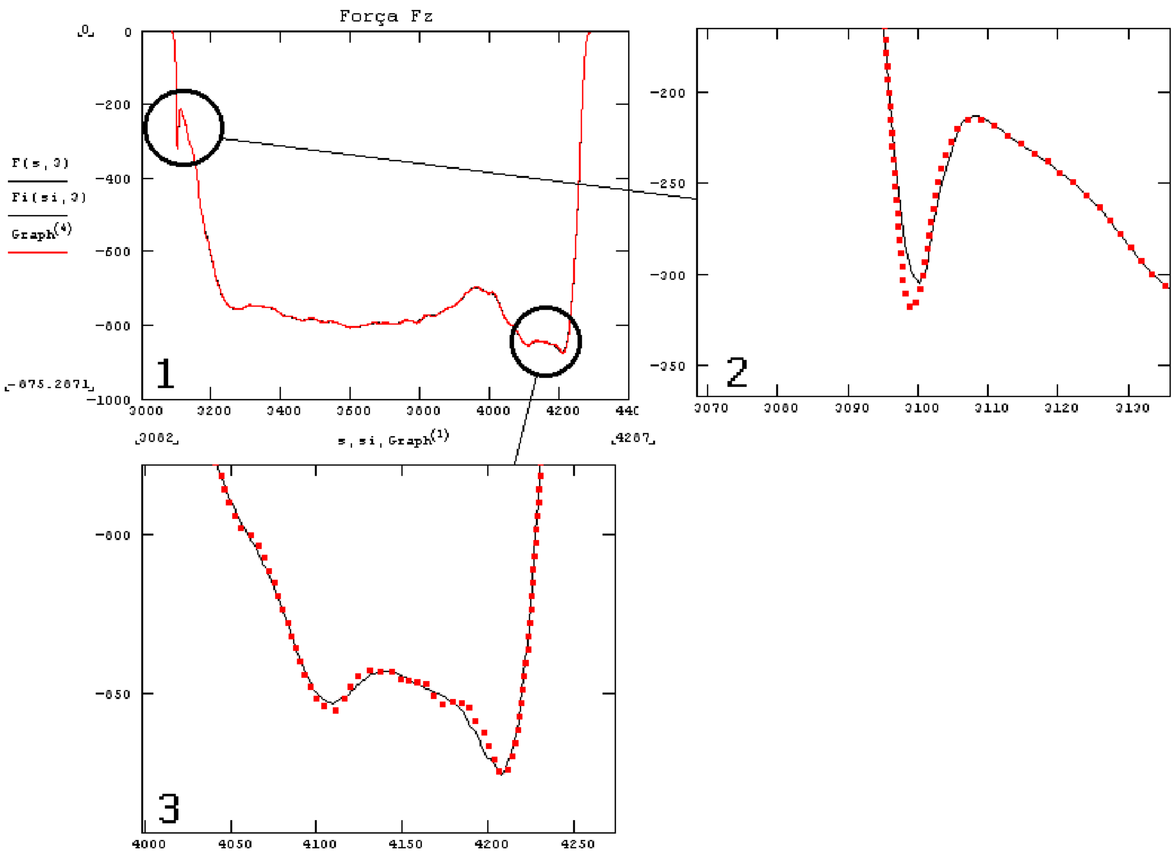
5.5.1 Smoothing of the data of forces and moments

Note:
A new filtration was applied to the analogical data through the utilization of a polynomial regression. This recourse, available in the Mathcad 2000 program, allows a generation of different polynomials of second order for distinguishing forms of distributions of the experimental data, guaranteeing the homogeneous adjust of the curve to the coordinates of data.

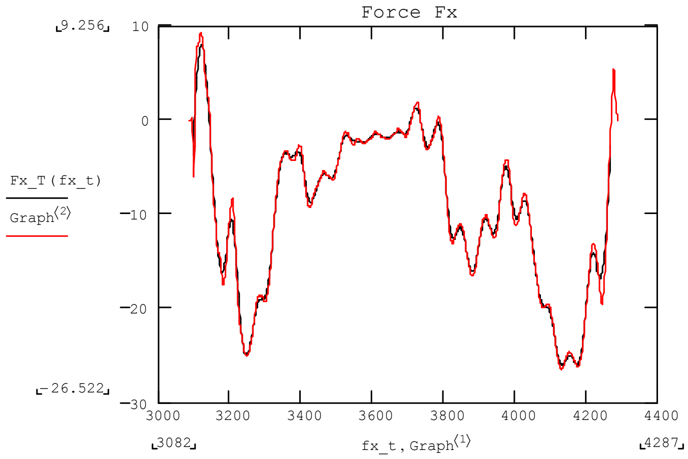
– Graphic of the Vertical Force = f (samples):

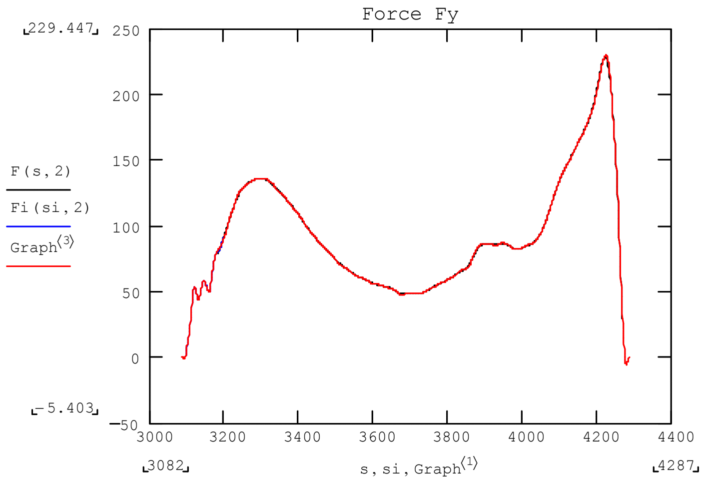
(1) Graphic complete, to the trial seg_03, of the vertical force (Fz).

