Wire measurements for the control of the FFTB-magnets

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1 The FFTB-Project

The new generation of accelerators will be linear colliders with lengths up to 10 km. As diameter of the beam is very small, some tenths of a micrometer, the magnets of a linear collider have to be aligned with a very high accuracy. At the SLAC-laboratory near San Francisco in California (USA) the problems of the new colliders will be studied for the first time /2/. This project is called "Final Focus Test Beam" (= FFTB)[1].

In the extension of the existing linear collider, the magnets of the new project will be arranged in five straight sections (Fig. 1). The lengths of the sections are up to 50 m. Within a section the tolerance of the alignment should be better than 100 μm for the horizontal and 30 μm for the vertical position. This value characterizes the deviations of the magnets from a smoothing straight line of a section. The magnets also have to be on their horizontal positions within a tolerance ~15 μm and on their vertical positions within a tolerance of <5 μm. The standard deviation of the measurement is in this case half of the tolerance, thus 2.5 μm. The intention is to measure the motion of the magnets continuously and to move the magnets back into their old positions by an automatic movement system /2/. The question is, which measuring techniques can one use? Here at DESY we are testing a stretched wire system for the FFTB-project. I will give you first results about our tests of the wire.

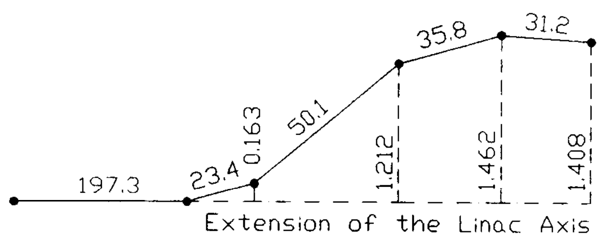

Figure 1: FFTB-Project

2 Techniques for wire measurements

Using a wire measurement system one has to measure the horizontal distance between the wire and, for example, the magnets. The system should measure the distance without any contact with an accuracy of a micrometer. The wire should not be changed in any case. Under these conditions I will discuss three techniques (Fig. 2):

[1] At present time the project is not officially approved.

Linear CCD-array
A parallel light beam makes a shadow of the wire on a linear CCD-array. The position of the middle of the shadow is determined by the CCD–sensor /1/. With two CCD–elements the horizontal and the vertical positions of the wire can be measured. The measuring range is 10 mm.

Differential diode
Instead of a CCD–sensor one can use a differential diode, however the measuring range is then very small perhaps 1 mm.

Electrical technique
By this technique the wire has to be electrically conducting. A short pulse with a time constant of a nanosecond goes through the wire. In between two metallic plates the pulse induces electrostatic influence charges. The difference of the charges tells us how far the wire is from the middle of both plates. The measuring range is also very small, perhaps 1 or 2 mm.

The disadvantage of the first two techniques is the danger of damage to the sensors as a result of the radiation in the collider.

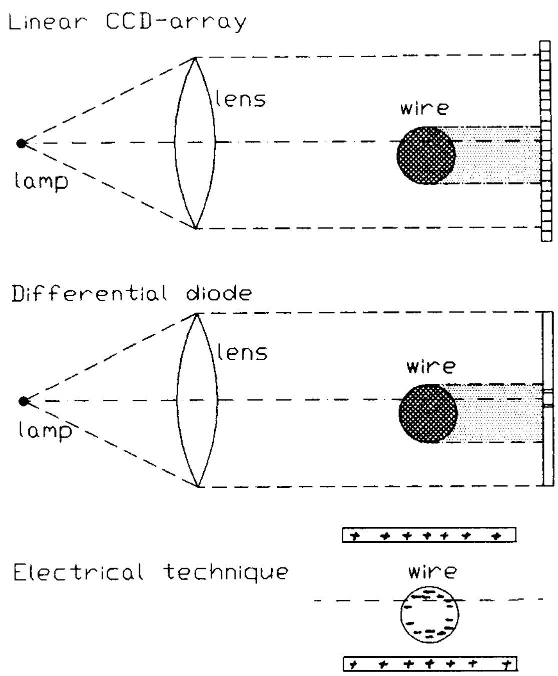

Figure 2: Techniques for wire measurements

3 Conception of a wire measurement system for continuous alignments

How can one use a stretched wire for continuous alignment of the magnets? To observe only the horizontal positions of the magnets it would be sufficient to stretch a wire on one side of the magnets in the height of the beam. Using this technique the distance between the wire and the magnet is independent of the roll of the magnet. The task for the movement system is to keep the distance between the wire and the magnet continuously constant. For this purpose the distance has to be measured with one of the techniques described in section 2. For each section of FFTB a wire has to be stretched.

