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The Optical Alignment Monitoring System of CHORUS (RASNIK)

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Abstract

For the first time, several imaging RASNIK optical alignment systems have been installed in a running experiment. Calibration, performance, and results of datataking are reported.

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1 Introduction

The CHORUS experiment [1] depends critically on the relative alignment of its subdetectors to maintain a high efficiency. In particular, its fiber trackers and a newly installed honeycomb tracking chamber are designed to determine track trajectories with a precision of 100–200 μm. Therefore, we require knowledge of the detectors' absolute positions and movements with at least this precision.

The honeycomb chambers [2] are mounted on aluminum supports and subject to the temperature changes of the hall. As a result movements of order 300 μm could be expected. The fiber trackers are kept in a temperature stabilized environment; however, the cooling cycles and the pulsing of a nearby magnet could cause short time-scale movements of these detectors.

The CHORUS experiment determines the positions of its elements using surveys, through-going muons, cosmic rays and tracks in neutrino data. In 1996, CHORUS began to monitor the relative alignments of some detector elements with the RASNIK system (Relative Alignment System of NIKhef), developed at NIKHEF, Amsterdam [3]. This system provides an inexpensive (~\$500/channel) means of determining relative positions with an accuracy better than 2 μm along two axes, and of order 30 μm (*e.g.*, for a 60 cm source-to-CCD distance) along the third axis. These measurements can be repeated several times per minute, limited by CPU power.

The RASNIK technique[1] is briefly described in the following section. Section 3 shows how the RASNIK performed in a test setup. Section 4 describes the installation into the CHORUS detector and shows how the RASNIK performed *in situ* as well as showing what could be learned about the CHORUS apparatus with the help of the RASNIK.

2 Technique

The basic idea of the RASNIK is to project a finely detailed image through a lens onto a CCD camera as shown in Figure 1. If any of these three elements moves, there will be a corresponding movement of the image on the CCD camera. Note that this is an imaging system of an incoherent light source; it does not require any lasers.

The light source is a 3×3 grid of infrared-emitting LEDs. These LEDs illuminate a "coded mask" which is printed with 85-μm black-and-white squares in almost a checker-board pattern. The checker-board pattern is not exact, but is interrupted by unique "codes", as shown in Figure 2. When the image of the mask moves by more than one square, the pattern may be used to decode the global position information. The image is focussed with a simple convex lens placed near or at the half-way point of the system. The focal length of the required lens depends on source-to-image distance of the system. Its diameter is about 3% of its focal length, to compromise between

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[1] This system should not be confused with a simpler system, with the same name, employed by the L3 experiment.

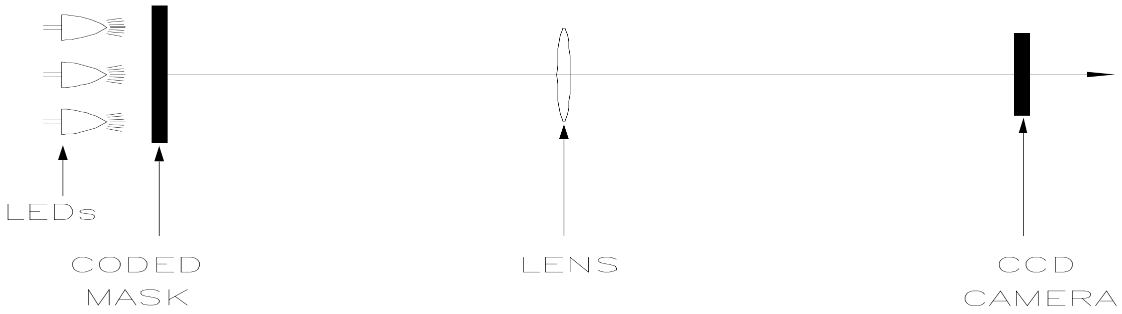

Figure 1: The optical elements of the RASNIK system.