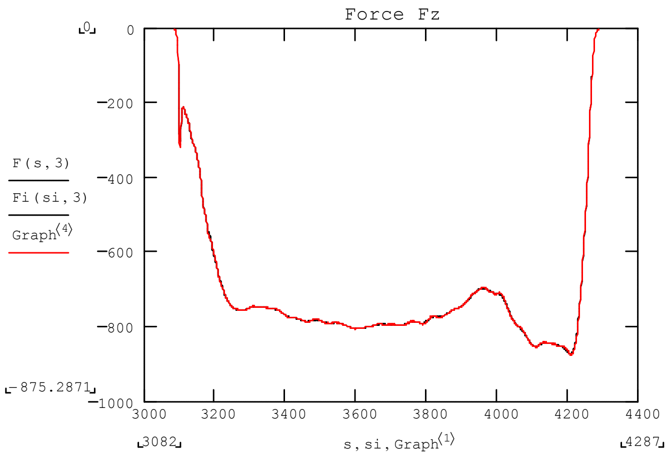
(2) and (3) Details of the adjust produced by the polynomial regression restrict.

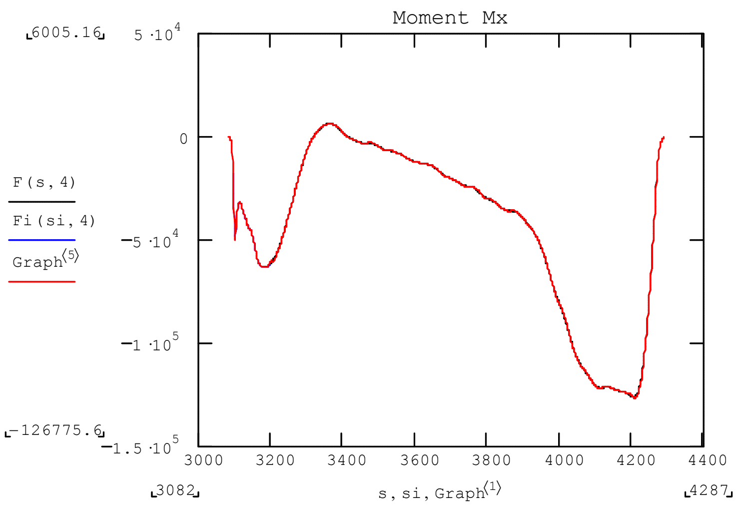


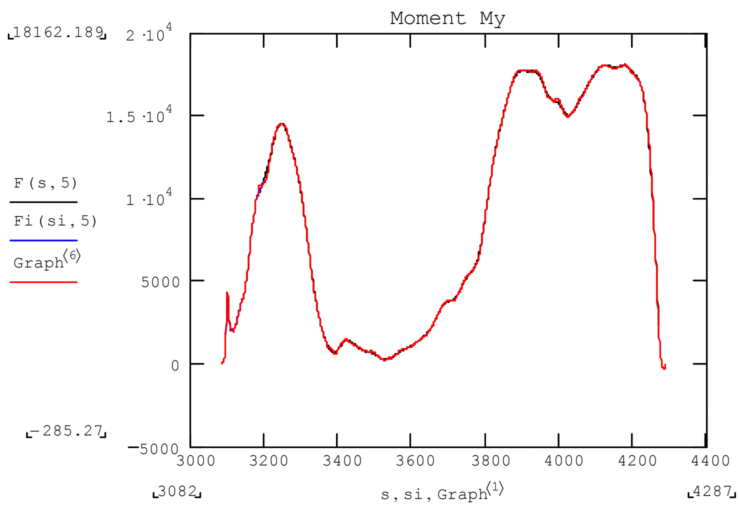
5.5.2 Graphics of Forces Fx, Fy and Fz and the Moments Mx and My for the trial seg_03:











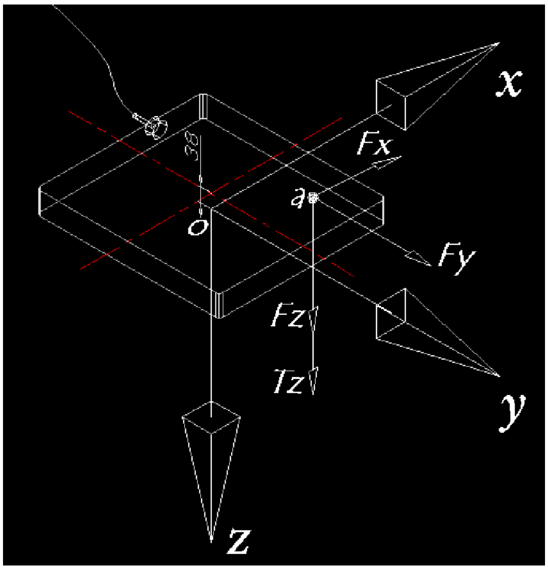
5.5.3 Coordinates calculation of the center of pressure through the Forces and Moments measured by the AMTI platform:

The origin of the coordinates system is near the geometric center of the platform and is located X_0, Y_0, Z_0 from the center of the top surface.

X_0 = -1.00 mm
Y_0 = -0.76 mm
Z_0 = 38.00 mm

Note:

The use of the support of fixation and the Footscan platform have produced the displacement of the surface of loading application. The calculation of the moments generated by tangential forces (Fx and Fy) in relation to origin of the AMTI platform will be moved 25 mm (thickness of the support = 15 mm + thickness of the Footscan platform = 10 mm) in relation to the plan which contain the tangential forces. The coordinate Z_0 will be then 63 mm instead of 38 mm.



$$\begin{pmatrix} Mx \\ My \\ Mz \end{pmatrix} = \begin{bmatrix} x \\ y \\ -(Zo+25) \end{bmatrix} \times \begin{pmatrix} Fx \\ Fy \\ Fz \end{pmatrix}$$

$$Mx = y \cdot Fz + 63 \cdot Fy$$

$$My = -63 \cdot Fx - x \cdot Fz$$

$$\text{Find}(x, y) \rightarrow \begin{bmatrix} \dfrac{-(My + 63 \cdot Fx)}{Fz} \\ \dfrac{-(-Mx + 63 \cdot Fy)}{Fz} \end{bmatrix}$$

Figure 5.5.1

Original equating with rectification of the coordinate Zo (38 mm)

$$x = \frac{-(My + 63 \cdot Fx)}{Fz}$$

$$y = \frac{(Mx - 63 \cdot Fy)}{Fz}$$

Legend:

a(x, y) - Point of loading application over the surface of the AMTI platform.