With this technique only the horizontal position can be controlled. Our intention is to control also the vertical position continuously by the wire. This aim is more difficult to achieve. The stretched wire has a sag. If the sag is constant for all conditions, then we don't have a problem. However we don't know this, therefore we have to go another way. For example some dozens of wire positioning devices are installed along the stretched wire (Fig. 3). The vertical position of the wire will be detected continuously with all devices. Now, if the sag is changed, the readings of the devices will also change in a systematic manner. The readings increase with the distance from both ends of the wire. In the middle of the wire there is the greatest difference. The differences of the readings can be approximated by a smoothing curve, for example by a parabolic function. Next we have to find out how many differences are on the smoothing curve and how many are not. If only a few differences are not on the smoothing curve, one can say, that only these magnets have moved in the vertical position. The deviation from the smoothing function is the value for the correction of the magnet. I hope this technique will also be suited to keep the magnets in their vertical position by the movement system.

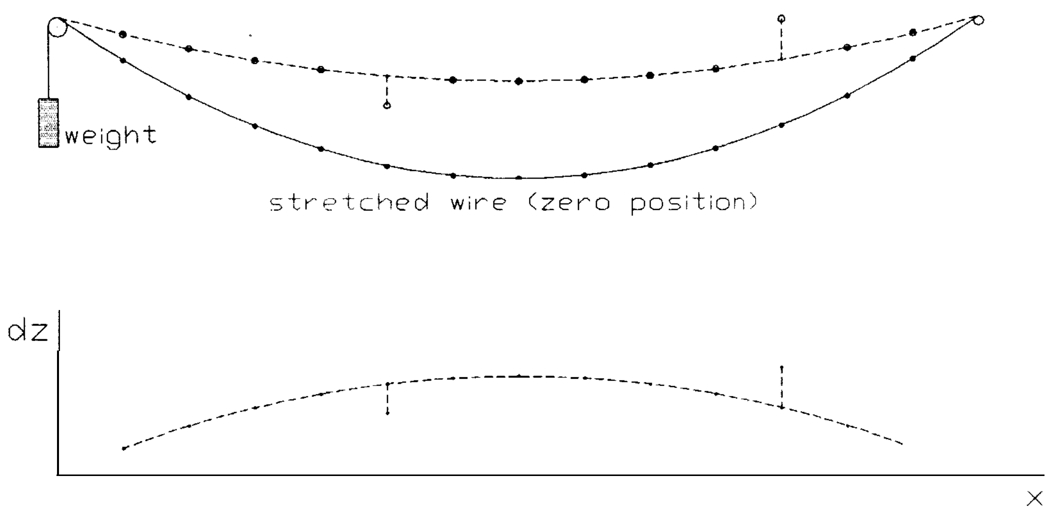

Figure 3: Conception of wire measurements for alignments

In the case of controlling the horizontal and also the vertical position of the magnets continuously with a stretched wire it will be better to have two wires, one on either side of the magnets. Then the mean of both vertical readings is also independent of the roll of the magnet. Furthermore the difference of both vertical readings determines the roll of the magnet. both horizontal readings are controlled by themselves.

4 Investigation of the wire

The stretched wire defines the datum for the continuous alignment, it is therefore very important to know what the wire is doing under various conditions. We have tested different materials for the wire:

- spring steel (diameter 0.5 mm)
- stranded wire (diameter 0.32 mm - 0.80 mm)
- synthetic material (Kevlar; diameter 0.18 mm)

4.1 The test stand

At DESY we have developed a method of testing various wires. Here you see the beginning of the test stand for fixing the end of the wire (Fig. 4). On the other side the wire goes around a guide pully (Fig.5). The wire can be stretched with different weights. The length of the test stand is 45 m, comparable to the FFTB. A pipe protects the stretched wire against air stream.

