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STABILITY OF THE BUILDING 363-R001 (THE FARADAY CAGE) AND ITS EFFECTS ON THE PHOTON FOCUS AT THE TARGET

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Introduction

An experiment is undertaken to investigate the possibility of creating a heavy ion source from a laser produced plasma suitable for acceleration into Linac 3. A CO_2 laser beam of several Joules is focused on a biased target housed in a vaccuum chamber. A plasma is formed on the target surface. It expands into an extraction system and then into classical focusing, steering and accelerating elements.
The Laser Ion Source (LIS) experiment presently installed in the building 173 will move to a more spacious lab in building 236. The laser will be placed on the low level of building 363, the Faraday cage for the 1MV Cockrolft-Walton generator previously used on Linac 2. The reasons for such a move are firstly a question of space and easy positionning of the photon path (~28 m) to protect the laser from photons reflected from the target. Secondly it is important to screen the electrical noise of the laser from the experimental area (bld. 236).
In order to guide the laser beam from building 363 to the experiment in building 236 two proposals have been made. The first one consists of fixing two mirrors on a 5 m height concrete tower, built in the Faraday cage (see **Fig. 1**), whereas in the second one the walls of the cage support the mirrors (see **Fig. 2**). It can be seen from these figures that one or the other layout implies a different experiment set up and element positions in building 236.
As the laser beam trajectory is sensitive to the mirror movements, a stability experiment was necessary. Thus the motions of both the tower and the walls have been measured in two directions. The effect of the outside temperature and humidity has also been taken into account. This note presents the results of this survey.

Set up

The tower and wall motions were recorded by four tiltmeters. The layout of the set up is shown in **Fig. 3**. On the top of the tower two sensors have been mounted on an adjustable thick plate. A support has been mounted on the wall parallel to the Jura direction in order to hold two further sensors. Each group of two tiltmeters measures the motions in two orthogonal directions: towards Jura and towards Bellegarde. Their range was from -3 to +3 degrees with a resolution of 10^{-4} degrees. The four sensors were connected to a device called DAISY including a 16 bit Analog-Digital Converter (ADC). The link between this device and a personal computer was a RS232C connection. The ADC and the sensors were fed by an external adjustable power supply whereas the memory and the clock of DAISY were permanently supplied with internal batteries.
Each sensor has been calibrated on a calibration bench. As it can be seen in **Fig. 4** it consists of a 600 mm length bar which could be tilted via a micrometer screw. The sensor fixed on this bar measured its angle relative to an arbitrary zero position. A comparison clock gave the vertical distance the bar moved in hundredths of millimeters.

The program "Inclinom"

In order to drive DAISY a program called "Inclinom" has been created. The source has been written in Turbo Pascal and it uses serial port drivers. The main menu of the program is shown in **Fig. 5a**. The more important options (number 2 and 3) of this menu enabled two measurements. The first one called "continuous acquisition" read continuously the values given by the sensors. In this mode the measurements were performed approximately every 15 seconds. The second type of acquisition was the "time programmed" one. It permitted the average of a certain number of measurements at a certain frequency. In both cases the output was an ASCII file composed of 6 columns: the date and the time of measurement and the angles in degrees of the four tiltmeters. A sample of such a file is shown in the **Figure 5b**.

Measurements

Before carrying out the tilt measurements several tests have been done. The four tiltmeters have been calibrated with the bench presented in **Fig. 4**. They showed approximately the same linear characteristic. In addition it had been found a factor 3 between the angle given by the sensor and the angle obtained from the calibration bench. The sensors have also been tested in parallel measurements and they produced the same signal in variation and amplitude. Furthermore it was observed that there was a delay of about 4 hours before the equipment became stabilized after its installation. On top of that a voltage variation survey has shown an appropriate working voltage around 12V.
When the operation of the complete system was well understood the final tilt measurements were performed during several days.
A thermo-hygrograph Haeni had been placed in a rain and sun protected place outside building 236. It measured the outside temperature and the percentage of humidity during a week.
Furthermore, in parallel to the this tilt experiment some measurements have been made by CERN geometers. They have measured the tilts of the tower in the Bellegarde direction with the Invar wire method.

Results

During 13 days the tower and wall motions in Jura and Bellegarde directions have been recorded. 10 measurements were averaged every 15 minutes in the "time programmed" acquisition mode of the program "Inclinom". Then the output ASCII file was imported into Microsoft Excel. The data were corrected with respect to the calibration laws found previously. The average angles over this period were calculated for each sensor. **Fig. 6** shows the difference between the corrected data and these averages for the four tiltmeters. The unmodified data and the corrected variations from the average present the same behavior.
From the graph in **Fig. 6** one can notice that the variations are small for both the tower and the wall. The tilts are comprised between roughly -0.02 and more than +0.03 mrad around the average. However it is clearly shown that the tower is more stable than the wall (tower range: ± 0.01 mrad).

The temperature and the humidity have been recorded from the 25th of April to the 8th of May. Then an Excel file has been created by taking the temperature and the percentage of humidity every 2 hours. The data of this file are plotted on the **Fig. 7**. The two parameters are nearly perfectly in phase opposition.

In order to see the effect of the meteorological parameters on the tower and wall motions, they have been drawn on the sensor signal plots. The most relevant behaviors are exhibited on the **Fig. 8** to **11**. The tower tilts in the Jura direction seem to be temperature and humidity dependent only for strong fluctuations of these parameters (see **fig. 8**). In **Fig. 9** the Bellegarde tower movements follow the large as well as the small temperature variations (with ~ a 4h delay). In both cases, the amplitudes of the motions are not related to the temperature amplitude. The temperature and the humidity act together on the tilts. However on **Fig. 10** one can observe a good temperature dependence of the wall movement in the Jura direction (with roughly a 2h delay). Whereas on **Fig. 11** the wall tilt in the orthogonal direction (towards Bellegarde) is more related to the outside humidity evolution.

Concerning measurements done by the CERN geometers, the survey has been done from the 10th to the 26th of April after an one-month-tower-stabilization period. The Invar wire measurements gave a displacement at the top of the tower of about 0.1 mm in the Bellegarde direction. The tower height being 5 m this corresponds to a 0.02 mrad tilt. So this result is in complete agreement with the tiltmeter measurements.