Fx, Fy, Fz, Tz - Total loading

o - Origin of the coordinates system

x, y, z - Coordinates system of the AMTI platform

Note:

The values of the x and y coordinates should be analyzed with reserve, because it has not existed a estimation of the error occurred on the measurement of the forces and moments made by the AMTI platform for verification of the acuity of these measurements, it would be necessary to execute a similar process as realized to

calibrate the platforms. Other important limitation, still because of this problem, was the impossibility of the adjustment of a function to the phases of start and end of the loading application, an approximated period of 0.035s. It was not calculated the coordinates of the center of pressure in this phases.

It was evaluated the possibility to acquire a specific program to process the analogical data of the forces and moments (the AMTI has a program with this finality called Biosoft), but two limitation have existed: the cost of these programs and the impossibility of use of the data beforehand collected. All the commercial programs available operate collecting the data directly from the platform.

5.6 Conversion of the coordinates of the center of pressure between the systems Footscan and AMTI.

The clinic analysis program, which process the data generated by the Footscan platform, creates a coordinates system (x, y) relative (Figure 5.6.1), using as reference the axes longitudinal and transverse of the foot, for the measurement of the trajectory of the center of pressure. This characteristic, adequate to the main utilizations of the Footscan platform, makes impossible to apply the method of coordinates transformation of the analytical geometry (Figure 5.6.2) for the establishment of a relation of conversion between the two systems of axes existents (Footscan and AMTI). The transformation of coordinates was realized by mean of a mathematical process which search to estimate the better relative position between the two trajectories of the center of pressure, this through the calculation of the differences of shape between the trajectories and the successive adjust of position to minimize these differences. This process is detailed in the subsequent item.

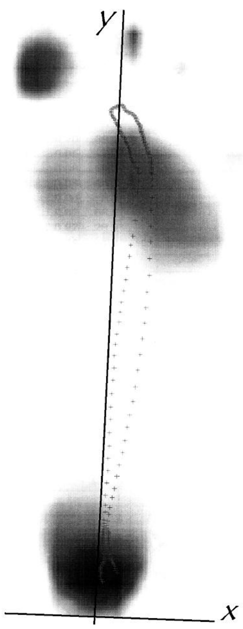


Figure 5.6.1 Coordinates Relative System (Footscan System)

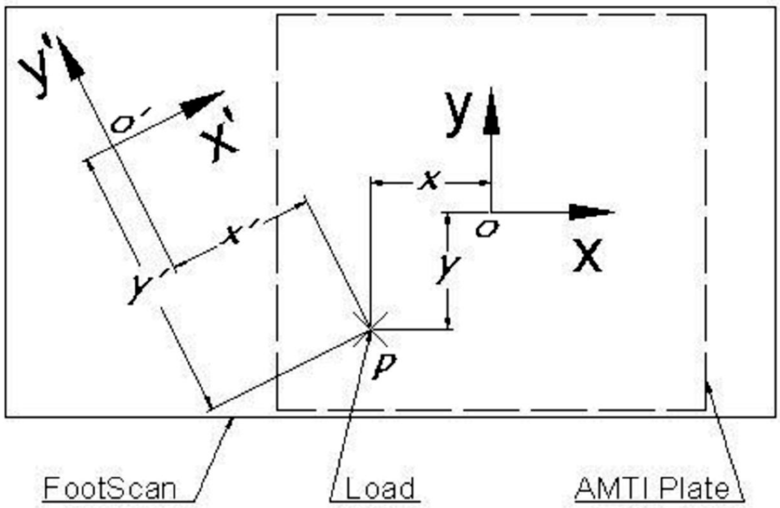


Figure 5.6.2 Coordinates Transformation between the systems ***O′, X′, Y′*** and ***O, X, Y***

Note:

Coordinates Transformation:

Being ***S* = (O, X, Y)** the system of Cartesian coordinates of the AMTI platform and admitting, for analysis purposes, the system of Cartesian coordinates not relative ***S′* = (O′, X′, Y′)** for the Footscan platform, the relations which determine the transformations of coordinates of the point ***P*** from the system ***S′*** to ***S*** will be:

$$x = a_{11} * x' + a_{12} * y' + a_{13}$$
$$y = a_{21} * x' + a_{22} * y' + a_{23}$$

for the determination of the values a_{11}, a_{12}, a_{13}, a_{21}, a_{22} and a_{23} it is necessary the collection of 3 points for the generation of 6 equations.

5.6.1 Superposition of trajectories of the center of pressure

5.6.1.1 Insertion of the coordinates generated by the Footscan system in the axes system of the AMTI platform.

This proceeding place the center of pressure measured by both systems not only dislocated on the axes ***x*** and ***y*** and gyrated around of the axis ***z*** of the AMTI platform, but even inverted one in relation to other, cause the axes ***z*** of the both systems are directed in opposed directions (Figure 5.6.1.1)

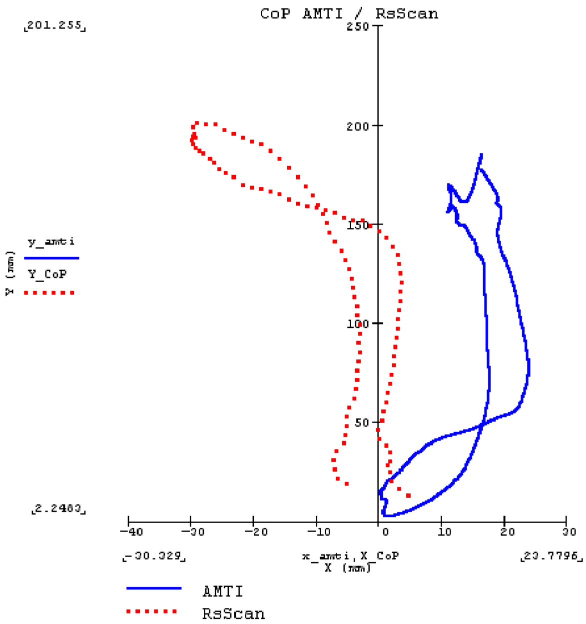


Figure 5.6.3

To invert the axis ***z*** of the Footscan system it were applied a factor of correction, multiplying the coordinates in ***y*** by (-1) (Figure 5.6.4).