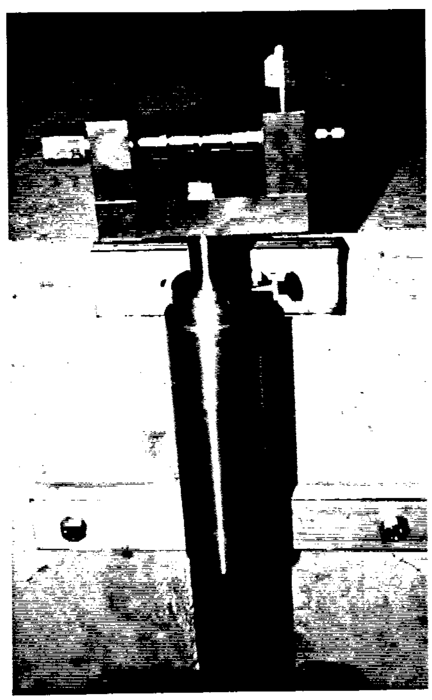

Figure 4: Beginning of the test stand

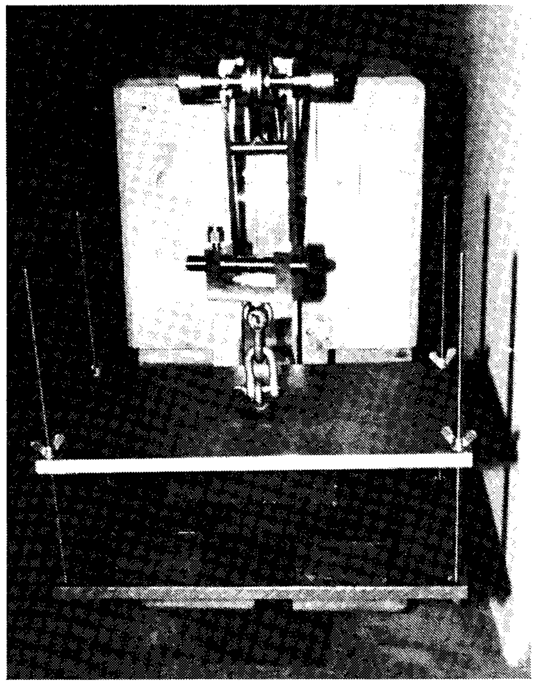

Figure 5: End of the test stand

4.2 Straightness check of the wire

Does a stretched wire generate a straight line in the ground plan? To answer this question we measured the straightness of a spring steel wire with a theodolite. Along the wire there are mounted five tripods. The single bay distance is 12 m. The wire was marked with a felt-tip pen at intervals of one meter. From each tripod the directions were measured with a theodolite to these marks. Fig.6 shows the results. The horizontal deviations are <0.05 mm. This value represents the accuracy of the direction measurements. One can therefore say the straightness of the tested wire is in any case better than 0.05 mm.

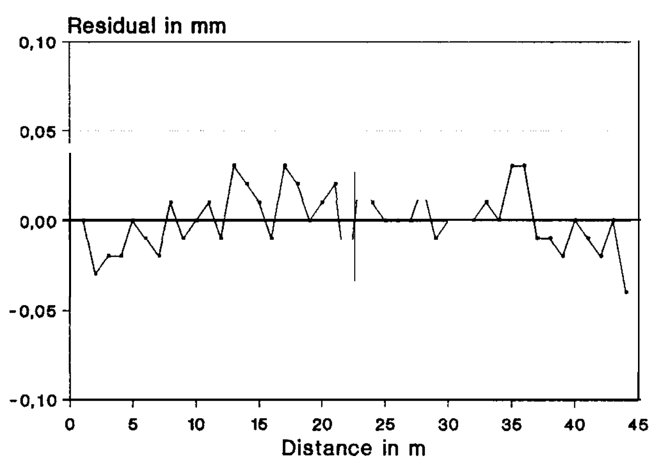

Figure 6: Straightness of the wire

4.3 Check of the sag

The sag of the stretched wire should be kept very small. Why? If a magnet makes motions in the longitudinal direction you have an effect in the vertical position. For example, if the sag is 5 cm by a length of 45 m the maximum change in the vertical position will be 4.4 μm per 1 mm motion in the longitudinal direction. For the spring steel wire we measured the sag with different weights. Fig. 7 shows the results. It is no problem to stretch the wire so taut that the effect of the sag to the vertical position is negligible.