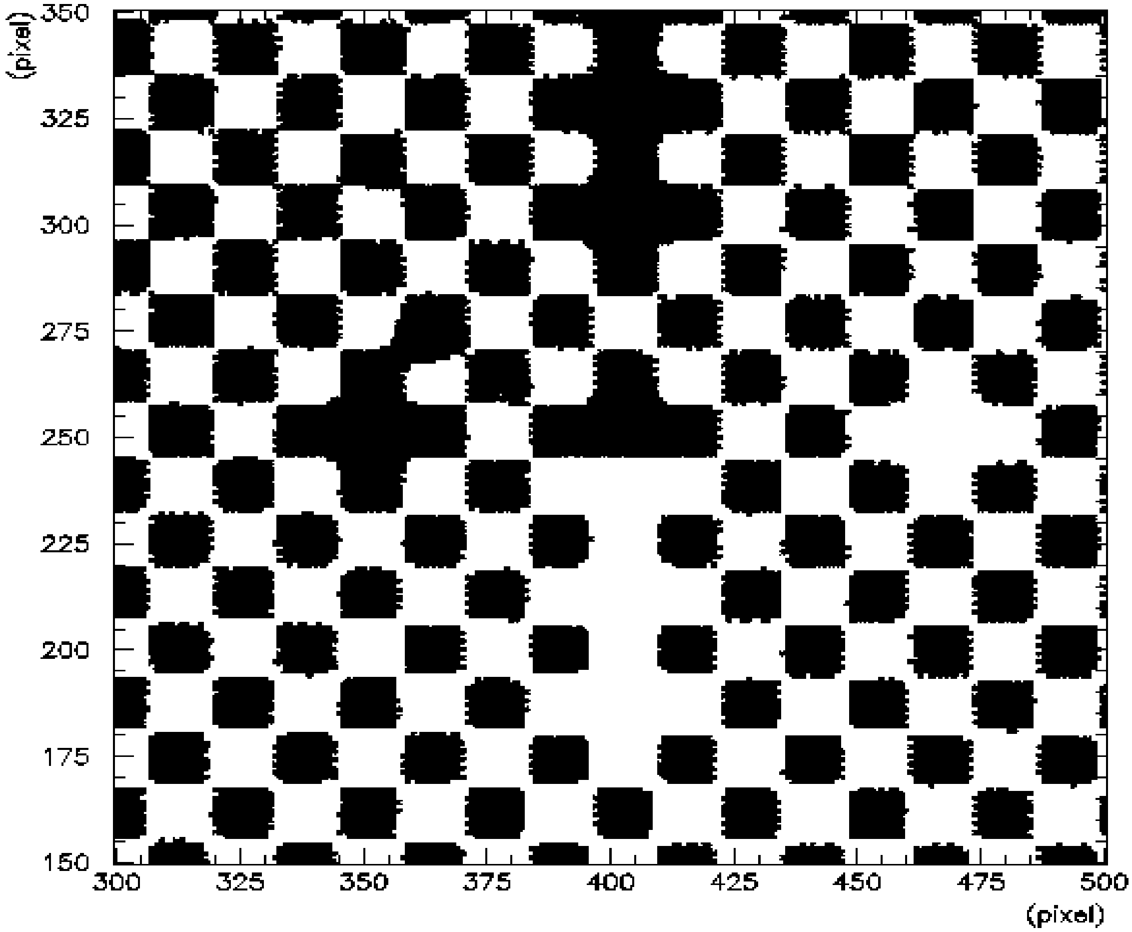

Figure 2: Portion of an actual image taken by one of the RASNIK systems. The full image is 768 × 512 pixels (10 times the area shown). Each square is about 13 pixels wide.

diffraction and spherical aberration. The image is recorded by a 1/4" CCD with a pixel pitch of 6 μm $\times$6 μm. The image on the CCD is transmitted as a standard video signal to a personal computer where a single frame is digitized and recorded as a binary file.

The digitized picture is 768×512 pixels, each with an 8-bit gray level. An analysis program finds all the black/white transition points. The edges are located and the pattern is decoded for global position information. Since the size of the squares is known, movements in the two directions transverse to the image are readily converted to movements in microns. There are so many transitions to measure (a typical image has about 60×40 85-μm squares) the precision in these directions should be better than 1 micron. Movements along the third axis, *i.e.*, parallel to the infrared beam, are measured by noting the change in the size of the image. This is clearly measured with a lower resolution (tens of microns) but is sufficient in this case. This resolution could be improved by taking multiple pictures or by mounting an orthogonal RASNIK system.

3 Testbench results and Calibration

Before being installed on the detector, a RASNIK system identical to that installed on the honeycomb trackers (see Section 4) was installed on an optical bench. Here the linearity, scale, and other features were tested by mounting the CCD on a movable stage which could be positioned to 2 μm precision. Figure 3 shows the measured displacement versus true displacement in one of the transverse directions. The differences between the set and recorded positions, shown in Figure 4, are consistent with being due solely to the ability to position the camera. The same plots for the other axes give similar results.

One can also look at the recorded movements in the direction which is not being moved. One sees almost no correlated movement (0.3% correlation). The residual correlation may be due to non-orthogonality of the mounting. A new version of the analysis software determines any non-orthogonality of the mounting (and removes their effects) by measuring the skewness of the video image [4]. However, the correlation is sufficiently small for this application.

There is no calibration of the system necessary for movements along the two axes orthogonal to the infrared beam. Since the image moves by fractions of a square on the CCD, and the square size is known, these image movements are directly converted into distances. However to measure movements parallel to the infrared beam, the RASNIK software uses the change in size of the squares. Hence the effective pixel size of the CCD-camera and frame-grabber combination must be known. This was accomplished on the test bench using a lens position so that the magnification was equal to unity. Since the size of the squares is well known, its size in number of pixels of the CCD gives a pixel size of 6.24 μm $\times$6.28 μm.