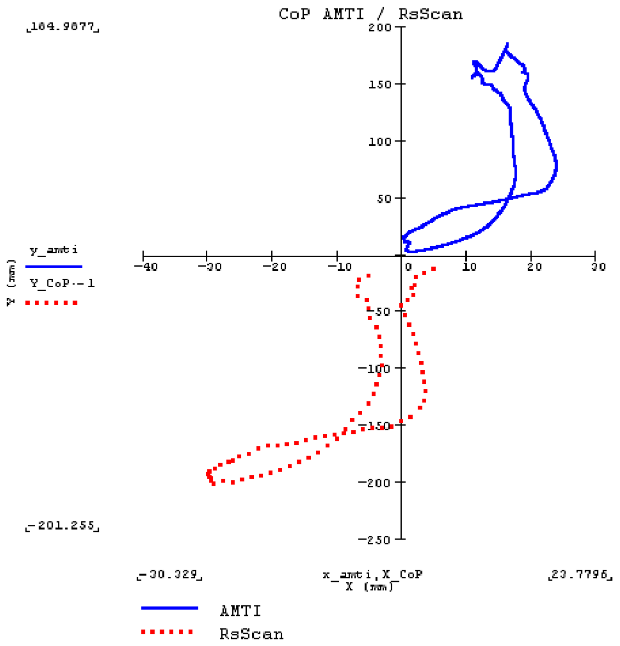
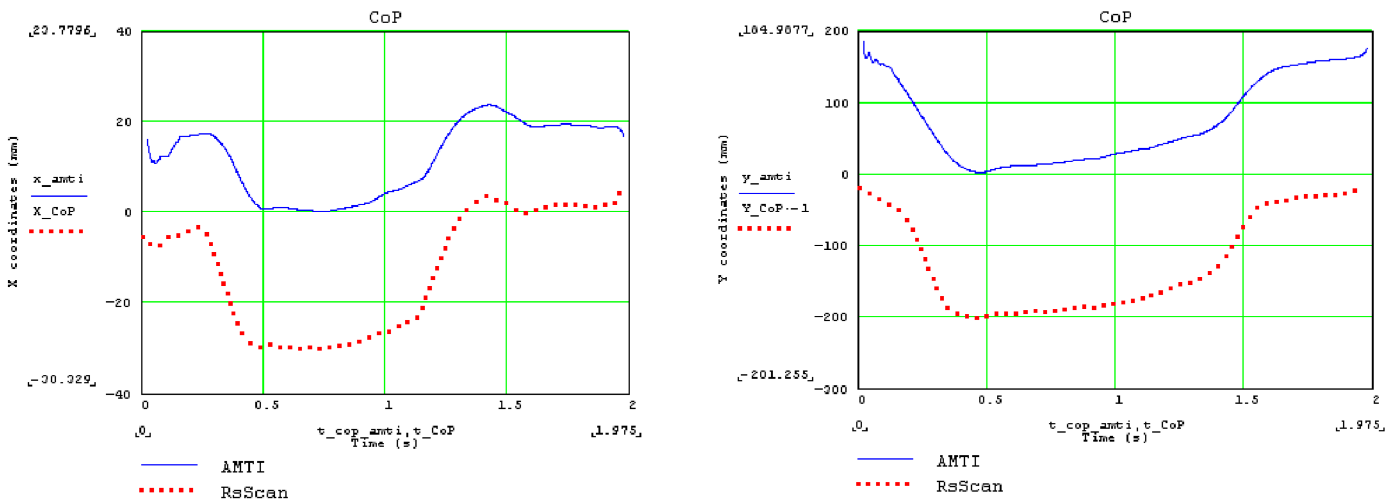


Figure 5.6.4
The trajectories are deformed by the scale of the graphics

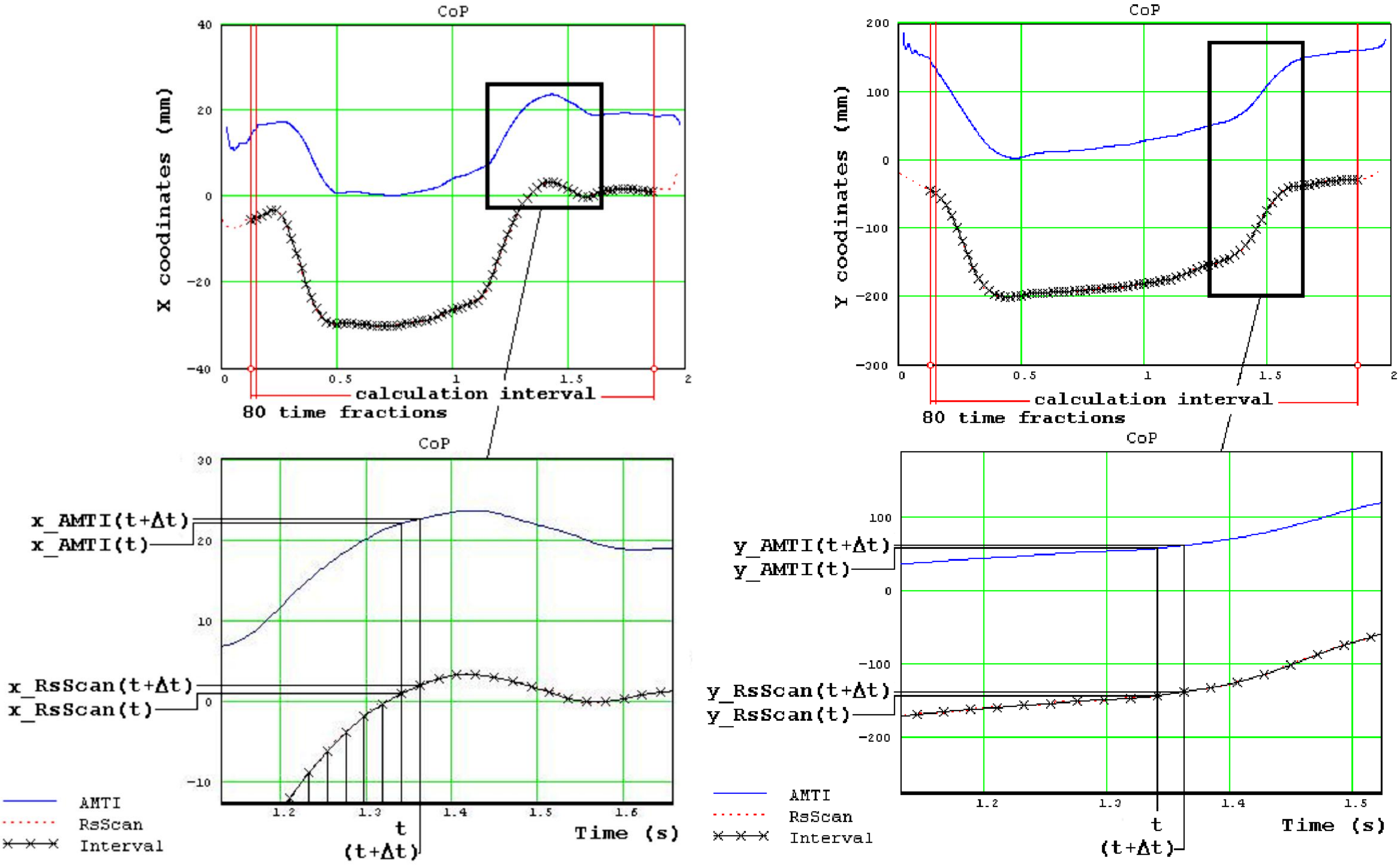
The synchronization of the events were made equalizing the instants of start of loading in the two systems, as described in the item 5.3. Nevertheless, it was used the total time of loading in each system as reference (*), it was verified that this procedure is one more generator of source error. The graphics of the coordinates ***x,y*** of the systems Footscan and AMTI, as function of the time, are showed in Figure 5.6.5.