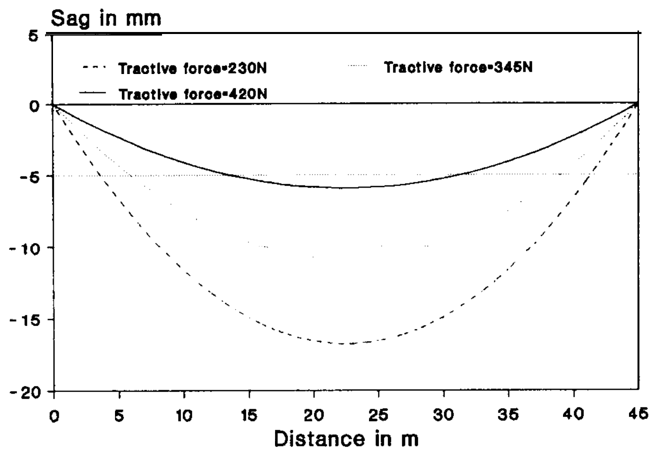

Figure 7: Dependence of the sag from the weight

Furthermore we measured also the curve of the stretched wire with a levelling instrument. In a textbook you can read, that the curve of a stretched wire is a catenary. But the adjustment with a catenary shows systematical deviations (Fig.8). If you make an adjustment with a parabolic function the residuals will be significantly smaller and more random. The theory of a catenary demands that the wire isn't extensible. But in our case the spring steel wire is extensible. This can explain the difference between theory and practice.

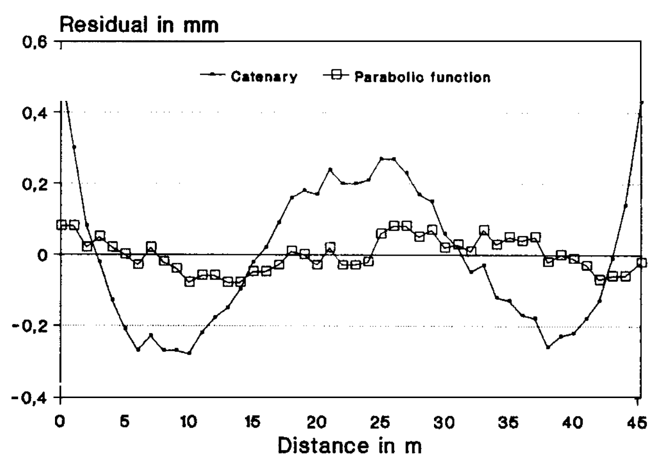

Figure 8: Residuals for a catenary and a parabolic function

4.4 The characteristics of vibrations

A stretched wire is an oscillator. If you give the wire a sideways shift and then let it go, what happens? The stretched wire makes damped vibrations. After a certain time the wire comes to a rest position. To investigate this effect we have bought the device LPG 10 G provided by the firm of OMT in Munich, which is used for manufacturing cables with high precise diameters (Fig.9). The measuring range of this device is 10 mm. The two measuring axes determine the horizontal and the vertical positions of the wire. The device works with parallel light beams and linear CCD-arrays. The single bay distance between the pixels is 13 μm. The device makes 1,000 - 10,000 internal measurements per second. The transfer rate with the RS 232 input/output-port is at this time only 40 readings per second. But in the future with a new output-port (16 bit parallel) it will be able to transfer 1000 readings per second into a connected computer.

