MRO Delay Line

Trolley Concept Description

The Cambridge Delay Line Team

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Objective

To provide an annotated diagram that describes the conceptual design of the prototype MROI delay line trolley. This description is intended to clarify the locations and space envelope of the active components on the trolley, and indicate how they are controlled.

Scope

This document forms part 2 of the Cambridge delay line team's answers to MRO's questions arising from the results of the Risk Reduction Experiments, and is the answer to "Can the internal team get some better insight of the active elements on the cart".

We feel that the best insight would be given by a holistic view of the trolley together with the external sensors and control system used to close servo loops. We provide such a description here.

This description is of our current idea of the prototype system, which is not expected to change at the level of detail provided until after initial tests of the prototype are complete. The production trolley may differ from the description here, but we expect that all proposed changes will be discussed with NMT at future design reviews.

The top-level (functional) requirements for the delay line were listed in Section 3 of INT-406-VEN-0000, "Risk Reduction Experiments Review". To keep this document brief, we do not describe the flow-down to implementation requirements or justify our design choices here.

1 Introduction

In our concept, continuously variable path compensation is achieved by bouncing the starlight off a moving retroreflector (Cat's-eye) inside a vacuum pipe. The vacuum ($\sim$1 mbar) is necessary to avoid atmospheric dispersion restricting the observing bandwidth.

The vacuum containment pipe both supports and guides the Cat's-eye via an intermediate carriage (the combination is referred to henceforth as the trolley). There are no precision rails to align, and the size of the pipe is minimised.

Two innovations make this possible. Firstly the Cat's-eye has a tiltable secondary mirror which maintains the return light beam position (shear) in spite of small errors in pipe straightness, and secondly the separate carriage with resilient wheels allows smooth motion in spite of roughness or unevenness of the pipe surface.

This document describes the two main physical parts of the moving trolley: the Cat's-eye retroreflector, and the carriage. The description should be examined in conjunction with Figure 1, which is a diagram of the trolley concept. We also outline certain aspects of the prototype control system, in order to explain the origin of the signals used to control the active components on the trolley.

This description of the trolley concept will necessarily refer to other parts of the delay line system. The components of the complete path compensation system (for one telescope unless stated) are as follows:

- A trolley consisting of a carriage (Sec. 3) supporting the Cat's-eye (Sec. 2).
- 200 m of vacuum pipe to support and guide the trolley, supported on flexure legs to accomodate thermal expansion.
- A laser metrology system to measure the position of the Cat's-eye by bouncing a laser beam off it. The laser is fed into and out of the "near" end of the vacuum pipe, in the Beam Combining Area (BCA). Each laser head is used for up to six trolleys.
- A shear sensor in the BCA, which uses a small fraction of the metrology light to sense the position of the metrology beam and hence the shear of the science beam.
- An inductive power supply to deliver electrical power to the trolley, via a wire lying in the bottom of the vacuum pipe.
- A distributed control system (Sec. 4) involving the following computers:
    - A "workstation" PC (shared between all trolleys) to act as a supervisor, and provide a user interface for testing the delay line and interrogating

  delay line telemetry. The workstation is a natural place to add an interface to the Interferometer Control System (ICS) if the control system architecture described here is used for MROI operations.
  - A VME-bus CPU (shared between all trolleys) to read the metrology signal and hence control the Cat's-eye.
  - A low-power PC104 single-board micro on each trolley, to control onboard functions with undemanding timing requirements, and to send telemetry to the workstation.

- Two separate radio-frequency (RF) links between the trolley and the external control system:
  - A low-latency 900 MHz link used to close the Optical Path Delay (OPD) loop (Sec. 4.3) in "Tracking" mode.
  - A standard 2.4 GHz wireless ethernet link used for communication between the onboard micro and external control computers.

- A "datum" switch, to act as a fixed fiducial point on the pipe from which to reference the laser metrology measurement.

- Speed limit switches, to force the trolley to slow down when it approaches either end of the pipe.

The inductive power supply and RF transmitter/receiver electronics and aerials are located at the "far" end of the delay line, away from the Beam Combining Area.