(*) Total time of loading (AMTI) = (4287-3082)/600 = 2.0083 seconds
Duration of loading on the Footscan platform (value measured directly by the own system):
Total time of loading (Footscan) = 1.973 seconds
Time difference between the systems = 0.0353 seconds

5.6.1.2 Method of comparison between the shape of trajectories of the center of pressure.
It was used, as parameter of comparison shape, the medium inclination angle of the following equivalent (simultaneous) of trajectories of the center of pressure Figure 5.6.6).

Figure 5.6.6 Interval of calculus and generation and fractioninzing ***(Δt)***.



It was delimited, originally, a central interval to execute the calculations, cause the curves borders showed visible differences in the design. This interval was subdivided into 80 equal fractions of time, and the respective coordinates ***(x_AMTI, y_AMTI) = f(t)*** and ***(x_RsScan, y_RsScan) = f(t)***, from the two trajectories of the center of pressure, it was used for the calculation of the medium inclination angle in each fraction of time (Figure 5.6.6). For the trial seg_03 the interval of central time is ***1.733″***, the instant of start is ***t=0.1267″***, the instant of ending is ***t=1.8600″*** and the fraction of time is ***Δt=0.0217″***.

Calculus:

For a any instant ***(t)***, inside of the central interval of calculation, we have at the same time the coordinates:

x(t), y(t) for the AMTI system and

x′(t), y′(t) for the Footscan system

For a instant ***(t+Δt)*** we have:

x(t+Δt), y(t+Δt) for the AMTI system and

x′(t+Δt), y′(t+Δt) for the Footscan system

The determination of the medium angle in the interval *Δt=0.0217″* follows the trigonometry equations:

$$hypotenuse := \sqrt{(x(t+\Delta t) - x(t))^2 + (y(t+\Delta t) - y(t))^2}$$

$$sine(angle) := \frac{(y(t+\Delta t) - y(t))}{hypotenuse}$$

$$cosine(angle) := \frac{(x(t+\Delta t) - x(t))}{hypotenuse}$$

$$angle := \left| \frac{180}{\pi} \cdot arcsine(sine(angle)) \right|$$

```
 If sine >= 0 And cosine >= 0 Then
   angle = angle
   ElseIf sine >= 0 And cosine < 0 Then
   angle = 180 - angle
   ElseIf sine < 0 And cosine <= 0 Then
   angle = 180 + angle
   ElseIf sine < 0 And cosine > 0 Then
   angle = 360 - angle
End If
```

The Figure 5.6.7 shows a comparative graphic between mediums angles of the trajectories segments AMTI and Footscan, for each time interval.

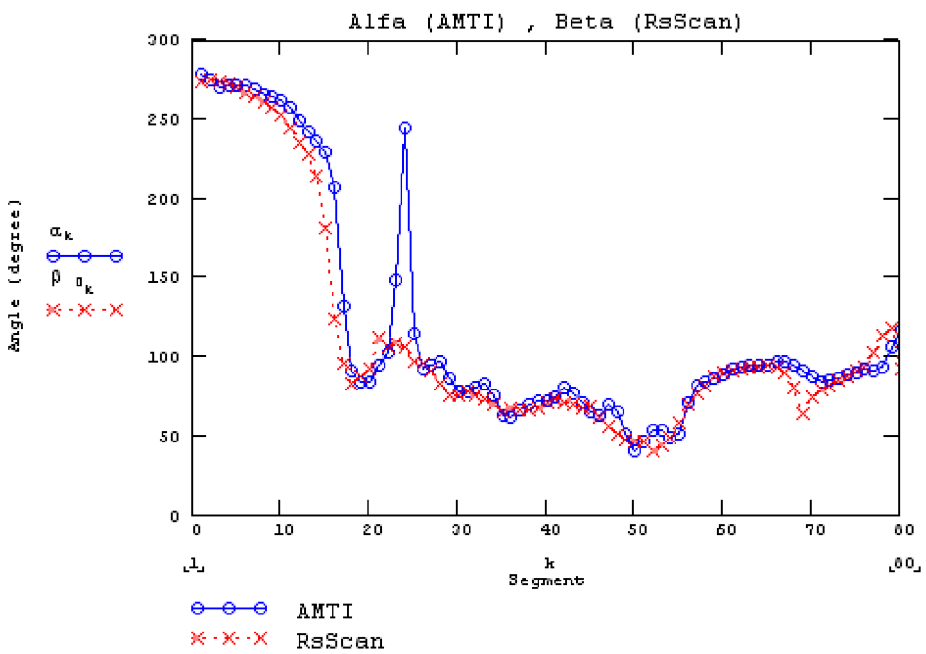


Figure 5.6.7

Note:
Comparing the graphics of the Figures 5.6.4 and 5.6.7 it is possible to note the alignment and the likeness between the shape's trajectories of the center of pressure.

5.6.1.3 Alignment and superposition of trajectories of the centers of pressure.

The expression alignment is applied in this item to define the quantity of variation between the angles of the correspondent segment, or simultaneous, of the two trajectories of the centers of pressure. The condition of better alignment between the trajectories will occur when the summation of the absolute values of the differences between the angles of the correspondent segments (Figure 5.6.8) was minimum.