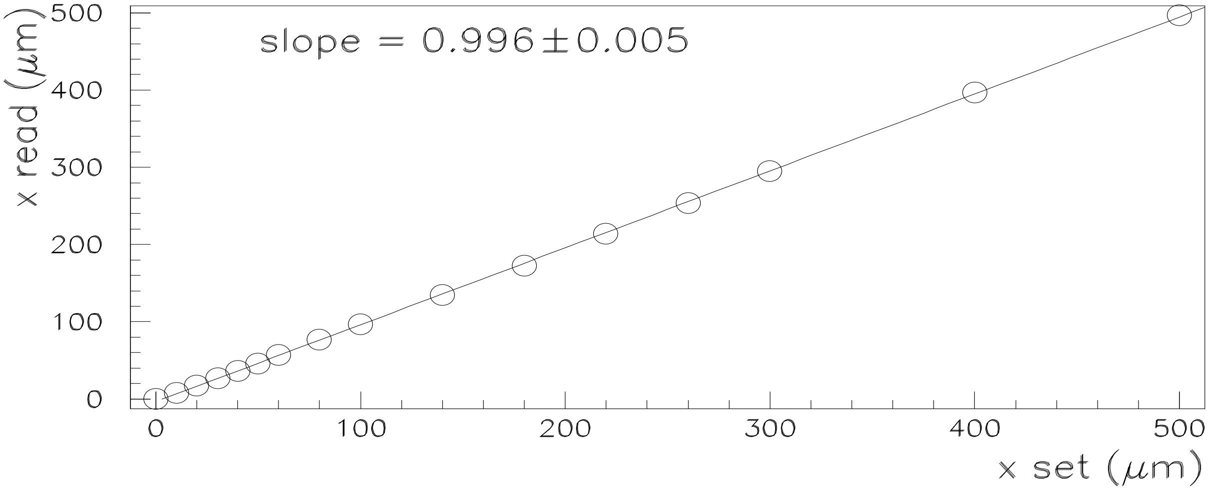

Figure 3: Linearity of the RASNIK response. The horizontal axis is the position of the camera set by a movable stage. The vertical axis is the displacement recorded by the RASNIK. A similar linearity with unity slope is seen for the y and z axes.

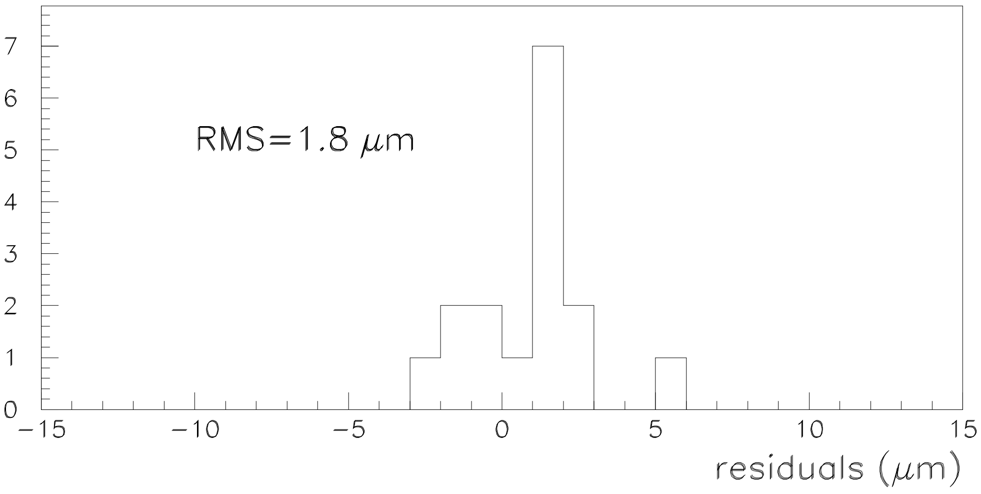

Figure 4: Deviations of the RASNIK response from the set position. The spread, 2 μm, likely corresponds to the ability to position the movable stage by hand.

4 Installation in CHORUS

Four RASNIK systems were installed into the CHORUS detector in August 1996. Three were installed at the same time as the installation of new honeycomb tracking chambers to which they were mounted. A fourth was mounted to monitor the movements of one of the most upstream diamond-shaped fiber trackers.

4.1 RASNIK data acquisition

The video signal from each RASNIK system is sent over a video cable to a dedicated IBM PC (486, 66 MHz). Here, each channel is connected to one of eight inputs of a video multiplexer card (Data Translation DT2859) in the PC. The output of the video multiplexer is connected to the input of a video "frame grabber" card (Matrix Vision MVLC) in the same PC. The PC selects one of the video inputs to the multiplexer and causes the frame grabber to digitize a single frame. The picture is 768 × 512 pixels with an 8-bit gray level, resulting in a temporary 400 kbyte file. Concurrently, a parallel file containing the time and RASNIK channel number is written. These files are continuously transferred via FTP to an online Unix system (IBM Power PC 601, 100 MHz) which continually runs a process which looks for and analyzes new data files. The time to analyze an image, 20 seconds, is the current limitation of the throughput. The result of each analysis is three position numbers, a rotation angle, time, and information about the fit quality. After each analysis the large image file is discarded. One month of data from a RASNIK occupies 320 kbytes. The operational live-time of the system was 97%.