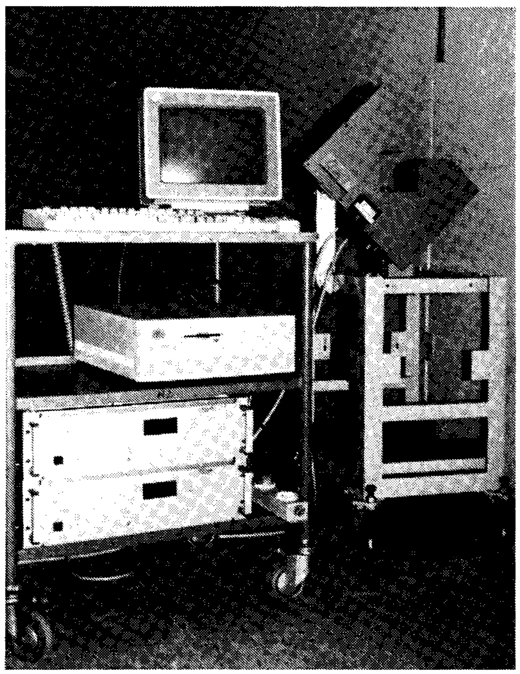

Figure 9: Device for measuring the position of the wire

At first we investigated the accuracy of this device with a laser interferometer. A small drill was moved on a support through the measuring range. The motions of the support and with that the motions of the drill were measured with the laser interferometer with an accuracy of 1 μm. Fig. 10 shows the results of one experiment. The accuracy of the device is 1 μm or 2 μm.

To study the vibrations of the stretched spring steel wire we made several experiments. The device was mounted at the middle position of the wire. At this place we gave the wire a sideways shift of 3 mm and let it go. Fig. 11 shows the results. The mode of vibriation is sinusoidal. The frequency of the vibration is 5 Hz. This value corresponds with the characteristic frequency of the wire. Under the conditions of the experiment the characteristic frequency is calculated at 5.0 Hz. This is a good agreement.

In this Fig. 12 you see all 6000 readings of the experiment. The measuring time was 2½ minutes. After about two minutes the elongations of the wire are only some micrometers. The time constant of the damped vibrations is about 16 seconds. If you give the wire an

