HARPS Secondary Guiding

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ABSTRACT

The HARPS spectrograph, after its first six years of operations has established itself as the worldwide reference for accurate Doppler measurements. The radial velocity precision of the instrument on a single measurement is estimated around 60 cm/sec.

One of the main limitations to the radial velocity precision is the variation of the injection illumination function due to tracking errors.

A light and fast guiding system has been recently developed for HARPS. In this way it is expected to increase the guiding closed loop bandwidth by a factor of 10 with respect to the standard guiding performed with the telescope.

Keywords: 3.6m Telescope, Instrument, HARPS, Guiding system

1. INTRODUCTION

HARPS spectrograph (Fig.1) is installed in the 3.6m telescope in La Silla in an especially temperature controlled environment. It is contained in a vacuum vessel to avoid spectral drift due to temperature and air pressure variations.This instrument is fed by an optical fiber that goes to a special adapter (Fig.2) placed at the Cassegrain instrument rotator-adapter flange. One of the two fibers collects the star light, while the second is used to either record simultaneously a Th-Ar reference spectrum or the background sky.

The spectrograph has a currently velocity precision of 1 m/sec in the long term that permitted to discover the majority of the “super Earth” type of extra solar planets up to date. The instrument is designed as an Echelle spectrograph fed by a pair of fibers and optimized for mechanical stability.

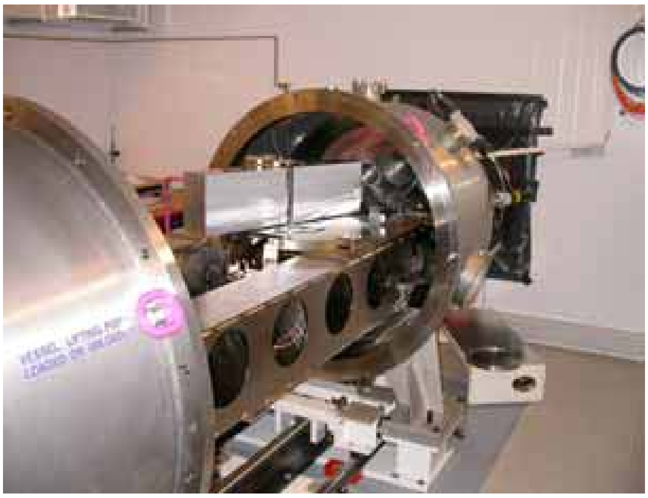

Figure 1

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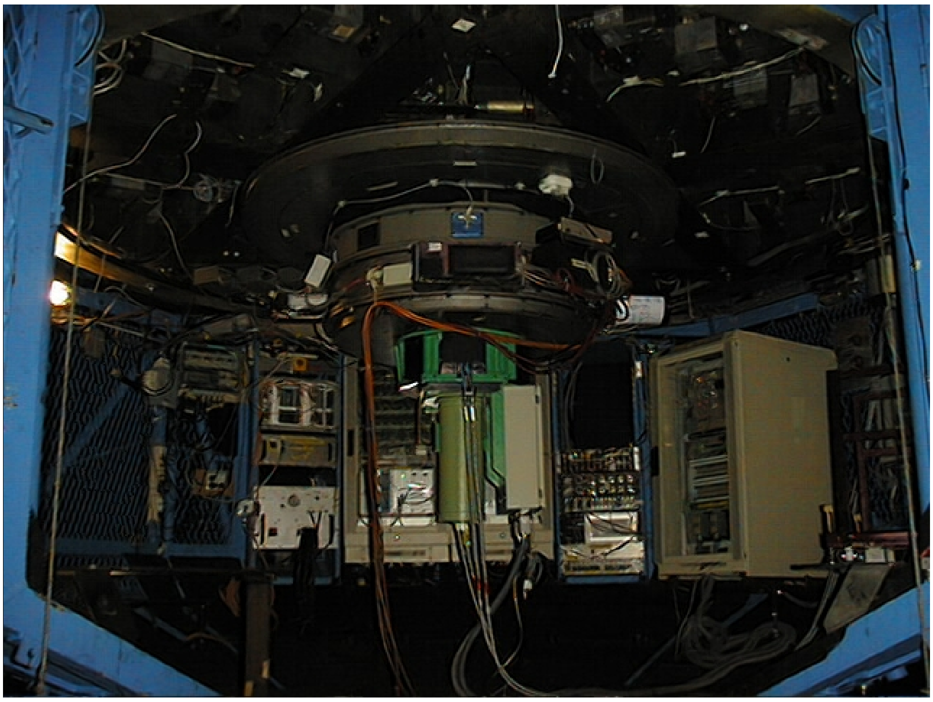