4.2 The honeycomb chamber RASNIK systems

Three RASNIK systems were mounted on the honeycomb tracker – one on each outer corner of its support frame. The goal is to use these RASNIK systems to monitor the position of this tracker relative to the next upstream tracker, the CHORUS fiber "diamond" trackers. As shown in Figure 5, the source and lens are mounted in a common assembly on the diamond trackers. The CCD camera is mounted on the aluminum frame which supports the honeycomb trackers. The distance between the source and camera is 61 cm. In this orientation, the infrared beam parallel to the neutrino beam, the two precisely measured axes are those orthogonal to the neutrino beam; the third, less precise, axis is the one parallel to the neutrino beam.

Figure 7 shows the movements of a RASNIK for a three-hour period in the two transverse directions and the one longitudinal. This plot illustrates the repeatability from one measurement to the next – better than 2 microns, which may well be due to the rigidity of the detector and not an instability of the RASNIK response. Figure 8 shows the same results over a three-day period. The maxima and minima are separated by 24 hours and correspond to 6h00 and 16h00, the coolest and warmest times in the experimental hall. The structure at the level of every few hours corresponds to the cycles of the ventilation system. The data-taking for a month is shown in Figure 9. The envelope of the daily maxima and minima correspond to changes of the extremes

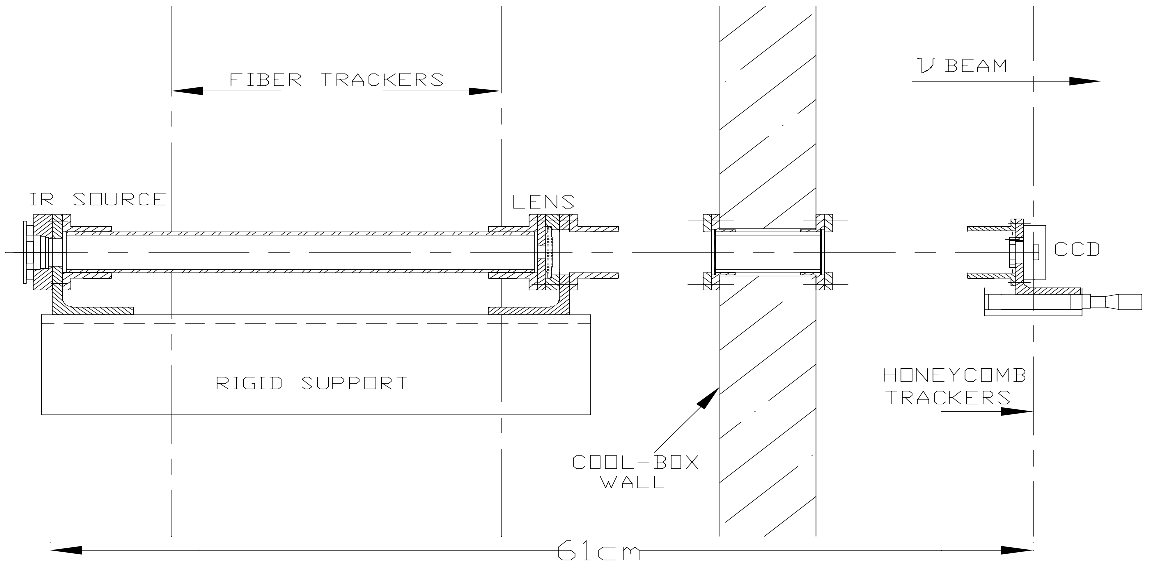

Figure 5: One of the three RASNIK systems monitoring the honeycomb tracker movements relative to the upstream fiber trackers.