Figure 5.6.8

$$dif\_\beta\_\alpha = \sum_{t=1}^{80} |\beta_k - \alpha_k|$$

Legend:

k - counter of fractions of time (1, 2,..., 80)

β - angle of segment of the center of pressure trajectory of the Footscan platform relative to the fraction of time ***k***

α - angle of segment of the center of pressure trajectory of the AMTI platform relative to the fraction of time ***k***

dif_βα - summation result of the difference between the angles β and α, in module, for all central interval of calculation.

To calculate the position of better alignment, it was applied to the center of pressure trajectory of the Footscan platform successive rotations around the axis ***z***. A function was generated to relate the values recalculated of the summation ***dif_βα*** with the rotations applied. It was determine a interval of verification of 60 degree (± 30 degree), with unitary increments (θ = -30, -29,..., 30) taking as start point a rotation of -30 degree in relation to the initial position of the center of pressure trajectory (Figures 5.6.9 and 5.6.10). Afterwards, this function was derived to determine the rotation angle in which the summation represent the minimum value, or "minimum point" (Figures 5.6.11 and 5.6.12).

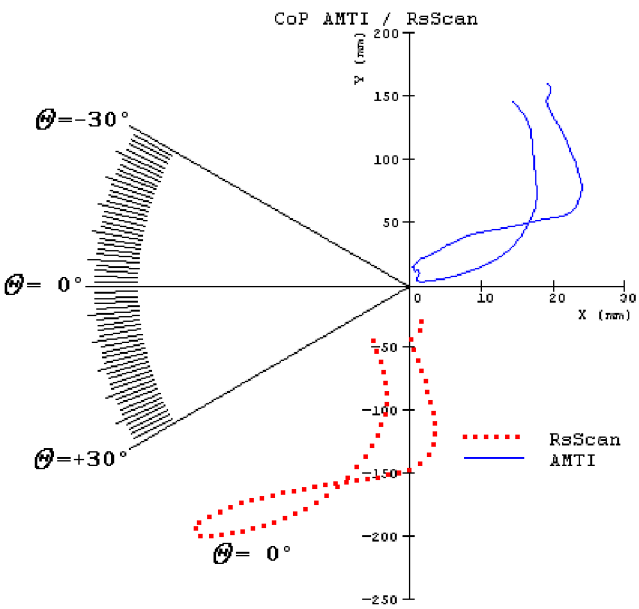


Figure 5.6.9

Calculation:

The recalculation of the segments angles of the center pressure trajectory is made by the addition of the rotation applied, as it is verified in the example:

It is applied to the straight line ***s*** a rotation ρ around the point ***o***, the angle γ, which correspond to the angular difference between the initial position and final position of the straight line ***s*** will be:

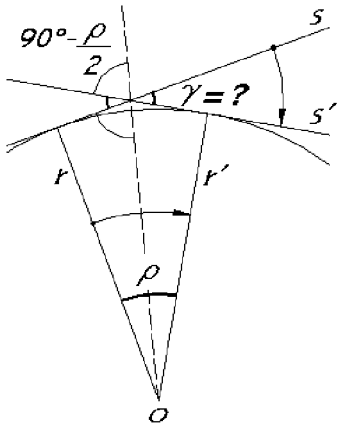


Figure 5.6.10

$$\gamma + 2\left(90 - \frac{\rho}{2}\right) = 180$$

$$\gamma + 180 - \rho = 180$$

$$\gamma = \rho$$

A series of 61 rotations, in the interval of ± 30 °, was applied to the center pressure trajectory of the Footscan platform. Thus, the equation of the summation of angles differences between the two trajectories (***dif_***$\beta\alpha$) may be writing in function of the variable θ:

$$\mathbf{dif\_\beta\_\alpha(\Theta)} = \sum_{k=1}^{80} \left| \beta(\Theta)_k - \alpha_k \right|$$

$$\Theta = -30, -29, .., 30$$

Where:

k - counter of fractions of time (1, 2,..., 80)

θ - trajectory rotation, in degree, in relation to its original position ($\theta = 0°$).

Partial matrixes of results to the trial seg_03:

k =	θ =	β(-30,k) =	β(0,k) =	β(30,k) =	α_k =	dif_β_α(θ) =
1	-30	243.6571	273.6571	303.6571	278.2414	3010.3602
2	-29	244.2966	274.2966	304.2966	274.4521	2930.3602
3	-28	243.359	273.359	303.359	270.3682	2850.3602
4	-27	242.2708	272.2708	302.2708	270.755	2770.3602
5	-26	239.941	269.941	299.941	271.0224	2690.3602
6	-25	236.5735	266.5735	296.5735	271.1214	2610.3602
7	-24	234.0693	264.0693	294.0693	268.9846	2530.3602
8	-23	230.7998	260.7998	290.7998	266.0027	2450.3602
9	-22	227.031	257.031	287.031	263.9995	2370.3602
10	-21	222.1645	252.1645	282.1645	261.8083	2290.3602
11	-20	214.1443	244.1443	274.1443	256.7838	2210.3602
12	-19	205.3182	235.3182	265.3182	248.5624	2131.2308
13	-18	197.6503	227.6503	257.6503	241.6125	2053.2308
14	-17	183.4285	213.4285	243.4285	236.1395	1975.3332
15	-16	150.7062	180.7062	210.7062	228.7263	1899.3332
16	-15	93.3439	123.3439	153.3439	206.2585	1823.3332

Legend:

k - counter of fractions of time (1, 2,..., 80)

θ - trajectory rotation (θ = -30, -29,..., 30), in relation to its original position (**$\theta = 0°$**).

β - angle of segment of the center of pressure trajectory of the Footscan platform relative to the fraction of time ***k***

α - angle of segment of the center of pressure trajectory of the AMTI platform relative to the fraction of time ***k***

dif_$\beta\alpha$ - summation result of the difference between the angles β and α, in module, in rotary function θ.

To determine the better position of alignment it was interpolated (Figure 5.6.11) and subsequently derived (Figure 5.6.12) a cubic spline to the function **dif_$\beta\alpha$ = f(θ)**.