Simulation of the tilt effects at the target position

The effects of the tower tilts with respect to the position of the laser spot on the target has been evaluated by making some assumptions. Firstly the rotation center of the tower was assumed to be located at its foot. Secondly the rest of the system was supposed to be stable when the tower (and the two mirrors on it) was moving. According to the previous measurements the angular variation of the tower has been taken in the range ±0.02 mrad. The angle under which the laser beam enters the building 236 was, for simplicity, set to zero (it is 10 degrees-see in **Fig. 1** the angle the protection pipe does with the wall of the building 236). So due this assumption the system is coplanar and it is represented in **Fig. 12**. Furthermore, the mirrors M1 and M2 (see in **Fig. 12**) are supposed to be rigidly fixed to the column and are assumed to have the same movement when the tower tilts.
The method applied to calculate the laser beam deviation at the target position is based on a vector representation of the rays ($\vec{S}_i$). In addition to this the plane mirrors are substitued by their normal ($\vec{l}_i$) **[1]**. In **Fig. 12** the ray vectors and the mirror normals are shown.
The ray vector after the mirror M_i is given by the following equation:

$$\vec{S}_{i+1} = \vec{S}_i - 2(\vec{S}_i.\vec{l}_i)\vec{l}_i \quad \text{with i = 1 to 4} \quad \textbf{(Eq. 1)}$$

The calculations based on this formula have been performed at the first order for the angles. Indeed the angle variations were very small compare to the mirror angles. When the tower tilts in one or the other direction only the mirrors M1 and M2 move(i.e. $\vec{l}_1, \vec{l}_2$ change). The other ones (M3 to M5) keep the same position (i.e. $\vec{l}_3, \vec{l}_4, \vec{l}_5$ are unchanged).

Tilt of the tower towards Bellegarde:
This tilt corresponds to a variation $\Delta\alpha$ of the angle α ($\alpha \rightarrow \alpha + \Delta\alpha$ where α = (M1,ox) =45 °). The mirrors M1 and M2 are moved by the same angle so their normals become:

$$\vec{l}_1 = w\begin{pmatrix}-1\\1\\0\end{pmatrix} \rightarrow \vec{l}_1^{\,*} \approx w\begin{pmatrix}-(1+\Delta\alpha)\\1-\Delta\alpha\\0\end{pmatrix} \quad and \quad \vec{l}_2 = w\begin{pmatrix}-1\\-1\\0\end{pmatrix} \rightarrow \vec{l}_2^{\,*} \approx w\begin{pmatrix}-(1+\Delta\alpha)\\-(1-\Delta\alpha)\\0\end{pmatrix}$$

$$where \quad w = \sin(45°) = \cos(45°) = \frac{1}{\sqrt{2}} \quad and\ with \quad \Delta\alpha << \alpha.$$

The equation **(E1)** enables to see that the beam after M2 is still parallel to the plane (xoz). However it is shifted in the y-direction by : $\Delta y \approx -2.D_1.\Delta\alpha$. This modification in the beam height is carried through the optical system until the last mirror M5. As D_1 equals 4.5 m and $\Delta\alpha$ is ±0.02 mrad (maximum) then this deviation is: $\Delta y \approx \mp 0.18\ mm$. The laser beam remaining parallel to the parabolic mirror axis it will hit the target at the focal point.

Tilt of the tower towards Jura:

This tilt corresponds to a variation $\Delta\beta$ arround the x-axis. The M1 and M2 mirror normals become:

$$\vec{l}_1 = w\begin{pmatrix}-1\\1\\0\end{pmatrix} \rightarrow \vec{l}_1^{\,*} \approx w\begin{pmatrix}-1\\1\\\Delta\beta\end{pmatrix} \quad and \quad \vec{l}_2 = w\begin{pmatrix}-1\\-1\\0\end{pmatrix} \rightarrow \vec{l}_2^{\,*} \approx w\begin{pmatrix}-1\\-1\\\Delta\beta\end{pmatrix}$$

$$where \quad w = \sin(45°) = \cos(45°) = \frac{1}{\sqrt{2}} \quad and\ with \quad \Delta\beta << 1.$$

The equation **(E1)** gives the beam angle after M2: $\Delta\gamma \approx 4.w.\Delta\beta$ (relatively to the x-axis). This corresponds to a shift in the z-direction of $\Delta z \approx 4.w.\Delta\beta.D_2$. The beam stays parallel to the (xoz) plane. So on the last mirror M5 the beam arrives parallel to the (xoz) plane but with an angle $\Delta\gamma \approx \frac{4}{\sqrt{2}}.\Delta\beta$ and with a shift in the z-direction of $\Delta z \approx 4.w.\Delta\beta.D_4$. As D_4 equals 1.5 m and $\Delta\beta$ is ±0.02 mrad (maximum) then: $\Delta\gamma \approx \pm 0.057\ mrad$ and $\Delta z \approx \pm 0.085\ mm$. Due the fact that M5 is a parabolic mirror the angle $\Delta\gamma$ will provoke a change in the focal spot position. The new spot will appear on the z-axis at a distance

$$z' = -f.\tan(\Delta\gamma)$$

where f is the focal length of the parabolic mirror.

As f equals 300 mm the spot deviation will be: $\boxed{z' \approx \mp 17\ \mu m}$ (it corresponds to ~17% of the laser beam diameter at the target position).

Conclusion

The stability experiment achieved in the building 363-R001 shows that the tower and the walls of this building have weak motions (< ~ ± 0.04 mrad). The tower appears to be more stable than the walls and less temperature and humidity dependent.

The effect of the tower tilts (< ± 0.02 mrad) on the mirrors and therefore on the optical path and the laser beam trajectory has been simulated in order to see the effect on the photon focus at the target. Assuming the rest of the system stable when the tower moves, the laser spot onto the target is displaced by a maximum distance of ±17 µm along the z-axis (the laser beam arriving on the parabolic mirror M5 with a ~0.06 mrad angle with respect to the x-axis). A mirror compensation device will be built in order to get rid of the tower movements.

Acknowledgements

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Reference

[1] J. Fluegge, Leitfaden der geometrischen Optik und des Optikrechnens, 1956.