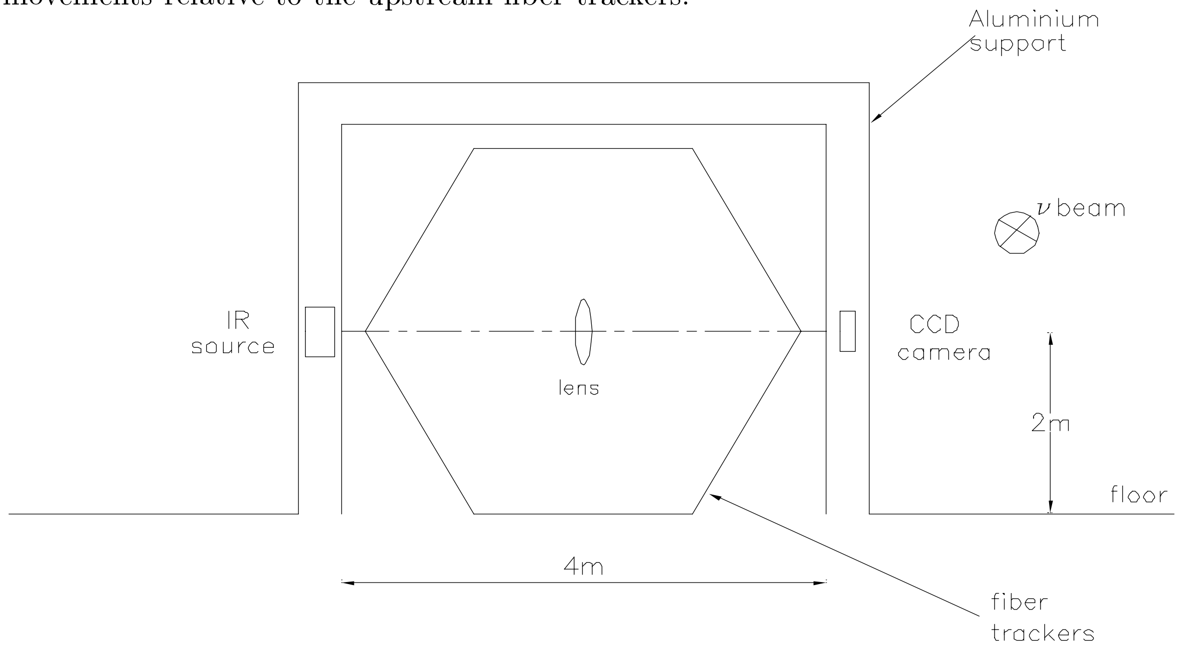

Figure 6: The RASNIK system used to monitor movements of the “DT1” fiber tracker.