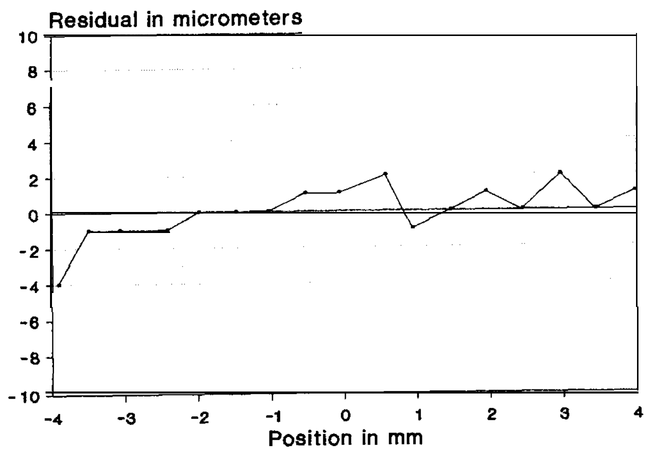

Figure 10: Test of the accuracy of the device

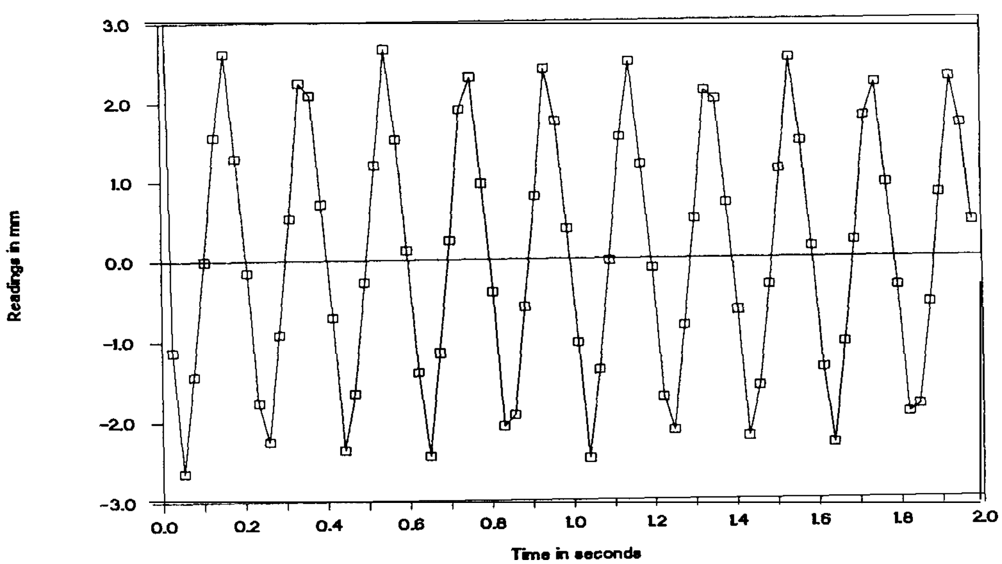

Figure 11: Vibriations of the spring steel wire

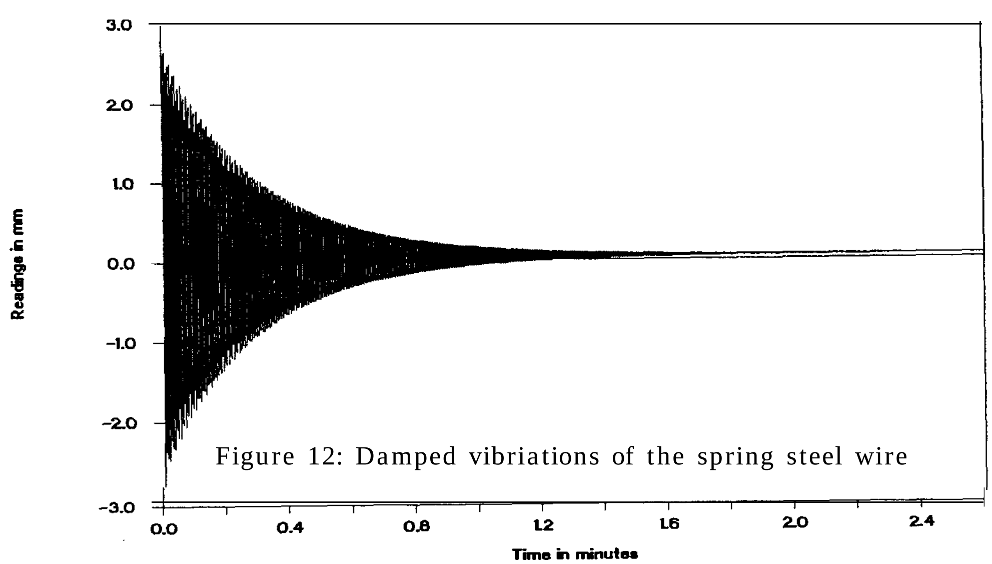

Figure 12: Damped vibriations of the spring steel wire

impact excitation on the end, the wire makes vibrations as shown in Fig, 13. The shifts look like a pulse.