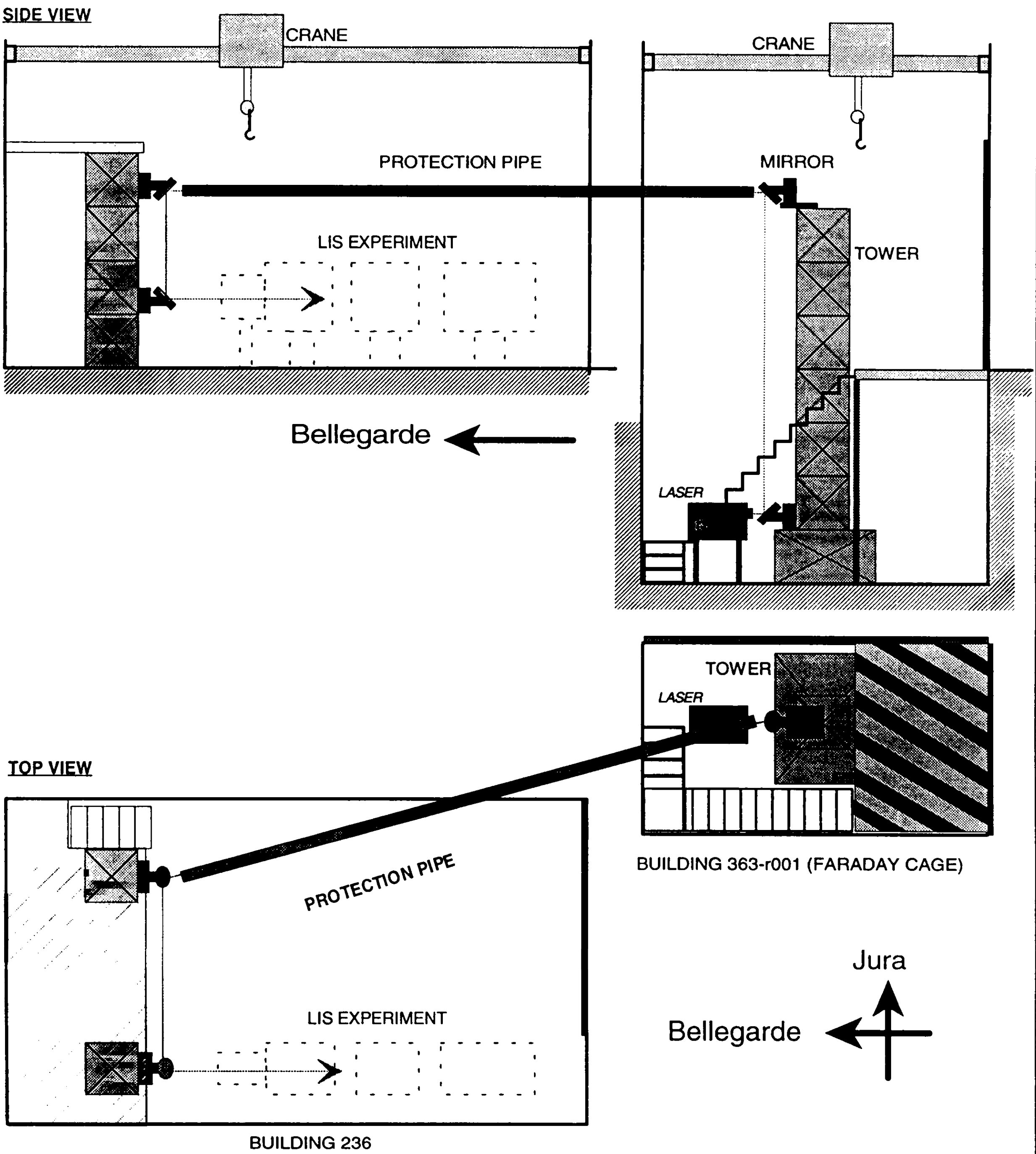


Fig. 1: Side and top view of the tower proposal layout

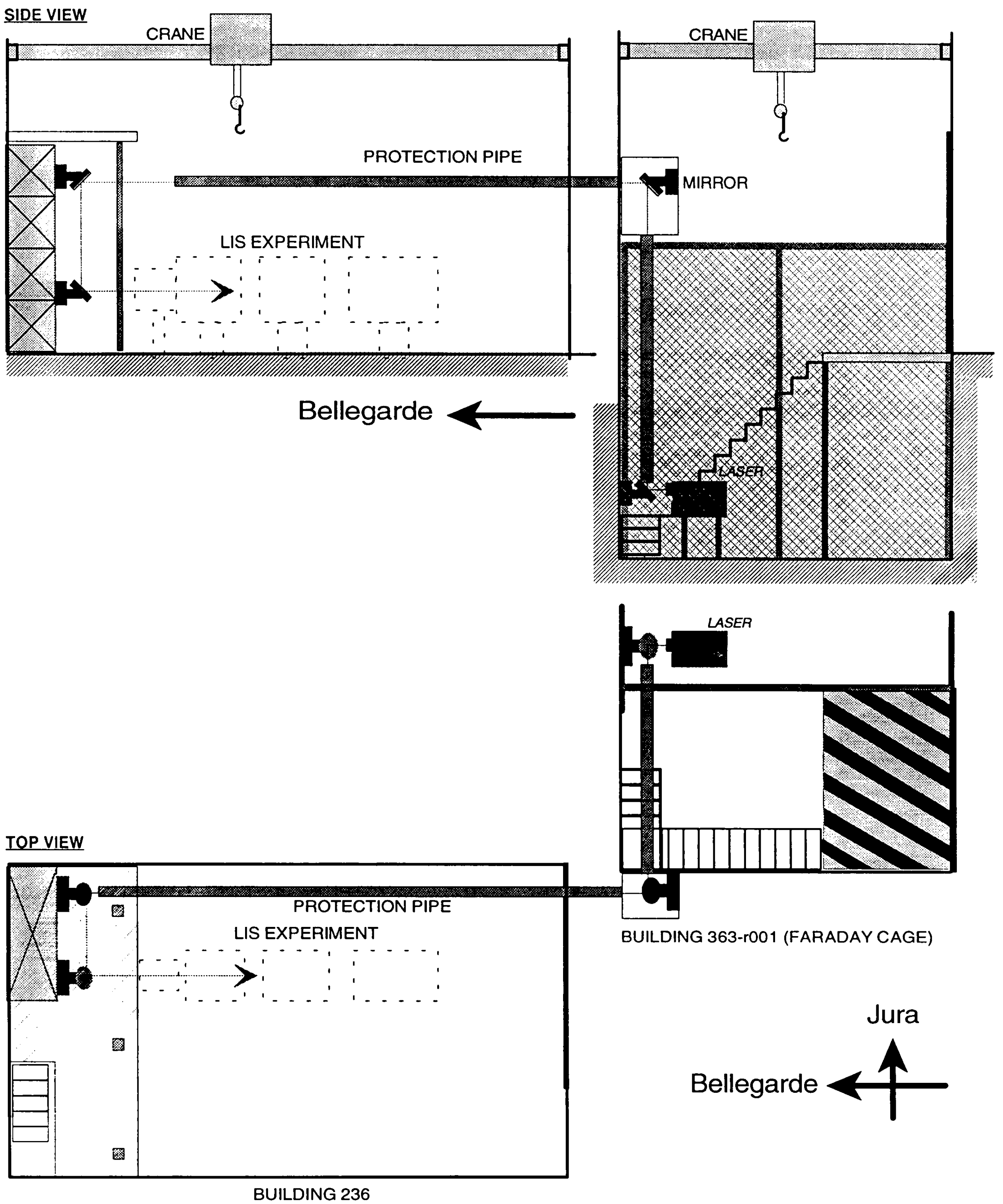


Fig. 2: Side and top view of the wall proposal layout

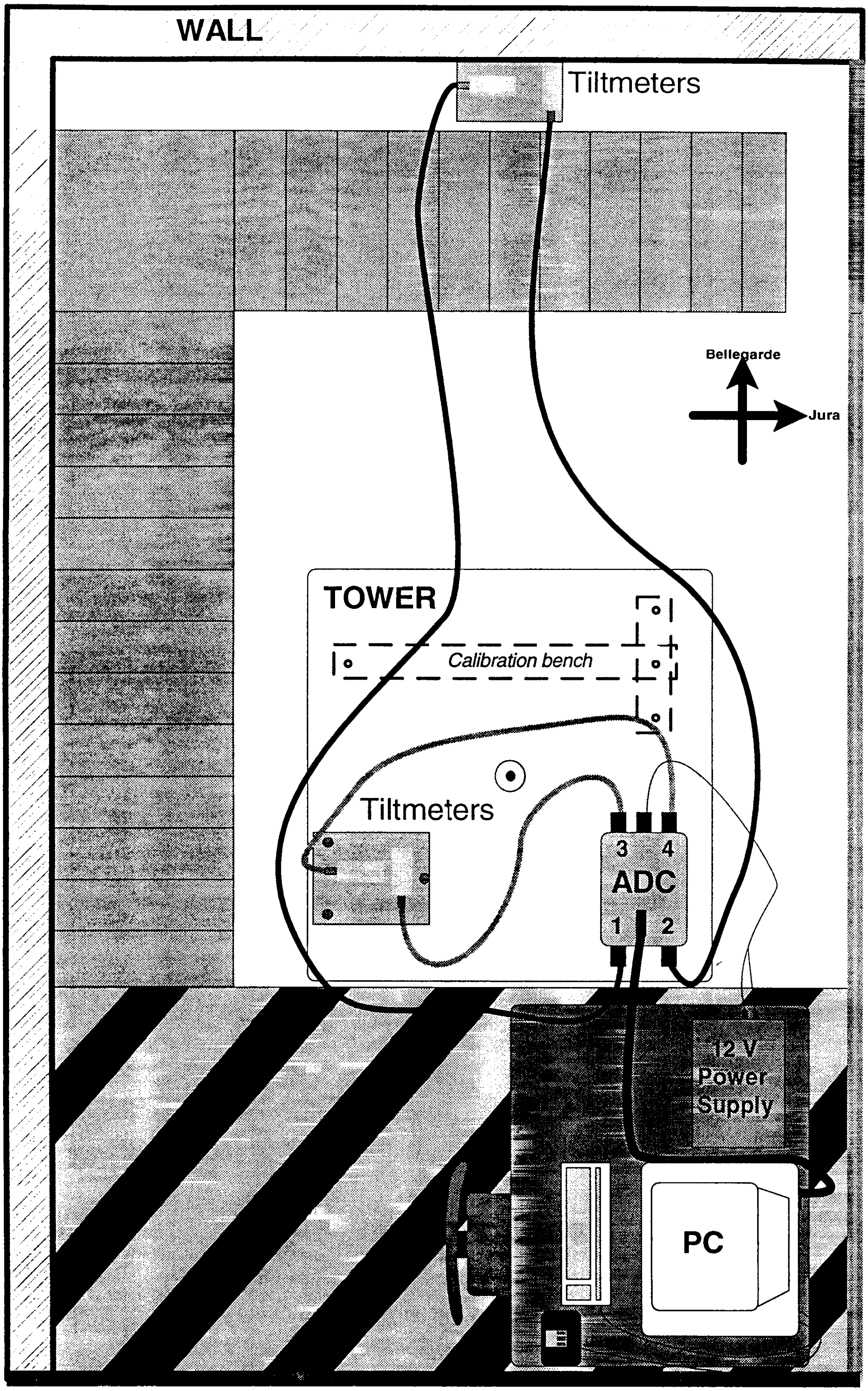


Fig. 3: Stability experiment set up

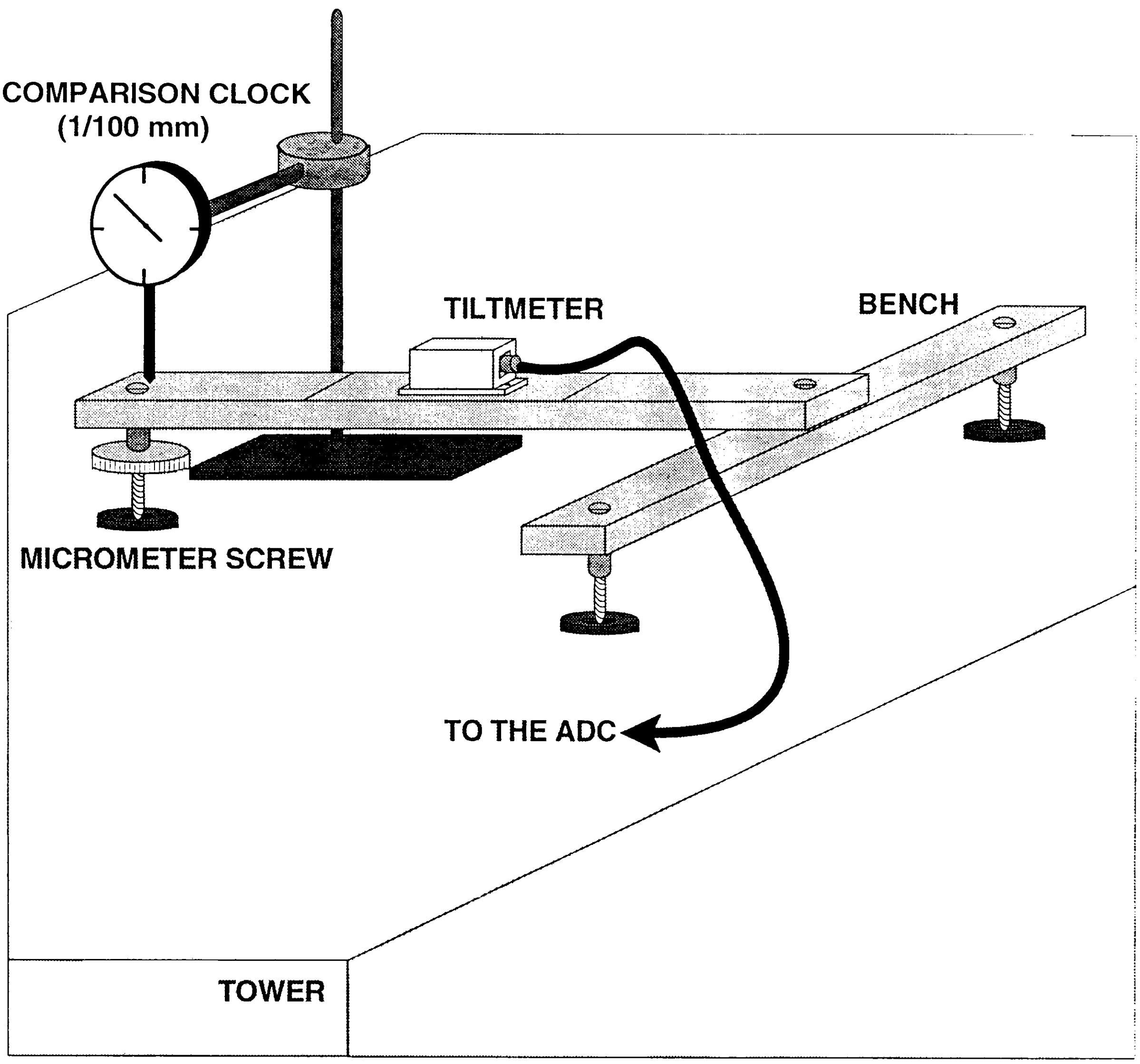


Fig. 4: Tiltmeter calibration bench

```
05/05/1995  15:22:05     INCLINOMETER DATA ACQUISITION


MAIN MENU

 1. Do one measurement
 2. Do a continuous acquisition
 3. Do a time programmed acquisition
 4. Print a data file
 5. Serial Port options

 0. End Program

Select an option and press enter :
```

Fig. 5a: Main menu of the program INCLINOM

DATE	TIME	SENS1 (dg)	SENS2 (dg)	SENS3 (dg)	SENS4 (dg)
05/05/1995	09:04:00	0.09051	−0.02736	0.04948	0.00011
05/05/1995	09:23:54	0.09047	−0.02730	0.04946	−0.00012