Figure 2

The HARPS adapter section with the ADC and the section of the volume used by the tip-tilt table are shown on Fig.3

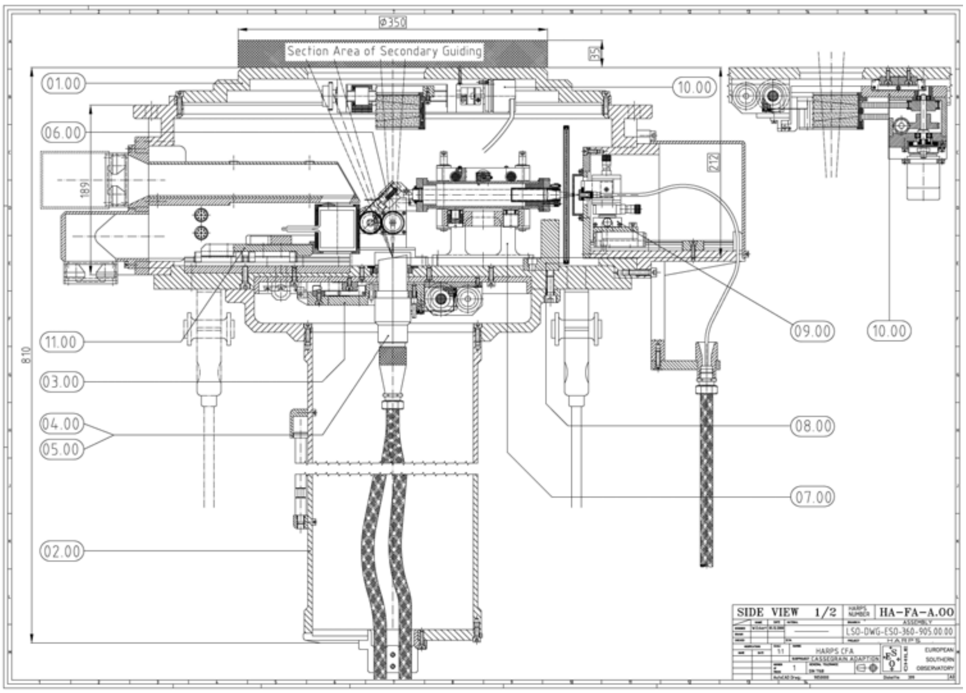


Figure 3

2. CONCEPT

The final objective of this modification to the actual instrument configuration is to reach a radial velocity accuracy of 30cm/s with HARPS, allowing the detection of Earth mass planets around M dwarf stars or 3 Earth mass planets around G dwarf stars. Moreover important experience would be gained towards the development of future radial velocity instruments requiring 10cm/s precision or better.

Due to the not perfect image scrambling, guiding and centering errors introduce RV offsets on the data. This is a general problem of precise Doppler measurements in Astronomy. The contribution to the HARPS radial velocity error budget coming from the guiding is of the order of 30cm/s. Therefore a more accurate guiding system, possibly to be used in conjunction with an image scrambler, has to be devised when aiming at RV precision of the order of 10cm/s. The aim is to achieve a better guiding, with an effect lower than 10cm/s on the final RV measurement, which equals to requiring a centering accuracy, at the end of the integration, better than 0".01, or 10marcsec on HARPS.

The guiding system has to be accurate and fast. The speed of the system should be confronted to the exposure time on the science object, to the stability of the telescope tracking on the short and long time scale, and to the relaxation time of the component to be moved to keep the star centered in the fiber. In the case of HARPS at the 3.6m, guiding corrections are sent directly to the telescope, which has a relaxation time of approximately 2sec. A guiding correction should be sent well before the accumulated tracking error becomes noticeable to the spectrograph, and it is desirable to have several corrections within the science exposure, to average out guiding errors. Moreover tracking errors on the short time scale, generated by mechanical problems such as hard points, friction, sudden movements under gravity, should be addressed by the guiding system.