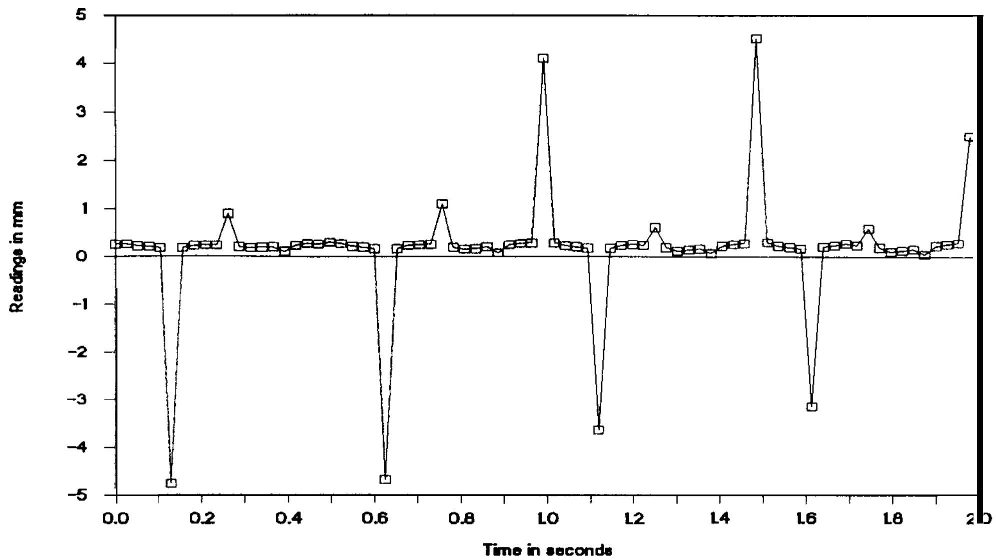

Figure 13: Vibrations of the spring steel wire by impact excitation

We have made the same experiments with a stranded wire with a diameter of 0.6 mm covered with synthetic material. The time constant of the damped vibrations is a little bit longer than that of the spring steel wire (Fig. 14).

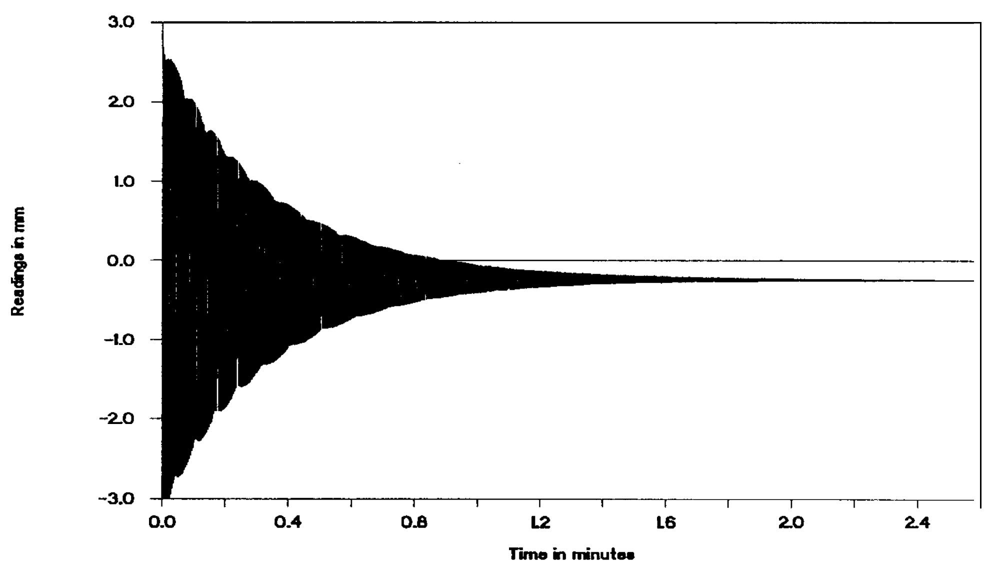

Figure 14: Damped vibrations of a stranded wire

Fig. 15 shows the results of the synthetic material wire (Kevlar). The time constant is very short, only some tenths of seconds.