05/05/1995	09:43:47	0.09053	−0.02730	0.04955	0.00013
05/05/1995	10:03:41	0.09060	−0.02742	0.04950	0.00019
05/05/1995	10:23:34	0.09067	−0.02741	0.04947	0.00020
05/05/1995	10:43:28	0.09079	−0.02724	0.04951	0.00045
05/05/1995	11:03:22	0.09092	−0.02727	0.04935	0.00043
05/05/1995	11:23:15	0.09094	−0.02711	0.04942	0.00053
05/05/1995	11:43:09	0.09085	−0.02717	0.04944	0.00038
05/05/1995	12:03:02	0.09096	−0.02720	0.04953	0.00077
05/05/1995	12:22:56	0.09116	−0.02725	0.04945	0.00076
05/05/1995	12:42:49	0.09136	−0.02730	0.04960	0.00054
05/05/1995	13:02:43	0.09156	−0.02734	0.04959	0.00069
05/05/1995	13:22:36	0.09164	−0.02764	0.04950	0.00096
05/05/1995	13:42:30	0.09194	−0.02781	0.04955	0.00098
05/05/1995	14:02:24	0.09210	−0.02796	0.04954	0.00103
05/05/1995	14:22:17	0.09228	−0.02805	0.04963	0.00136
05/05/1995	14:42:11	0.09258	−0.02810	0.04959	0.00091
05/05/1995	15:02:04	0.09277	−0.02818	0.04982	0.00137
05/05/1995	15:21:58	0.09281	−0.02835	0.04977	0.00146
05/05/1995	15:41:51	0.09298	−0.02837	0.04981	0.00177
05/05/1995	16:01:45	0.09328	−0.02859	0.04978	0.00175
05/05/1995	16:21:38	0.09338	−0.02864	0.04986	0.00181
05/05/1995	16:41:32	0.09349	−0.02862	0.04987	0.00164
05/05/1995	17:01:26	0.09387	−0.02883	0.04992	0.00169
05/05/1995	17:21:19	0.09368	−0.02891	0.04998	0.00158
05/05/1995	17:41:13	0.09409	−0.02890	0.05013	0.00193
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.

Fig. 5b: Sample of a tilt ASCII file.

Fig. 6: Tower and wall tilts in the Jura and Bellegarde directions from the 25/04/95 to the 08/05/95. Note the 4 hour stabilization delay at the beginning of the measurements.