3. OPTO-MECHANICAL DESIGN

Two alternatives were discussed during the mechanical design phase: to move the entire fiber to produce the desire effect of centering the light in the fiber center or to refract the light to the center of the fiber by means of a glass. The last one comprises the possibility to use the ADC as a tilting glass or another refracting glass.

The movement of the fiber and fiber head to obtain the best centering of the light in the fiber had advantages and disadvantages. One of the clearest advantages was not loosing efficiency by adding new optics in front of the actual configuration. This concept has a risk and it was related to the strength of the fiber-fiber head construction under fast and continuous movements of the assembly and the mass necessary to move at frequencies up to 10Hz.

The idea of the tip-tilt method to correct for displacements of the guide star's image is to use a glass to refract the light going to the fiber head. This can be located on top of the HCFA and operates in closed loop using the 3.6m slit viewer CCD to locate the guide star image or to use the ADC as a refracting glass.

A change to the tilt angle of the glass would move the image of the guide star into a different location on the focal plane, where the fiber head is placed. The amount of displacement on the focal plane would be defined by the thickness of the glass, its refraction index and its tilt angle. The tip tilt device is actuated by voice coils or piezos. On the other hand to refract the light by means of a glass in front of the fiber has the clear advantage of not risking the fiber-fiber head configuration, being a sensible and fragile system.

Both alternatives were amply discussed and the decision was in favor of the tip-tilt table where the refracting glass is placed. The advantage of this solution is also seen as a less invasive solution to the existing configuration leaving the existing fiber-fiber head as built.

A second iteration regarding the type of tilting and where to apply it was analyzed in the engineering study made by Tomelleri s.r.l., Verona, Italy. In this study three alternatives were considered and are summarized in the following table 1:

	Tip-Tilt Table	**Gimbal Mount**	**ADC Tip Tilt**
Tip-tilt accuracy	Very accurate	Accurate	Very accurate
Pivot point stability	It is very accurate and furthermore it can be adjusted at any time	It is very difficult to reach accuracy and stability better than 5 microns	It is not accurate as required but it can be adjusted at any time
Dynamic accuracy	Very high	Very high	Low
Power consumption	Low	Low	High
Sensitivity of performances from machining	Low	High	Low
Maintainability	High	High	Low
Performance verification	Easy	Easy	Possible only on site or with dummy

From this study it was concluded that a refracting glass installed in a tip-tilt table on top of the ADC supporting flange was the best solution to apply and less invasive to the actual configuration existing in the HARPS adapter.

3.1 Mechanical Requirements

The characteristics and requirements that the tip-tilt table design has to fulfill are described in table 2:

Description	**Characteristic**	**Design requirements**
Tip-tilt	Range	• +/- 7.5 mrad (+/- 0.43 deg)
Load to carry in all positions, when using a refracting glass	Weight to carry	• 500 grms
Available space above ADC supporting flange	Space	• Ø350mm, h=35mm (limit free height=45mm)
Working limits	Absolute accuracy Frequency Repeatability	• 1 mrad (100 microns over 100 mm) • 10 Hz • 0.1 mrad (10 microns over 100 mm)

	Resolution	• 0.01 mrad (1 micron over 100 mm)
Environmental conditions	Operation Temperature Humidity	• -10°C to 30°C • Up to 90%
Control and interface	Controlled via RS232 interface	
Operating conditions		• The unit will operate attached to a telescope and its orientation with respect to the vertical will continuously change. The normal to the plane defined by the tip-tilt axis is vertical when the telescope is at Zenith. The maximum deviation from the vertical will be 70 degrees.
Pivoting point	X-Y position Z position X, Y, Z position stability	• To coincide with the center of guiding within 2% of its diameter: ~ 3 microns • Not critical but should be between the entrance and exit surface of the glass • To be stable in its lifetime within 1 micron
Heat dissipation by unit		• Temperature of unit to be =< 3°C

The table movement is done by means of three linear voice coil actuators controlled by an amplifier included in the controller GALIL - YPE DMC-4030(-16BIT)-C012-I100-D3040-SR90 and sending the information via a RS232 protocol to the telescope control system.