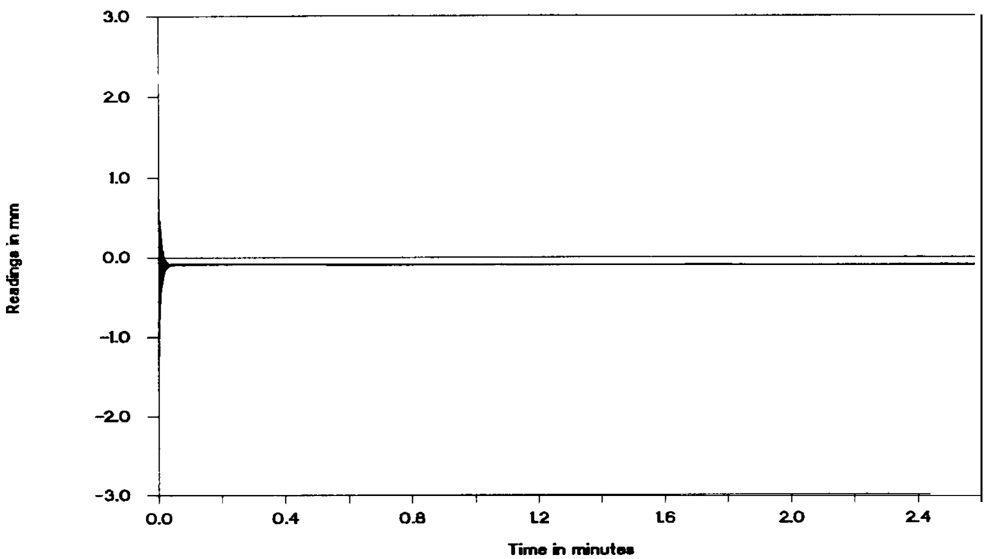

Figure 15: Damped vibrations of a synthetic material wire

4.5 Stability measurements

To test the long–term stability of the test stand and of the wire we have made measurements during several days. Every ten or twelve minutes 20 readings were determined. Fig. 16 shows the mean of the 20 readings for the horizontal position. The values decrease during eighteen hours. During the next thirty hours the readings are constant with a stability of better than 2 μm. The drift can be explained by a change of the inclination of the test stand. The readings for the vertical position (Fig. 17) also show a drift. The deviations from a smoothing curve determine only some tenths of a micrometer during the night. During the day the deviations are fluctuating by 12 μm. The reason for the drift is unknown.

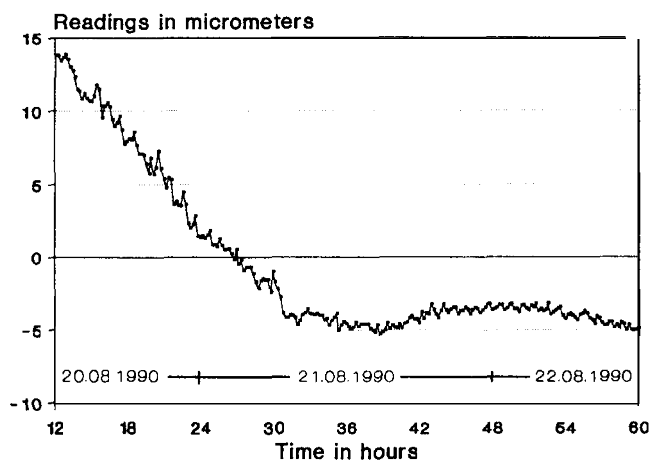

Figure 16: Stability measurements for the horizontal position

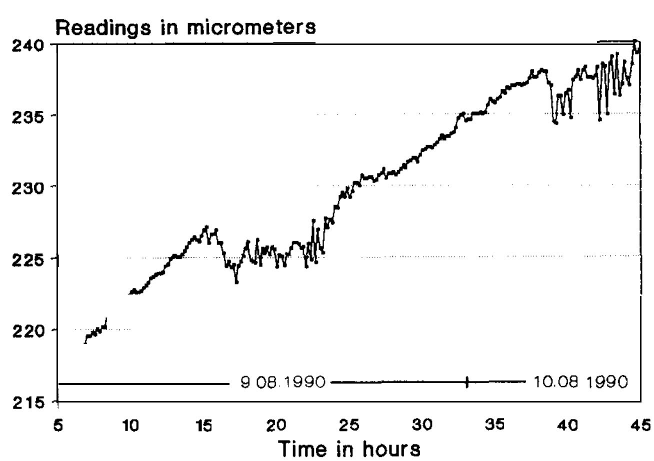

Figure 17: Stability measurements for the vertical position

5 Conclusion

At present we have not finished our investigations on the wire. But we are very hopeful, that the wire measurement system is suitable for the FFTB-project. The problem is having a sensor, which determines the position of the wire without any contact and that is also not affected by the radiation. It is hoped, that the electrical technique described in section 2 will have a sufficiently good accuracy. The sensor will be developed in the electronic division of DESY. In the near future we will test this system. We will also have to check the influence of the magnetic field on the position of the spring steel wire. The influence of the air stream will be eliminated by a pipe.

6 References

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