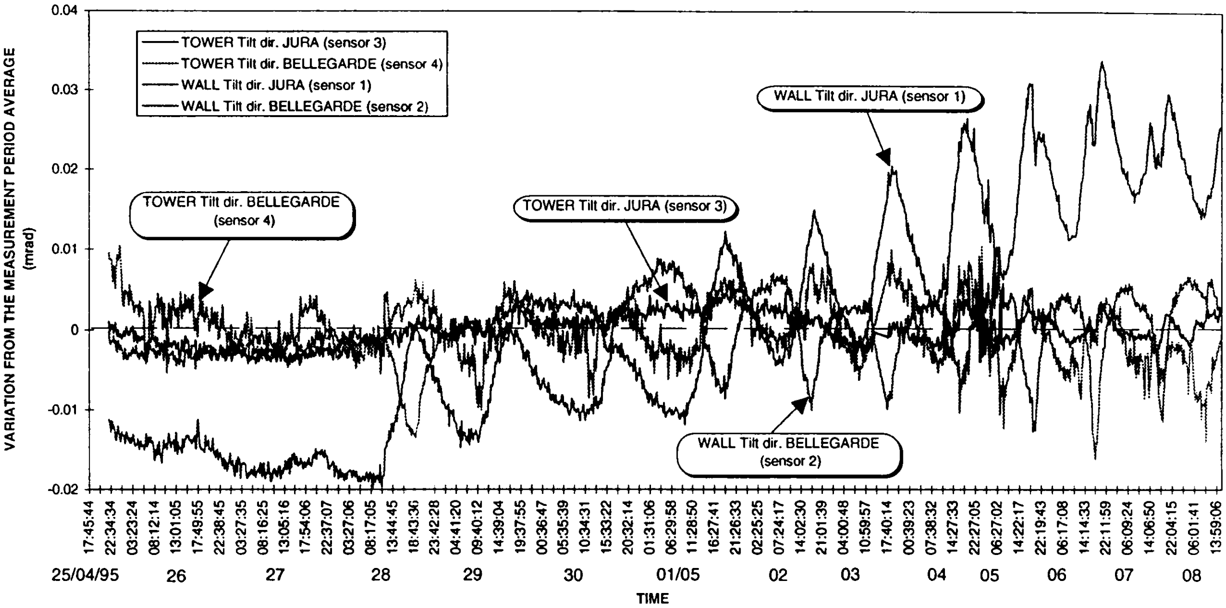


Fig. 7: Outside temperature and humidity near the building 236.

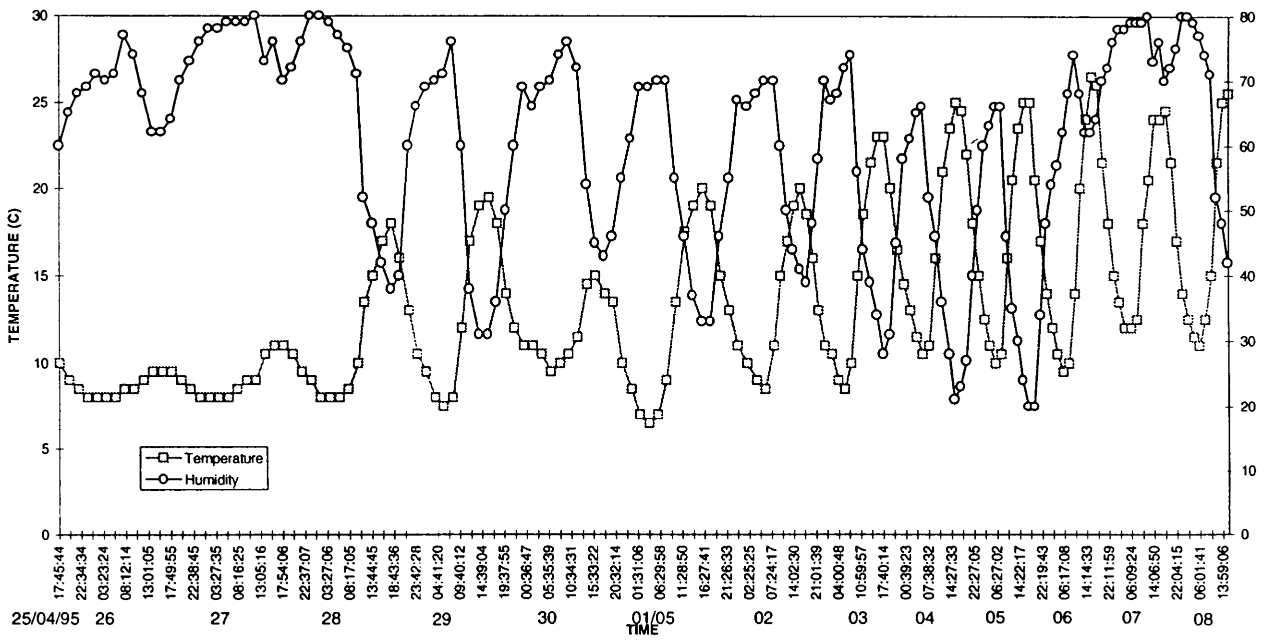


Fig. 8: Tower tilts in the Jura direction with respect to the outside temperature.

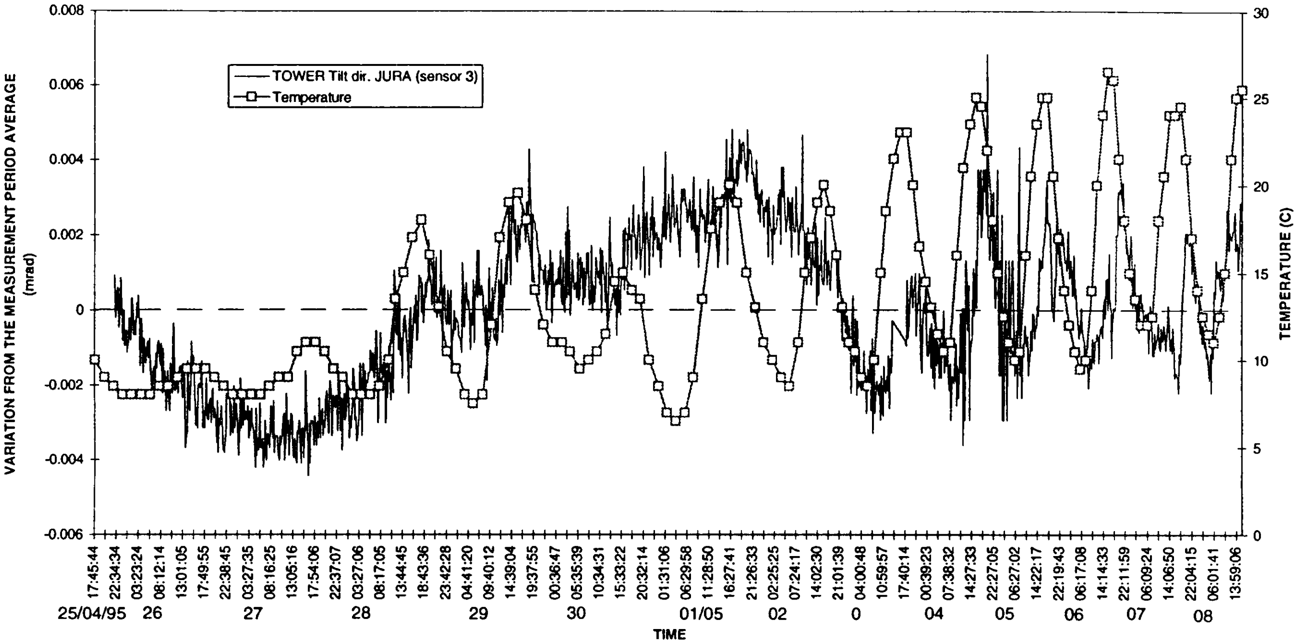


Fig. 9: Tower tilts in the Bellegarde direction with respect to the outside temperature.