Figure 5.6.11

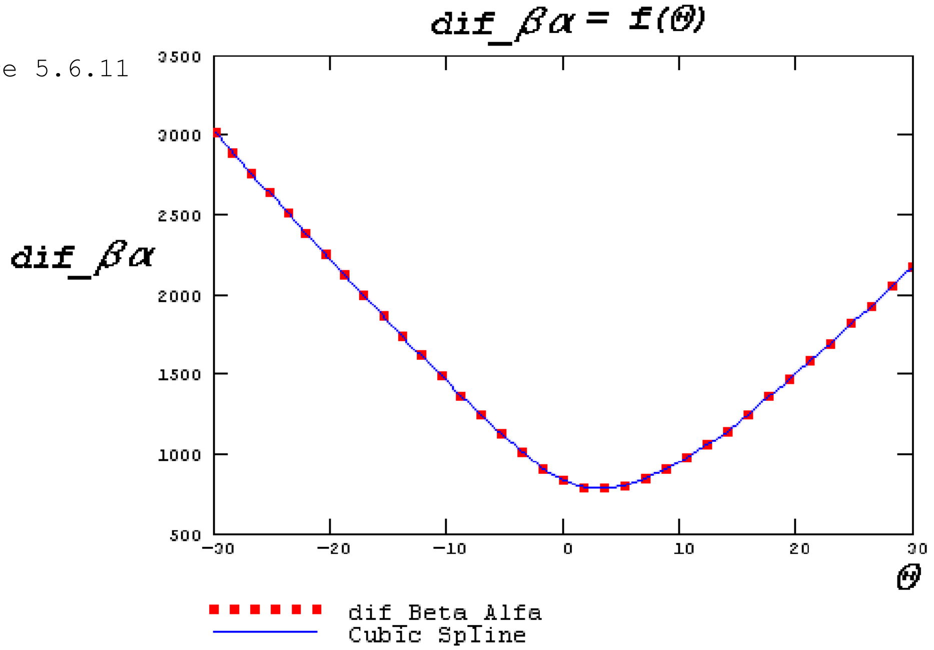
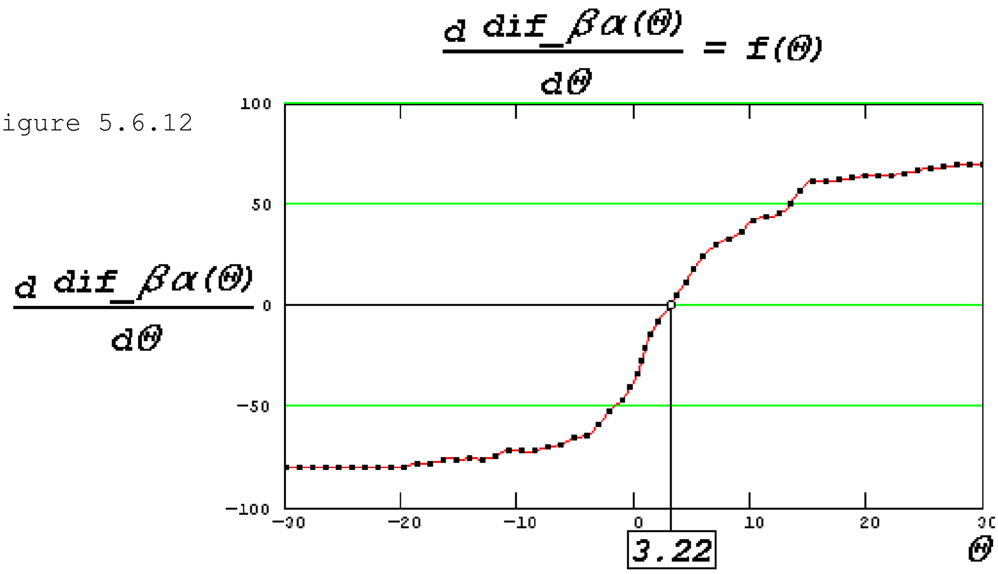


Figure 5.6.12



For the trial seg_03 the value of θ which determine the position of better alignment was ***3.22 °***.

The trajectory of the center of pressure of the Footscan platform is aligned with the trajectory of the AMTI platform, it is apply the rotation θ ***(3.22°)*** around the axis ***z*** of the coordinates system. The trajectory rotation is obtained through addition of θ to the angular component of polar coordinates of the (80 + 1) points. (***(x_RsScan, y_RsScan) = f(t)***, Figure 5.6.6) that subdivided the central interval of calculation in 80 equal intervals of time ***(Δt=0.0217″)***.

It follows the alignment operation to determine the displacement in the directions ***x*** and ***y*** to a superposition of the trajectories. It was used the arithmetic media of the differences between the coordinates of the correspondent points (simultaneous) between the two trajectories, as follows:

Rotationed coordinates of the center of pressure of the Footscan platform:

$$(x\_RsScan_{rot}, y\_RsScan_{rot}) = f(t)$$

Coordinates of the center of pressure of the AMTI platform:

$$(x\_AMTI, y\_AMTI) = f(t)$$

$$(t=0.1267'', 0.1267''+\Delta t, ..., 1.8600''),\ \Delta t=0.0217''$$

Displacement in ***X***:

$$\Delta X(t) = x\_AMTI(t) - x\_RsScan_{rot}(t)$$

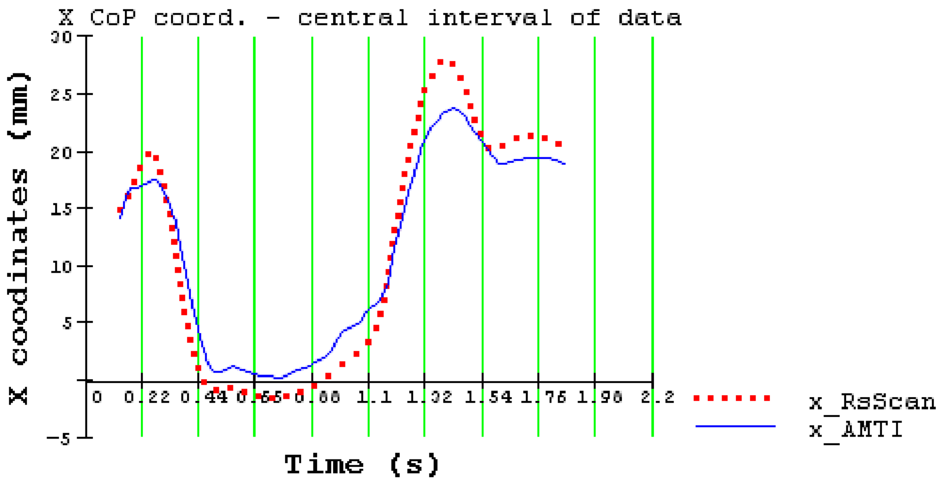
$$displacement\_X = mean\ (\Delta X(t))$$

For the trial seg_03 ***displacement_X = 17.8 mm***

Therefore, the final coordinates of the trajectories to the center pressure of the Footscan plate will be:

$$x\_RsScan_{final}(t) = x\_RsScan_{rot}(t) + displacement\_X$$

Figure 5.6.13 Graphic of superposition of the coordinates $x\_RsScan_{final}(t)$ e $x\_AMTI(t)$.