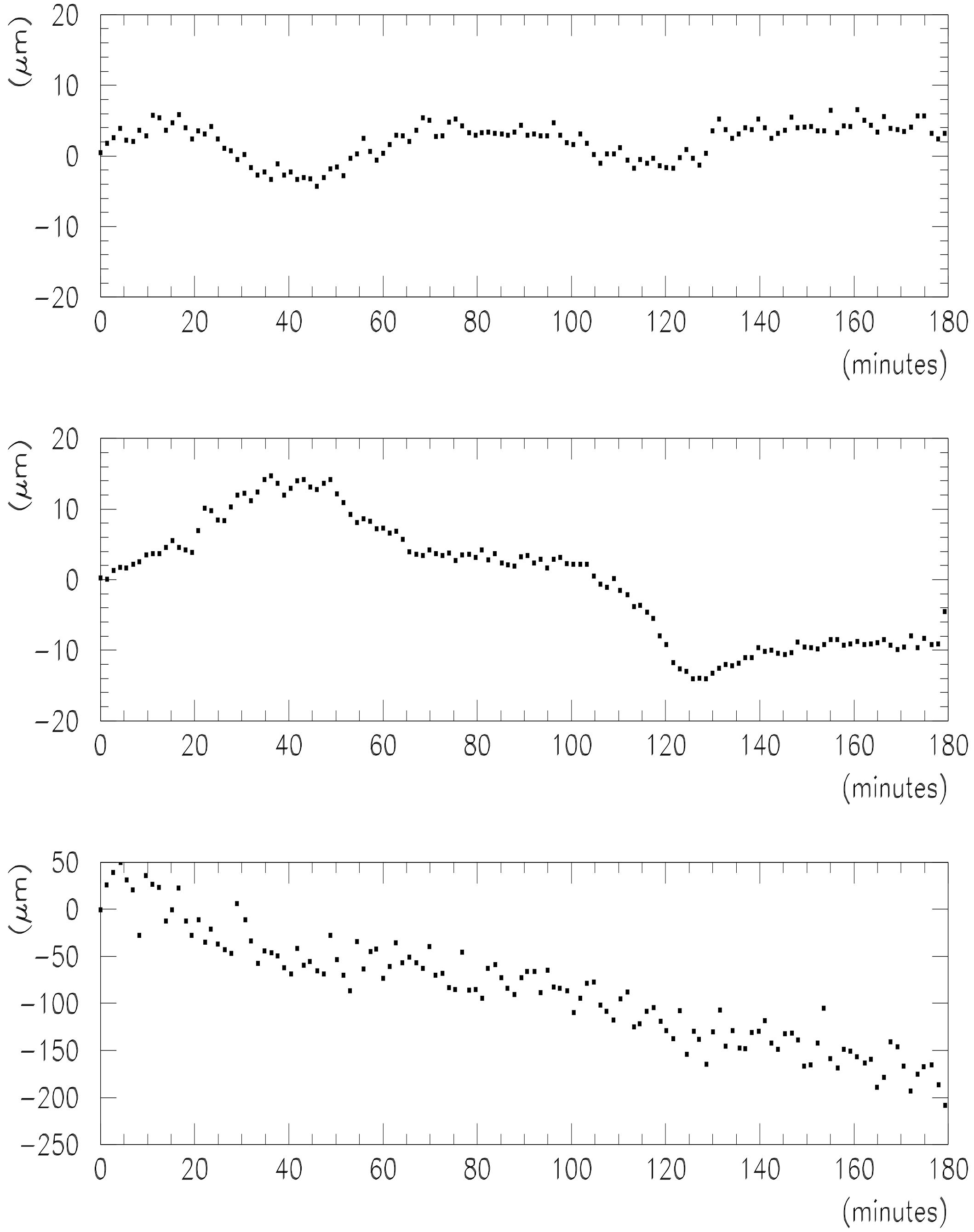

Figure 7: A three-hour record of movements along the three axes as measured by one of the three honeycomb chamber RASNIK systems. The upper two plots are for the axes perpendicular to the infrared beam. The lower plot is the measurement parallel to the beam, which is less precise.

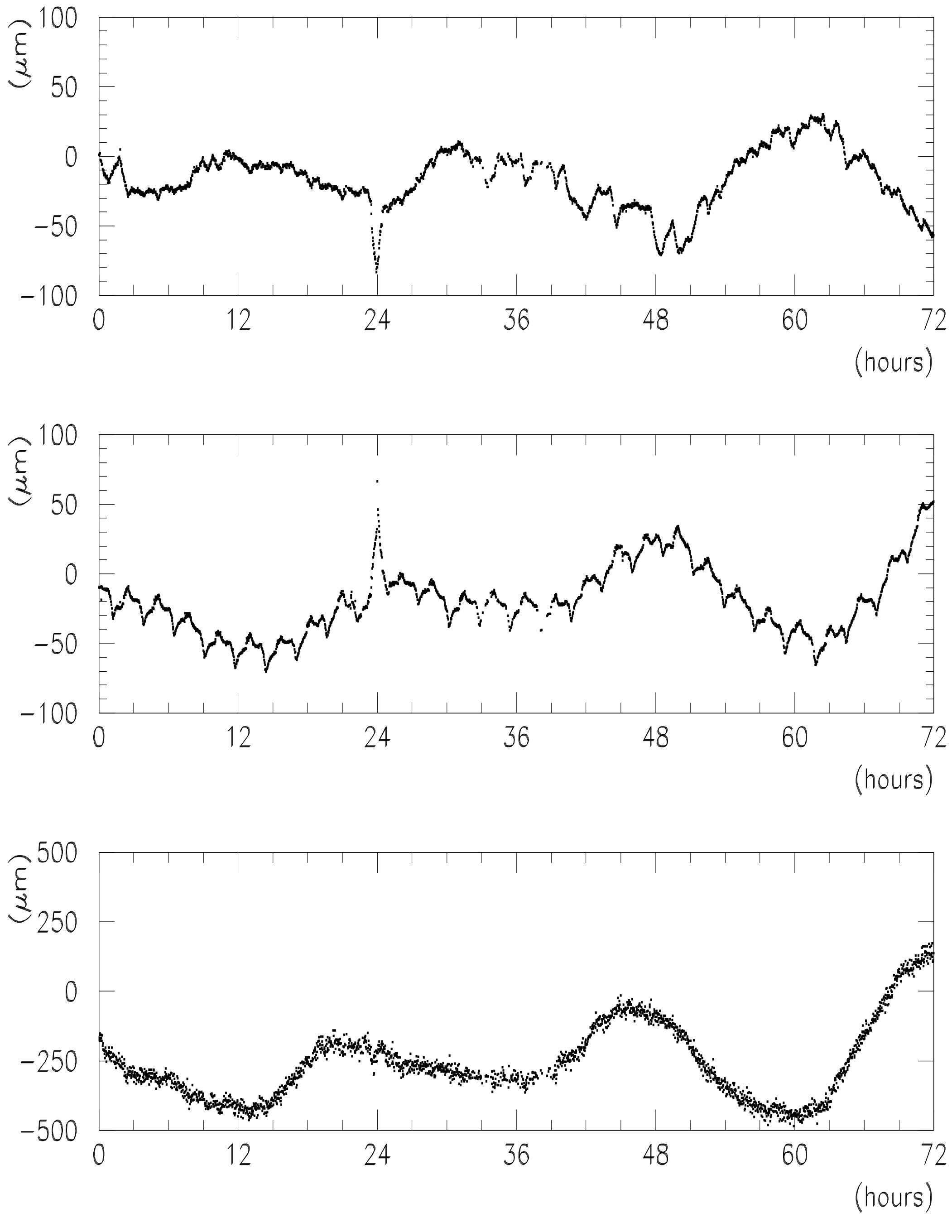

Figure 8: A three-day record of movements along the three axes as measured by one of the honeycomb chamber RASNIK systems. The upper two plots are for the axes perpendicular to the infrared beam. The lower plot is the measurement parallel to the beam, which is less precise.