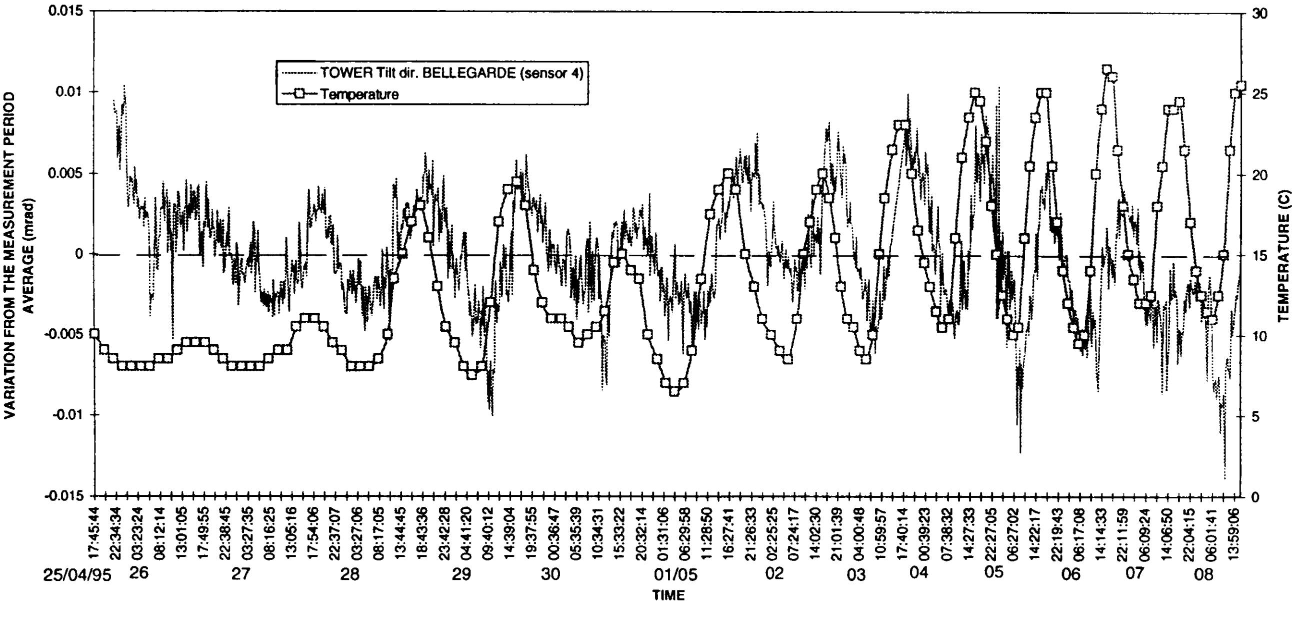


Fig. 10: Wall tilts in the Jura direction with respect to the outside temperature.

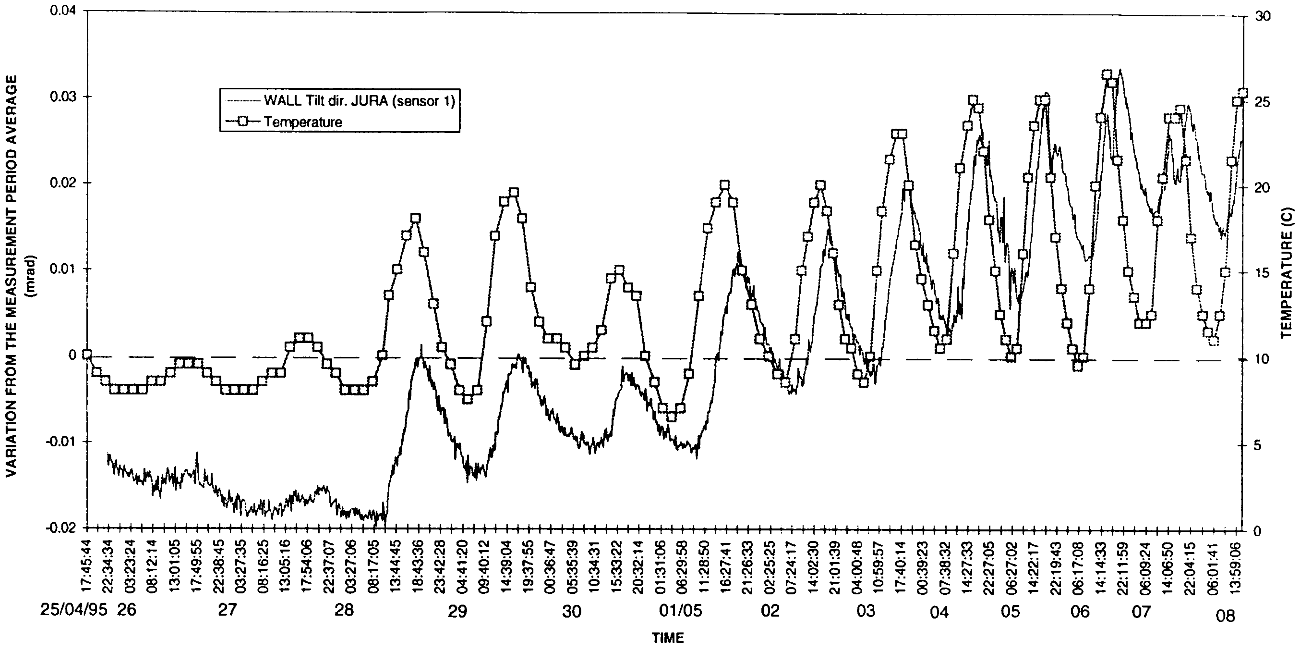
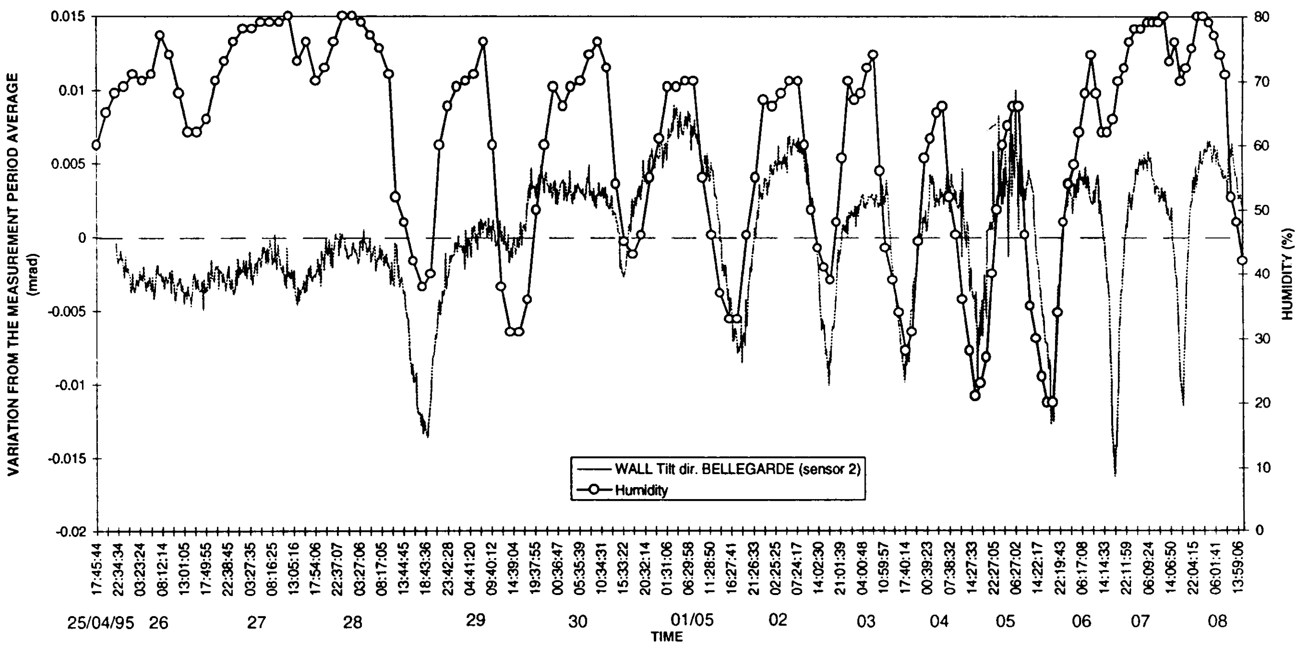