The resolution of the translation of the voice coils is 0.1 micron, while the maximum admitted amplitude of the input is from – 9000 up to 9000 that correspond to a displacement from – 900 micron up to 900 micron on each transducer.

The pivot point is in the centre of the triangle, the tip axis is orthogonal to the x axis and the tilt axis is aligned with the x axis oriented from the centre toward the actuator 1.

The position of the table is controlled by means of three LVDTs with an error due to linearity of less than =/- 0.75 microns. With a peak stroke equal to 10 mrad the required stroke is the full available stroke of the LVDT equal to 2 mm, for which the accuracy is +/- 1 micron

3.2 Operational Conditions

The tip-tilt system (Figs.4, 5) will be exposed to the external environment of La Silla (~2400m a.s.l.). The average pressure at the site is of 773 mBar with average temperature around 11°C. The tip-tilt glass, its coating and glue, will have to keep their optical characteristics when the environment parameters are in the specified ranges described in the requirements table 2.

The tip-tilt glass will be moved with a frequency of up to 10Hz, and amplitude of up to 7.5mrad in both the tip and the tilt axis. The entire guiding system will be attached to the telescope, and the gravity vector will vary during operations. At Zenith the gravity vector is perpendicular to the flat faces of the tip-tilt glass. Operation is expected to occur with inclination of up to 70 degrees from Zenith. However, for maintenance procedures, the telescope might be inclined by 90 degrees (with no operation of the tip-tilt table).

3.3 Tip-tilt Optical System

The tip tilt glass is a cylinder with diameter of 70mm (±0.1mm) and height of 32mm (±0.2mm). In order to keep chromatic and spherical aberrations to a minimum the glass to be used for tip tilt is actually a combination of LLF1 and PSK3 glasses cemented together, and the interface between the two glasses is a portion of a spherical surface. The thickness of each glass is of 16mm (±0.1mm). The curvature radius is of 1300mm (± 20mm): the LLF1 glass is convex, while the PSK3 glass is concave at the interface. The two glasses are cemented across the curved surface, and the external surfaces of the doublet are flat. The parallelism of the two external flat surfaces must be within 3mrad, or 0.2mm over 70mm.

Other characteristics are the spectral range of interest to be from 380nm to 690nm. The efficiency of the system must be > 95% at any wavelength in the spectral range. The external surfaces of the tip-tilt optical system must be anti-reflection coated. The reflection of each surface must be <1% within the spectral range and the wave front quality at 633nm must be better than $\lambda/4$ peak to valley over the whole surface.

Figure 4

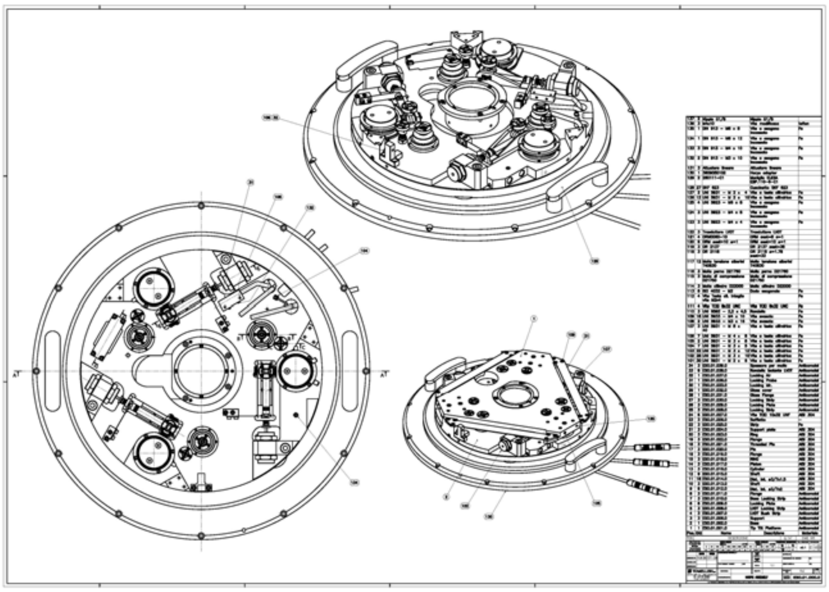


Figure 5

4. HARPS TIP-TILT TABLE SYSTEM ARCHITECTURE

The HARPS tip/tilt table guiding system is based on the interaction between three main subsystems of the telescope:

- Main tracking axes control system (Alpha and Delta movements)
- HARPS tip/tilt table control system
- Guide and Acquisition System

4.1 Main telescope tracking

Currently the guiding at the 3.6m telescope with HARPS is performed by sending the corrections directly to the telescope with frequencies in the range 0.2Hz – 0.05Hz, depending on the brightness of the target. On a first order approximation, a de-centering of the fiber is directly proportional to the error on the radial velocity (RV) determination. One of the main sources of RV uncertainty is due to the guiding errors. It is therefore imperative to reduce the guiding errors when trying to improve the RV performance of the instrument.

4.2 HARPS tip/tilt table control system

The HARPS tip/tilt table subsystem accepts corrections at high frequency, which are calculate using the following relations:
i.e., the movement of the image in the guide camera obeys the relations:

X1 = X01 - 0.5*K*(1-atip)*sin(delta)+(sqrt(3)/2)*K*(1+atilt)*sin(alpha)
X2 = X02 - 0.5*K*(1-atip)*sin(delta)-(sqrt(3)/2)*K*(1-atilt)*sin(alpha)
X3 = X03 + K*(1+atip)*sin(delta).

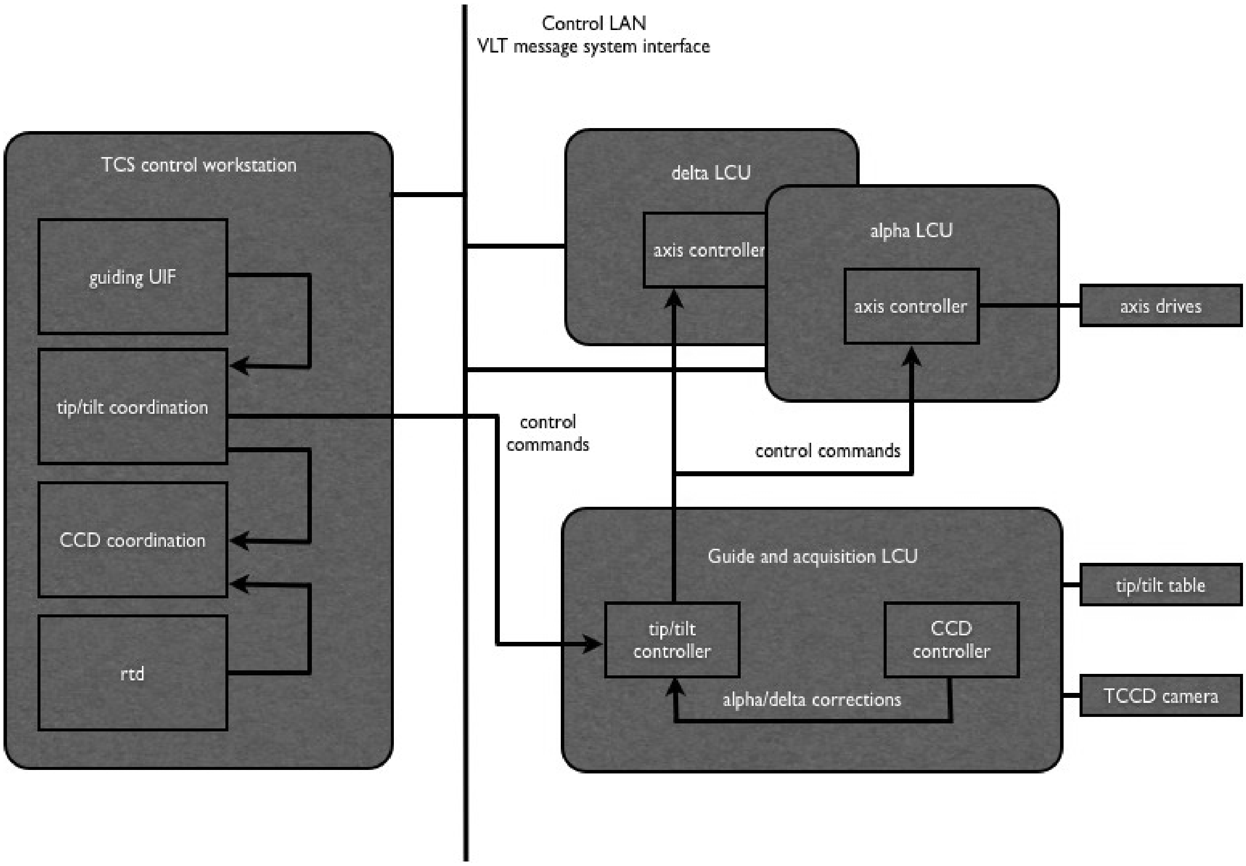
Where X1, X2 and X3 are offsets to the actuators.