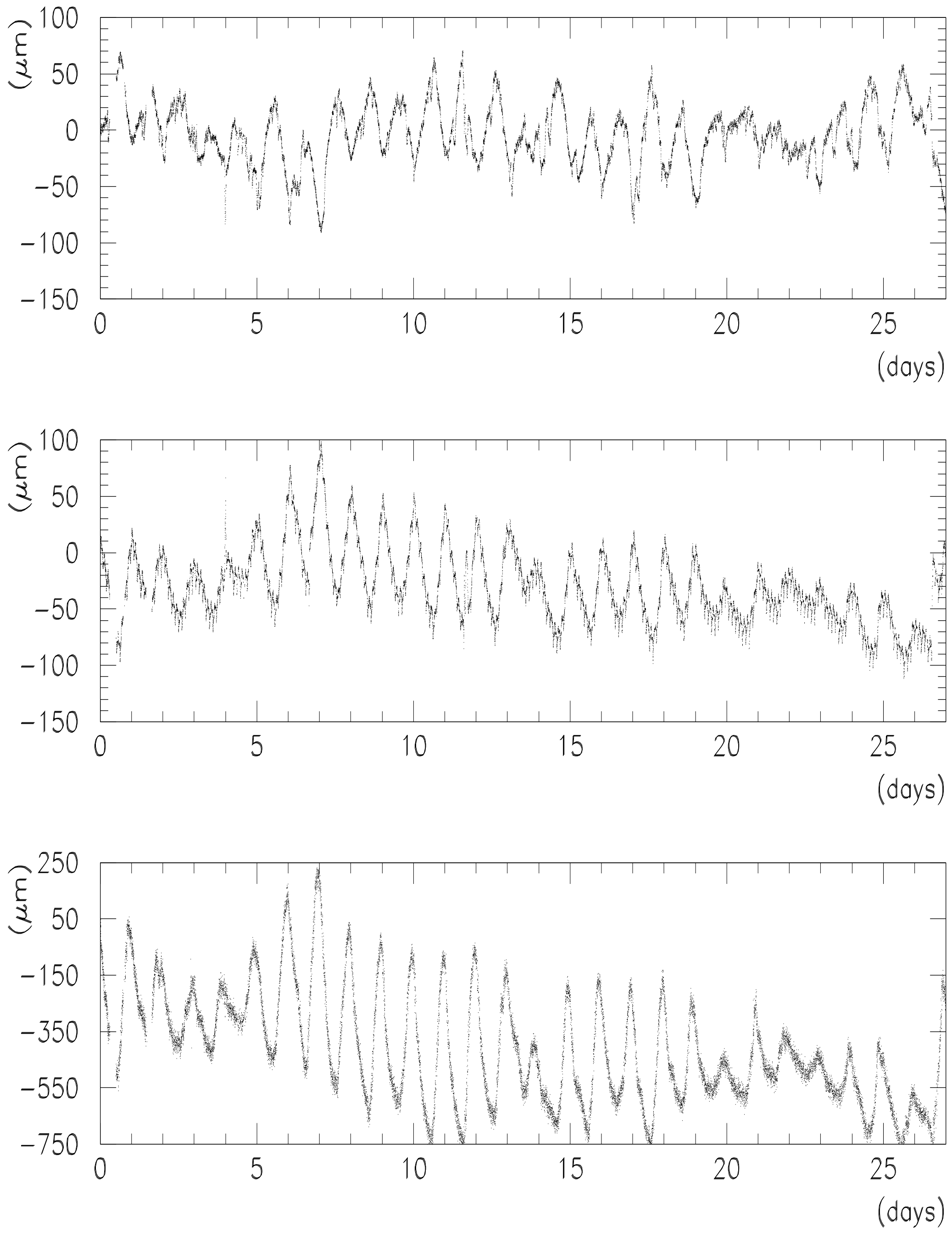

Figure 9: A one-month record of movements along the three axes as measured by one of the honeycomb chamber RASNIK systems. The upper two plots are for the axes perpendicular to the infrared beam. The lower plot is the measurement parallel to the beam, which is less precise.

of the daily temperature. The RMS deviations of the transverse movements are less than 60 μm, so no time-dependent alignment corrections to the data are necessary.