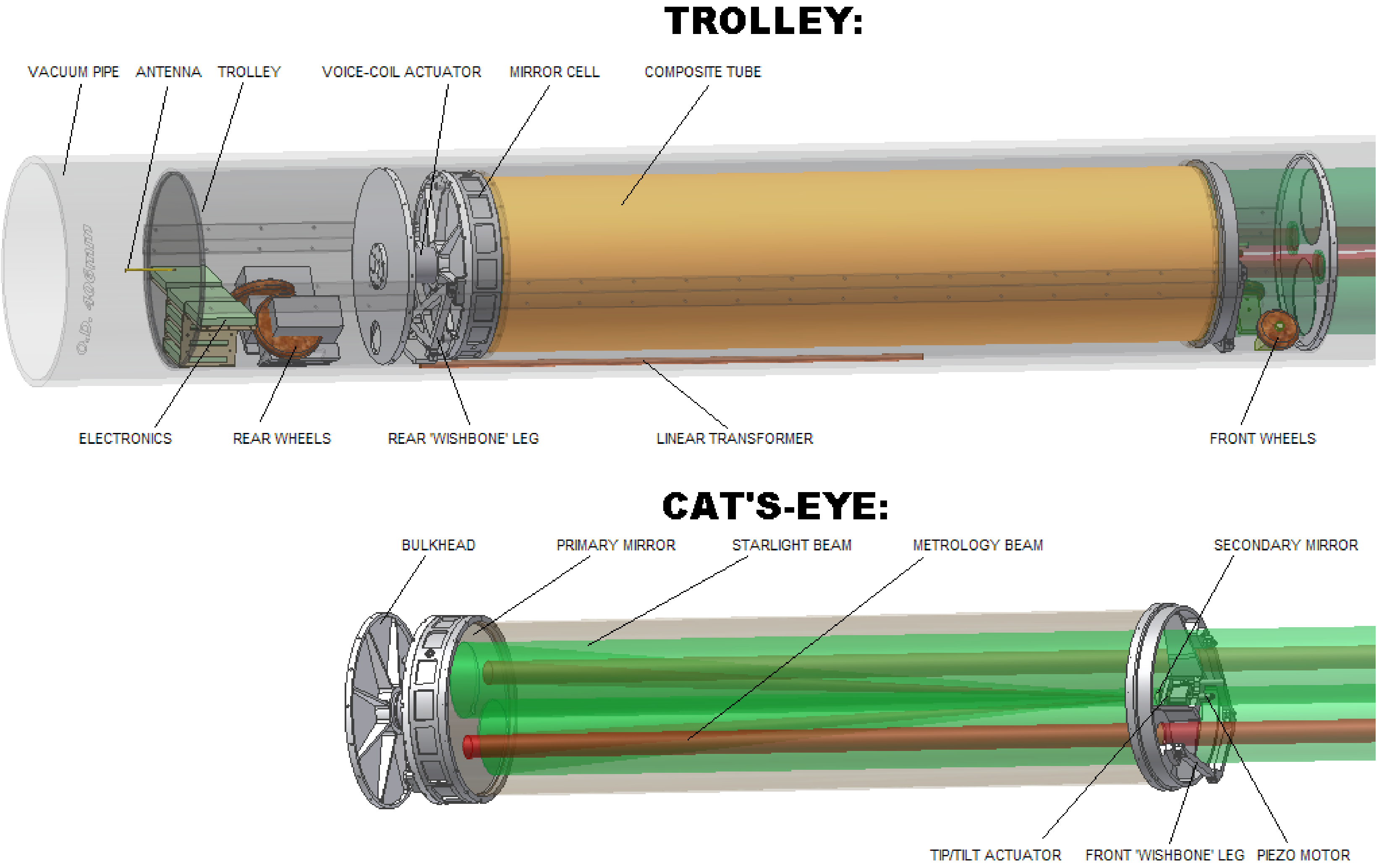

Figure 1: Concept diagram for the prototype delay line trolley, showing the physical locations and space envelope of the active elements. Components referred to in the text are labelled. The top part of the diagram shows the complete trolley (comprising the Cat's-eye and carriage) inside the vacuum pipe, and the lower part is an expanded view of the Cat's eye. The diameter of the carriage tube is approximately 14 inches, and the approximate wheelbase of the carriage is 1.8 m.

2 The Cat's-eye

The Cat's-eye has two major components, a large parabolic primary mirror, and a small flat secondary mirror at its focus. A parallel beam of light striking the primary mirror is brought to a focus on the secondary mirror, reflected back to the primary mirror, and returned parallel to its original direction. The relative positions (i.e. shear) of the two beams can be altered by tilting the secondary.

The physical realisation consists of a substantial aluminium alloy mirror cell to contain and locate the primary mirror, a rigid but light carbon fibre composite tube with bonded aluminium end rings, and a stiff aluminium front plate to support the secondary and its actuators.

The secondary mirror is directly attached to a piezo tip/tilt actuator, and this is built into a linear roller slide driven by a piezo motor for occasional focussing (based on measured temperature changes).

Also on the front plate are two shallow angle optical wedges to deflect the metrology laser beam so that its light does not come to a focus on the secondary at exactly the same place as the science beam and so risk being scattered into it.

The complete Cat's-eye assembly just described is mounted in the carriage on two "wishbone" legs so it is free to move axially. The legs have flexure pivots to avoid friction and stiction, and a voice-coil actuator and a position sensor are mounted between the back of the mirror cell and a bulkhead in the carriage.