K is a constant depending on the glass thickness, on the conversion factor between microns and number of counts of the digital to analog converter and on the plate scale of the telescope. It is possible to verify that the value of this constant is consistent with its "theoretical" value of 37250 if the corrections alpha and delta are expressed in arcsec.
The values X01, X02, X03 correspond to the mid-position of the table that should be around 32000 digital counts.
From the control software point of view, the alpha and delta values correspond to corrections sent by CCD image camera to the alpha and delta telescope axis.
If the image is out of range or the image is not between the actuators movement limits, a telescope offset is triggered by tip tilt control software, directly to the telescope axis, and the tip tilt table is set on a mid-position, this, in order to keep the image centered on the refraction glass.

4.3 Guide and Acquisition System

The HARPS tip/tilt table software architecture like most VLT subsystem, is split into two components:

- A coordination part running on the TCS workstation takes care of all configuration and administration.
- A control part running on a dedicated Local Control Unit (LCU) takes care of all real-time control and of interfacing with the hardware. LCUs are VME based systems running the VxWorks real-time operating system.



Both tip/tilt and guide/acquisition control software, running on the guide and acquisition LCU, are allowed to send directly Auto Guiding corrections to the tracking software running on the main axes LCUs.
The Guide and Acquisition LCU, is responsible for the control of the Technical CCD hardware and tip/tilt table

hardware. All image-processing functions as well as the actual tip/tilt control loop and it is serial communication software are deployed on this LCU.

From the operational point of view, the HARPS tip/tilt software has been designed for easy operation. There is a possibility to switch from the TCS auto guider operation panel between normal auto guider software or use the tip/tilt software.
When tip/tilt software is disabled, the tip/tilt table is in park or rest position, allowing the normal operation of the auto guider.

5. FIRST RESULTS

The first tests were done at Tomelleri headquarters in Verona, Italy and the results were exceeding the requirements. These tests comprise the dimensioning comply and the respond to commands send via the GALIL controller to the table.

During the technical commissioning basic functionality tests were performed on the assembled unit. However, more complex tests, or actual guiding could not be performed, as the high level guiding software was not yet functioning.

5.1 Table Movements

The tip tilt table was moved remotely from the control room by issuing commands from the telescope's TCS workstation. These commands went through the VLT software, proving that the unit could be controlled from within the VLT framework.

The commands to move the tip-tilt table are sent directly to the controller via commands from the TCS X terminal that sends to a process running on a LCU, which then relayed the command to the serial port connected to the GALIL controller.

Guiding "by hand" was possible just sending from the command line the desired offset in digital converter units after conversion from arcsec unit by an automated script.

5.2 Stability of the Tip-Tilt Table

Possible movements of the table left activated but in the middle position were not noticed and are at most comparable with the natural movements of the image of the fiber.

System operation with the table activated and set to the mid-position (32000) did not differ from normal.

6. CONCLUSIONS

The tip-tilt table tests in Tomelleri, Verona, Italy place where the unit was designed and fabricated, fulfilled all agreed requirements and in some of these tests the results were better than expected.

Once installed in La Silla 3.6m telescope, the table fit in the limited space and there was no mechanical interference between table and telescope adapter-rotator.

The first movements were accomplished resulting in positioning according to commands sent by the telescope's control system. The guiding has been tested so far only in simulation mode and it is planned to have this controlled in August during a technical time. However, simulation has shown that the system can guide according to the needs for this secondary guiding unit.

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