4.3 The DT1 RASNIK

A fourth RASNIK was installed on the diamond-shaped fiber tracker (DT1) used upstream of CHORUS' air-core magnet. As shown in Figure 6, the infrared beam crossed perpendicularly to the neutrino beam. The source and camera were located on the aluminum supports outside the tracker. The lens was mounted on the center of the tracker. With this orientation, the two most precisely measured axes were along the neutrino beam axis and in the vertical direction. The distance between the source and camera is 4 m. Since the IR source and CCD camera are fixed to much more solid material than the lens, the movements are likely to be of the lens; this was confirmed *in situ* with a survey while the tracker was moving. As soon as the RASNIK was turned on, one could see on a video monitor a rapid jitter (RMS$\sim 20\mu$m) in the neutrino beam direction. This vibration is due to the ventilation of the air-core magnet. In addition, a larger movement ($\sim 100\mu$m) is seen for every pulse of the air-core magnet.

The movements of DT1, especially in the neutrino beam direction, showed an additional surprising feature, as shown in Figure 10. The lens appears to move by 1 mm between two relatively stable positions in the neutrino beam direction. The corresponding transverse movements were on the order of $\sim 100\mu$m as shown in Figure 10. This effect is exactly correlated with the neutrino beam. When there is no beam, the nearby air-core magnet is not pulsed and rests at a lower temperature. This effect was not expected and it is important to be aware of it since alignment data is taken without pulsing the magnet (*i.e.,* no magnetic field), whereas beam data is taken with pulsing.

5 Conclusions

The RASNIK optical alignment system has been installed into the CHORUS experiment and works according to specifications. We observed day-night effects, cycles corresponding to the ventilation system, and other movements which were not anticipated. These data can be used to correct the alignments directly, or only as a guide to which effects need correcting. At the moment, for CHORUS, the RMS of the movements of the honeycomb chamber is smaller than the tracking resolution, so no correction needs to be applied. Similarly for the rapid jitter of DT1. The movement of DT1 correlated with the temperature change of the pulsed magnet is under study and a correction will be applied to the data.

Future RASNIK systems may be installed into CHORUS, but the possible locations are limited since a convenient line-of-sight does not always exist. The installation of RASNIK systems will work better if incorporated into the original design of an experiment.

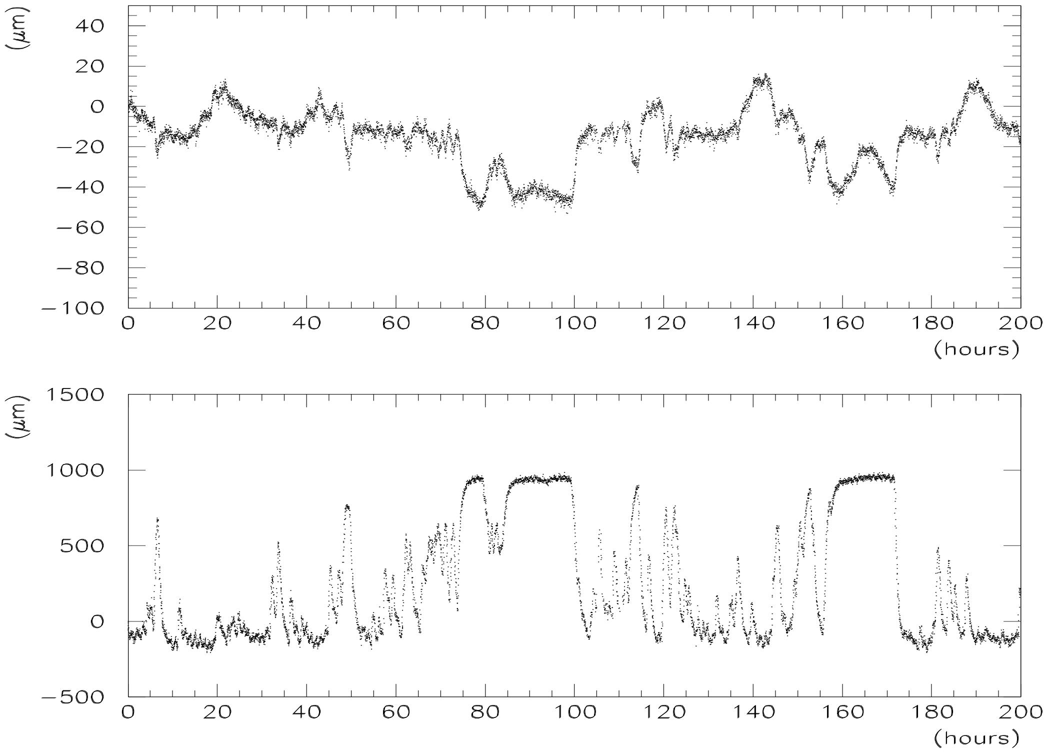

Figure 10: A 200-hour record of the RASNIK measurement of the movement of the center face of the diamond-shaped fiber tracker in one direction transverse to the neutrino beam (upper) and the direction parallel to the neutrino beam (lower). The structure is due to heating and cooling related to the datataking as described in the text.

6 Acknowledgments

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References

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[4] F. Linde and H. van der Graaf, private communication, 1996.