Cryogenic mechatronic design of the HIFI Focal Plane Chopper

R. Huisman a,b,⇑, J.W.G. Aalders a, M.J. Eggens a, J. Evers a, H.M. Jacobs a, B.J. van Leeuwen a, A.C.T. Nieuwenhuizen a, G.R. Ploeger a, K.J. Wildeman a, B. Jayawardhana b, J.M.A. Scherpen a

a SRON Netherlands Institute for Space Research, Postbus 800, 9700 AV Groningen, The Netherlands
b Faculty of Mathematics and Natural Sciences, Institute for Technology, Engineering & Management, Department Discrete Technology and Production Automation, Nijenborgh 4, 9747 AG Groningen, The Netherlands

Article info
Article history:
Received 1 March 2010
Accepted 20 March 2011
Available online 20 April 2011

Keywords:
Cryogenic
Chopper
Steering mirror
Space mechanism
Herschel-HIFI

ABSTRACT
This paper discusses the cryogenic mechatronic development of the Focal Plane Chopper (FPC) mechanism in the Heterodyne Instrument for the Far Infrared (HIFI) which is one of the science instruments on board the Herschel space telescope. The extreme cryogenic environment, in which the mechanism has to operate, places a number of constraints on the mechatronic design of the instrument. The paper gives an overview of cryogenic design issues applicable to the development of the FPC and provides solutions to the problems encountered.

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1. Introduction

The Herschel Space Observatory was launched in 2009 on the 14th of May from the European Space Agency (ESA) launch platform in Kourou – French Guiana. It will study the universe during a planned mission of three and a half years [1]. The Heterodyne Instrument for the Far Infrared (HIFI) is one of three astronomical instruments on board the Herschel Space Observatory. The HIFI instrument is developed by an international consortium led by the SRON Netherlands Institute for Space Research. It performs astronomical observations in seven frequency bands covering the range from 480 to 1250 GHz and from 1410 to 1910 GHz. For a complete description of the instrument and the scientific objectives of the mission, the reader is referred to [2].

The astronomical signal, collected by the main dish of the Herschel telescope, is reflected to the secondary mirror and picked up by the first mirror of the HIFI Focal Plane Unit (FPU). The FPU is situated inside the cryostat chamber of the telescope. Figs. 1a and 1b show respectively a photograph and a schematic drawing of the HIFI FPU. The schematic drawing reveals the interior of the FPU. The optics of the instrument are kept at a constant temperature of 15 K while the scientific detectors in the FPU, are cooled to temperatures of 2 K. These low temperatures are required for the operation of the detectors and to avoid degradation of the astronomical signal by thermal radiation from the internal optics of the instrument. The fourth element in the optical train of the FPU (sixth mirror when including the telescope optics) is the so-called Focal Plane Chopper (FPC). In Fig. 1b the location of the FPC, inside the FPU, is indicated by the red1 arrow. This steerable mirror can chop the telescope beam between an on-source and an off-source sky position. In this way, the background (off-source) signal can be subtracted from the astronomical signal, enhancing the quality of the astronomical observation. This also provides a way of compensating for (electronic) drifts in the instrument. Furthermore, the FPC can be used to reflect the HIFI beam to the internal hot and cold load for calibration of the instrument. The FPC has been identified as one of the critical elements in the FPU of the HIFI instrument. It is a potential single point of failure in the instrument which asks for high reliability and redundancy in the design of the mechanism.

The FPC has been developed by SRON Netherlands Institute for Space Research, an organization that has ample experience in building space qualified mechanisms since the 1980s. One of the examples, relevant to the development of the FPC, is the grating drive mechanism for the ISO SWS instrument [3,4].

This paper presents the mechatronic design of the FPC and several technical considerations in achieving nominal operation at 15 K with strict performance requirements and environmental constraints. In Section 2, the design of the FPC is given focusing on the mechatronic components and the control of the system. The different aspects, related to the development of the FPC mechanism for operation in cryogenic conditions, are discussed in...