Displacement in ***Y***:

$$\Delta Y(t) = y\_AMTI(t) - y\_RsScan_{rot}(t)$$

$$displacement\_Y = mean\ (\Delta Y(t))$$

For the trial seg_03 ***displacement_Y = 199.3mm***
Therefore, the final coordinates of the trajectories to the center pressure of the Footscan platform will be:

$$y\_RsScan_{final}(t) = y\_RsScan_{rot}(t) + displacement\_Y$$

Figure 5.6.14 Graphic of superposition of the coordinates $y\_RsScan_{final}(t)$ e $y\_AMTI(t)$.

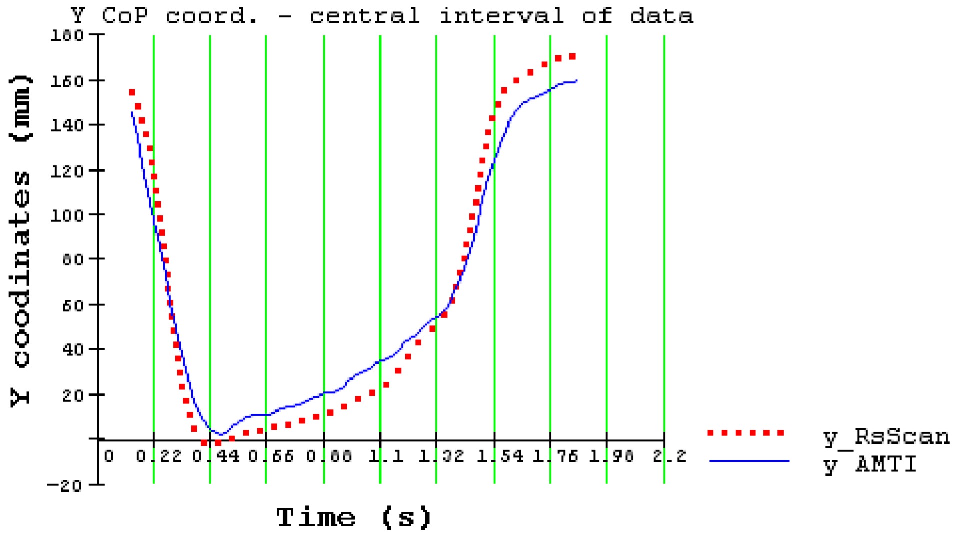
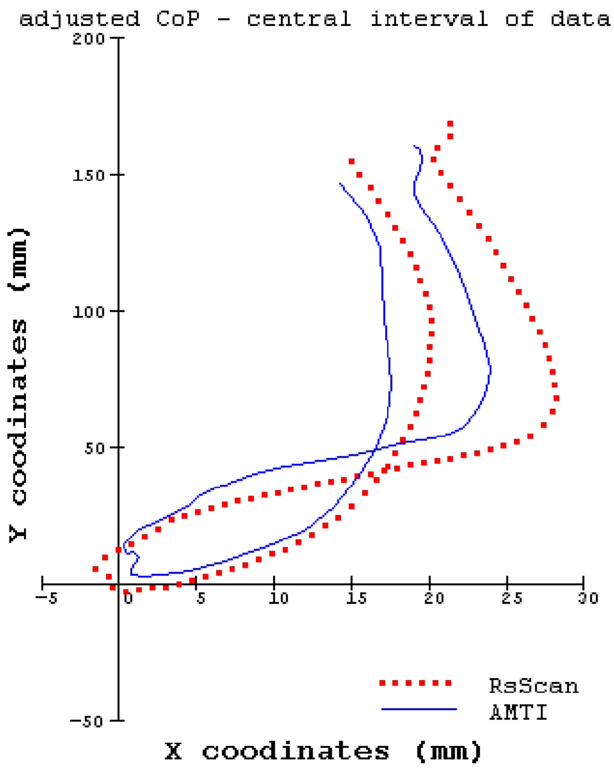


Figure 5.6.15 Graphic of superposition of the coordinates $(x\_RsScan_{final},\ y\_RsScan_{final})$ e $(x\_AMTI,\ y\_AMTI)$.



5.6 Determination of the deviations between the trajectories of the center of pressure

It was calculated, as deviations parameter between the trajectories, the mean of the absolute values (in module) and the standard deviation of the differences between the correspondent coordinates.

Differences mean absolutes:

$$\textit{mean difference}_x = \textit{mean}\ |(x\_RsScan_{final}(t) - x\_AMTI(t))|$$
$$\textit{mean difference}_y = \textit{mean}\ |(y\_RsScan_{final}(t) - y\_AMTI(t))|$$

For the trial seg_03:

$$\textit{mean difference}_x = 2.1mm$$
$$\textit{mean difference}_y = 9.9mm$$

Relative standard deviation to the difference mean absolute:

$$\textit{standard deviation}_x = 1.1mm$$
$$\textit{standard deviation}_y = 4.8mm$$

Note:

In the section 7, “final results”, it will be showed the data of processing of the 16 trials, including the file seg_03.

6. Conclusion:

The impossibility of the electronic synchronization of the systems and the utilization of a calculation model too restrict for the processing of the analogical data of the AMTI platform have constituted a limitation so important that made infeasible an appropriate analysis of other error source. The difference of sampling frequency (Footscan = 166 Hz and AMTI = 600 Hz), interference generated by the system of fixation and error of calibration, which caused differences on the measurement of the vertical force, could not be evaluated. The own conclusion of this project was questioned when the impossibility of synchronization was verified.

In the beginning of this year, the RsScan International Company disposed the version 3D-System of the Footscan platform, which may operate in combination with AMTI or Kistler platforms. This version works with frequency upper 500 Hz and allows the electronic synchronization with the biomechanic platform.

This version of the Footscan system, jointly with the Biosoft program of AMTI, would be the basic requirements to revise this project.

7. Final results:

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