3 The Carriage

The carriage is a cylinder which concentrically encloses the Cat's-eye, and is split longitudinally to simplify assembly and maintenance.

The carriage is supported and guided in the pipe by four wheels with polyurethane tyres. This four point contact keeps the carriage and consequently the Cat's-eye axially aligned with the pipe. The wheels are set at 45° to the vertical for equal constraint in the horizontal and vertical directions. The front wheels are limited in size by the need for clear apertures for the light beams, but the rear wheels are larger as more of the carriage and Cat's-eye mass is at the rear.

One rear wheel is driven by a brushless DC servo motor while the other one is actively steered by small angles to correct any rotation of the trolley in the pipe (see Sec. 4.1).

The linear transformer of the inductive power supply system is mounted under the carriage, and the antennae for the two RF data links on the back plate. The onboard control micro, drive and steering motor controllers, controllers for the Cat's-eye actuators, and power supply electronics are mounted in the space between the bulkhead and the back plate of the carriage, where waste heat can easily be transferred by conduction to the carriage shell and so dissipated to the surrounding pipe.

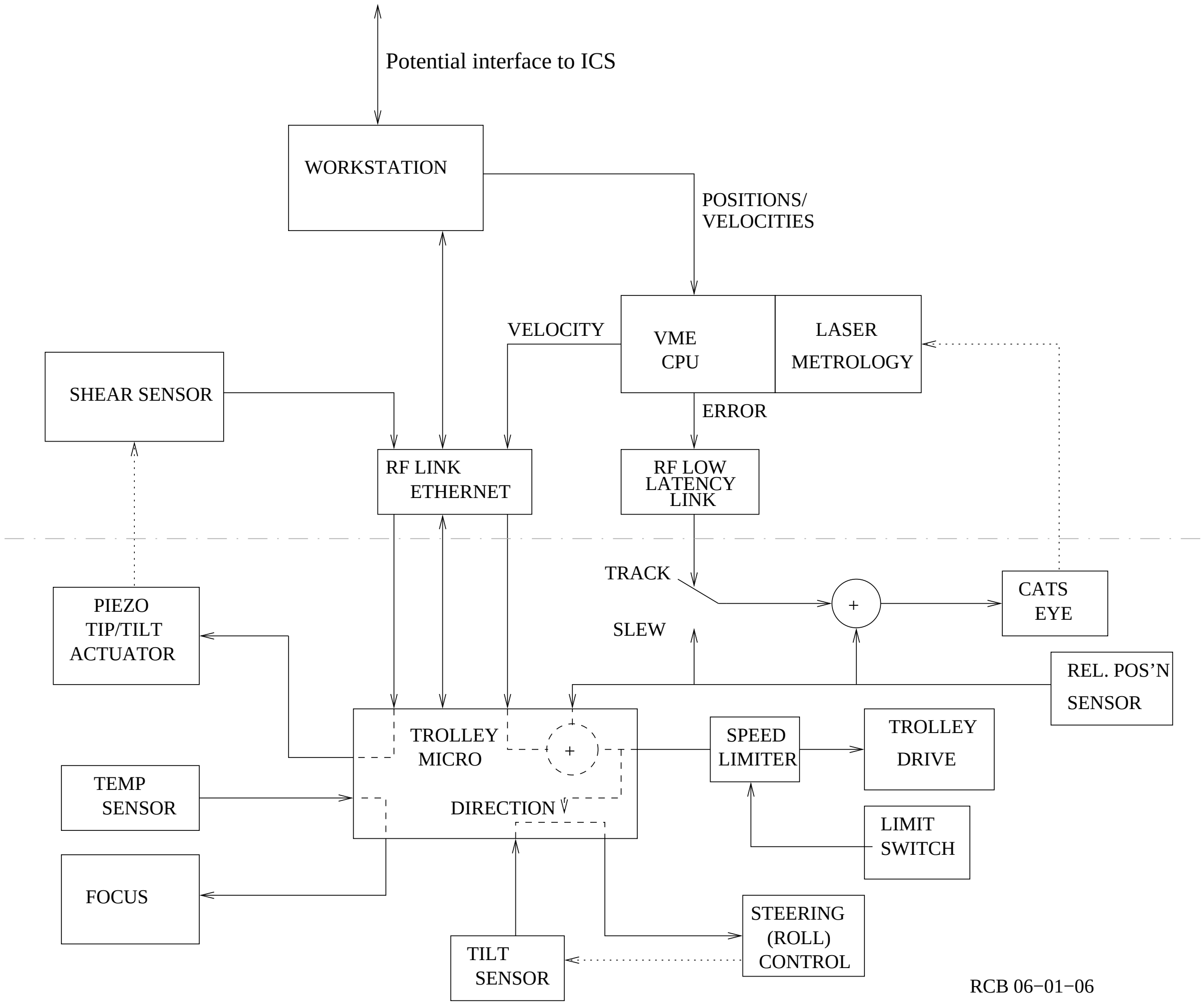

Figure 2: Overview of the control system for the prototype trolley, showing the origin of the signals used to control the active elements on the trolley. Components in the lower half of the diagram (except part of the speed limit switch) are physically located on the trolley. Each dotted line is drawn between an active element and a sensor whose output is *indirectly* affected by actuating the element. Dashed lines indicate connections made in software running on the onboard trolley micro. The "rel. pos'n sensor" (described in Sec. 2) measures the relative position of the Cat's-eye with respect to the carriage.