Fig. 11: Wall tilts in the Bellegarde direction with respect to the ouside humidity.



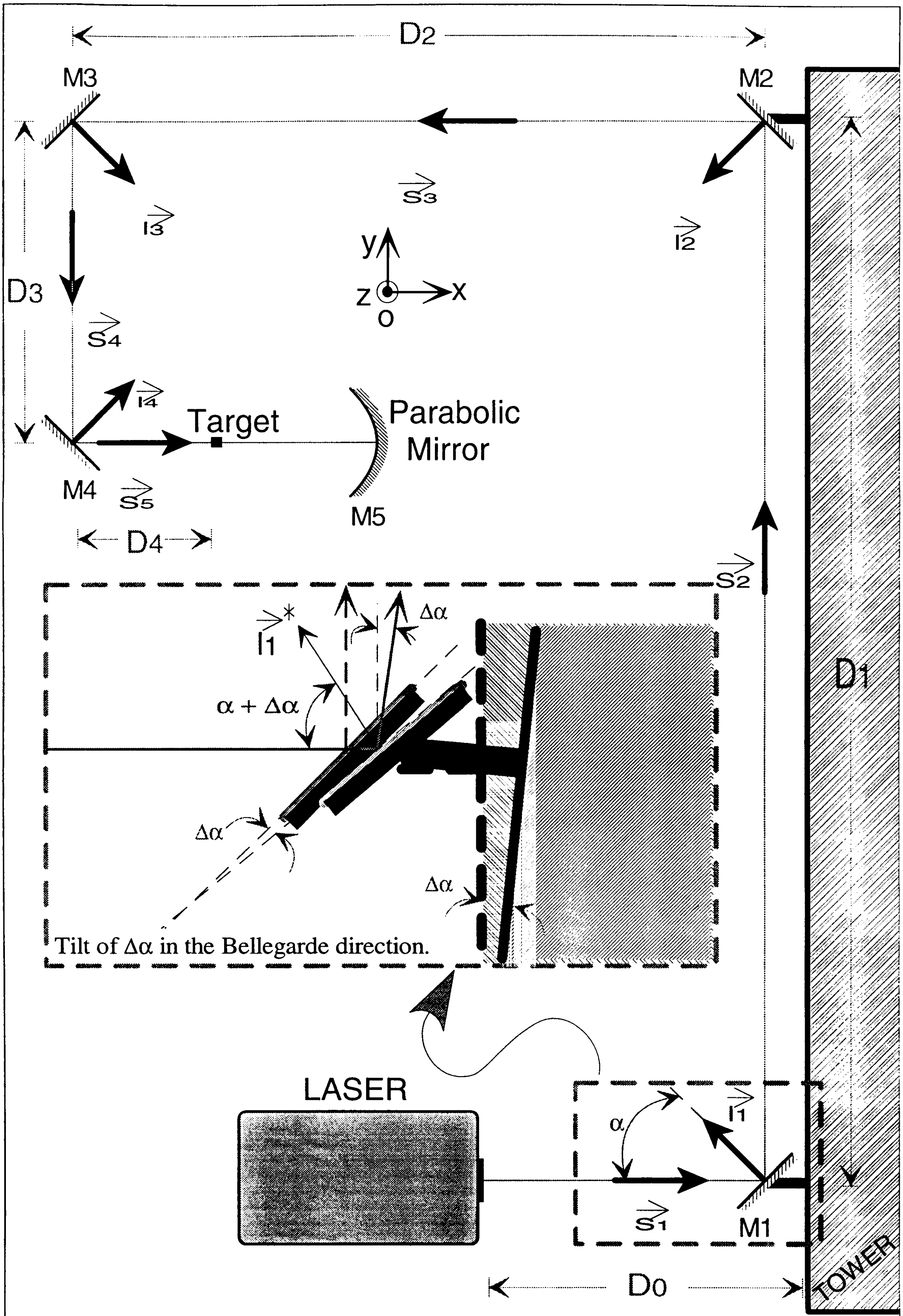


Fig. 12: Schematic layout of the LIS experiment (with the coplanarity assumption).