4 The Control System

There are several servo loops involved in the operation of the trolley. These are shown conceptually in Figure 2, which includes both the loops entirely contained on the trolley and those relying on signals from external components, transmitted to the trolley via the RF data links.

The servo loops may be re-configured for different modes of operation, and in general this is done by the onboard micro in response to commands via the ethernet link. The micro is also used as a real time processor by some of the onboard loops.

A more detailed overview of the control system was given in the slides presented at MRO by JSY in October 2005 (INT-406-VEN-0006). In particular this provided more information on the off-trolley control system components. A number of questions raised as a result of this presentation were answered in a subsequent pair of memos. The second of these memos, "Timing Requirements for Control Loops" (a.k.a. the 'timing memo'), lists the sampling and correction rates for each the servo loops described in the sub-sections below.

4.1 Steering

This is really a misnomer. The trolley is not being steered as it can only move axially along the pipe, so this is really roll control.

Mostly this is achieved by having the trolley centre of gravity below the centre line. This is a robust control – it is then almost impossible to capsize a trolley – but it is not very accurate, and accuracy is needed for two reasons. Firstly the axes of the secondary tip/tilt stage have to be kept matched to the beam shear sensor, and secondly the trolley wheels have to follow relatively narrow tracks to cross the pipe joints where the surfaces are aligned.

For accurate roll control an active trim system is included on the trolley. An electronic tilt sensor measures the roll angle of the trolley. This is digitised and read by the onboard micro, which controls a servo motor to adjust the tracking of the unpowered rear wheel to correct any error. This loop also needs an input from the drive motor controller as the sense of the correction required depends on the direction of travel, and its frequency response may also be altered depending on the speed of travel. This low frequency loop is entirely contained on the trolley.

4.2 Shear Control (Secondary Tip/tilt)

This is an "always-on" low frequency loop closed via the Ethenet RF link and onboard micro. The shear sensor in the BCA uses a small fraction of the metrology laser light to measure any shear, and sends correction signals to the tip/tilt stage in the secondary mount on the Cat's-eye. Only a low bandwidth is required, but this may be altered depending on the speed of travel.

4.3 Optical Path Delay (Cat's-eye and Carriage Control)

There are two main modes of operation for these loops. In either case the position of the Cat's-eye is measured by the laser metrology system, and the relative position of the Cat's-eye and the carriage is measured by an onboard sensor. However, the measurements are used in somewhat different ways in the two modes.

4.3.1 Tracking

This is the most critical mode, used when recording science data, and involves two stages to the servo loop:-

Cat's-eye The Cat's-eye position is measured by the laser metrology system and compared (by the VME CPU) with the current demanded position (interpolated from positions sent slightly in advance from the workstation). The resulting error signal is sent via the dedicated low latency RF link to the trolley (bypassing the onboard micro), where it is amplified and used directly to drive the Cat's-eye voice coil actuator.

Two small additional signals derived from the Cat's-eye/carriage relative position sensor are also applied (this is called "trolley management" in the timing memo). The first one is a proportional term used to reduce the effective stiffness of the "wishbone" leg flexure pivots. The second is a velocity term to offset dynamic drag caused by the voice coil. In addition electronic travel limits for the Cat's-eye are set by this sensor which clamp the voice coil drive signal if the limits are exceeded.

Carriage The carriage drive motor is directly controlled by the relative position sensor to keep the carriage centred under the Cat's-eye so the "wishbone" legs are upright. This is important for best noise rejection. A demanded velocity term sent via the ethernet RF link is added to reduce tracking error.

4.3.2 Slewing

This mode is used for rapid re-positioning of the trolley. The Cat's-eye voice coil is driven directly by the relative position sensor to hold it fixed relative to the carriage. The drive motor can then be ramped up to full speed until the desired position (monitored by the VME CPU reading the laser metrology) is approached and then slowed before reverting to tracking mode.

The carriage hardware will be designed such that it will be impossible to exceed the maximum desired slewing speed of 1 m/s.

4.3.3 Initialising/Emergency/Stop/Etc.

Various other modes of operation may be included if necessary, probably as low speed variations of slewing mode.