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Manufacturing of high precision filter arrays for the Sentinel 2 satellite

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Abstract
Satellite based instruments for earth observation detect the earth's surface in different spectral ranges for land use examination and identification of environmental disasters. The Sentinel 2 Satellites detect the earth's surface with a resolution of 10, 20 and 60 meters and a swath width of 290 km at 13 different bands from the visible near infrared (VNIR) to the short wave infrared (SWIR) spectral range [see 1, 4, 5].
Optical filters are necessary for the spectral wavelength selection. The single filter elements will be arranged into mechanical subassemblies made of titanium alloys and will be aligned into the optical instrument in front of the detectors [3]. During the integration of the single filter elements to filter arrays, the optical elements will be arranged into the mechanical holders with positioning accuracies of less than 10 µm. The optical apertures were realized by high precision manufacturing of the mechanical parts. Manufacturing accuracies of the functional opto-mechanical structures of less than ± 15 µm were achieved.
A requirement for the filter array manufacturing is the space qualification of every used process and material. The qualifications and the tests were performed during the development and test campaign realizing the Breadboard- , the Engineering- and the Flight Models. The characterization of components and assemblies, such as measurements of the filter aperture positions with respect to integrated alignment marks with µm-uncertainties, was necessary for the integration of the filter arrays into the Sentinel 2 Satellite.

Keywords: high precision manufacturing, optical filter arrays, earth observation,

1. Requirements and Specifications

The realization of components for space use requires the use of qualified and space proven materials and processes. All chosen materials must have low outgassing properties, especially if they are to be used near to detectors or optical components. The mechanical loads during launch require mechanical stable mounting of the brittle filter substrate materials. The material of the mechanical parts for the Sentinel 2 VNIR and SWIR filter arrays was chosen to titanium alloy, because of the high mechanical stiffness and low weight. The coefficient of thermal expansion (CTE) of the material is adapted to the CTE of the filter substrate to minimize the thermal induced mismatch.

2. Mechanical design of the filter arrays

The requirement on the positioning uncertainty of the single filter stripes requires mechanical stops, integrated into the mechanical parts for defining the filter surface plane. The mechanical stops were realized by milling. During integration, the single filter stripes will be integrated onto the mechanical stops to realize a planarity of the filter surface plane less than 20 µm. The filter stripes will be fixed and protected during launch by the use of an elastic adhesive, so the vibration loads during the rocket start will not damage the brittle substrate material of the filters.

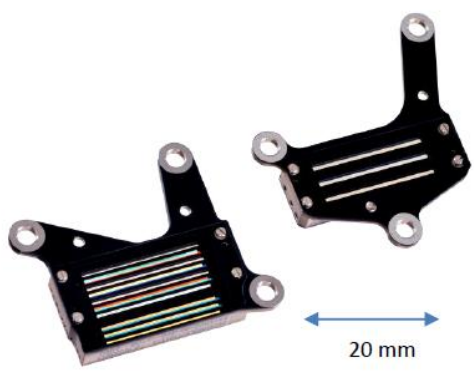

Figure 1. VNIR (left) and SWIR (right) filter arrays for the Sentinel 2 Satellite.

3. Manufacturing of the mechanical parts

3.1 CAD – CAM software

The manufacturing of the mechanical parts starts with the import of the CAD (computer-aided design) model into the CAM (computer-aided manufacturing) software. A software interface organizes the failure free handling of the 3-dimensional models into the CAM software. Additional software tools are used for the simulations of processes to decrease the manufacturing time up to 10-20 % depending on the required surface quality of the parts (see figure 2).

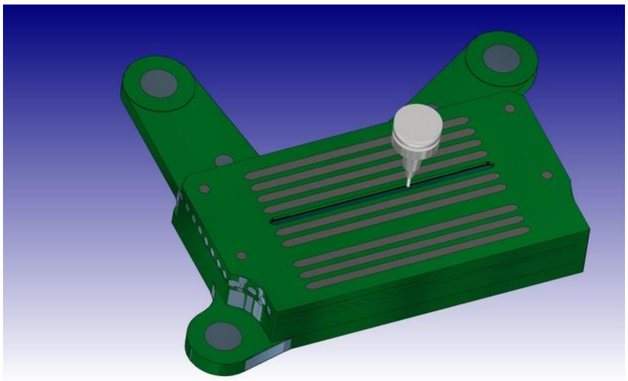

Figure 2. CAM Software – Process simulation.

3.2. Manufacturing Devices

For the manufacturing of the mechanical parts of the filter arrays, a five-axis milling machine was used (see Figure 3). This ultra-precise machine can handle work pieces up to a size of 80 mm x 80 mm x 80 mm. The positioning uncertainties of the five machining axes are specified to 1 µm by the manufacturer (Kern). The device is equipped with an automatic tool- and work piece changing system. The smallest structure sizes (fluidic channels) of 10 µm were realized in PMMA materials using this manufacturing device and milling tools with 10 µm diameter.

The milling tools were chosen by tool life time. During manufacturing, tool abrasion is measured and they will be replaced before the variation of the tool geometry generates manufacturing tolerances out of the specified values.

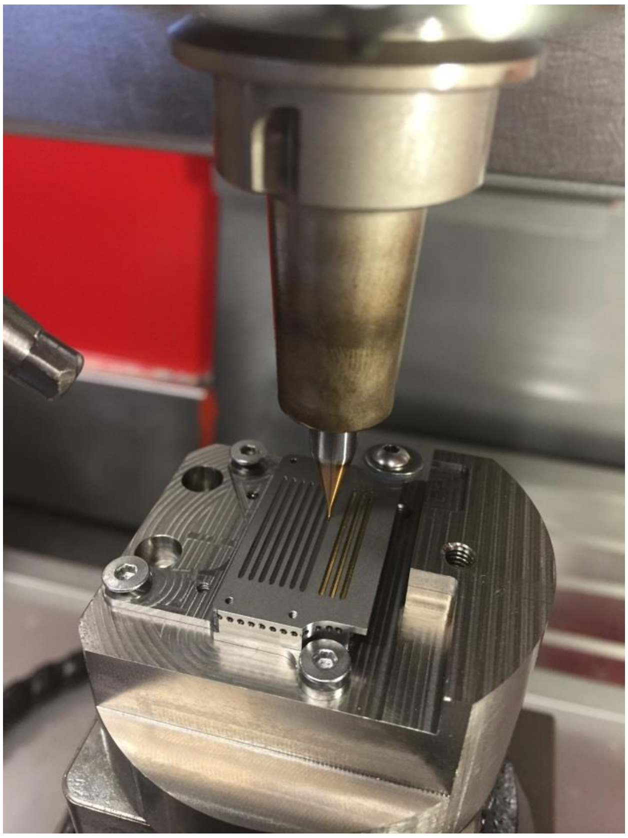

Figure 3. VNIR mount on manufacturing device.

3.3. Measurements of manufactured parts

The mechanical parts will be measured during the milling process by using integrated optical inspection tools. After manufacturing all geometrical dimensions will be measured at a coordinate measuring machine. If the mechanical parts meet the geometrical specifications, the surface of the mechanical parts will be coated by an absorbing coating to meet the stray light requirements [2]. After integration of the filter stripes into the mechanical parts, the Sentinel 2 filter assemblies will be characterized by optical 3-dimensional measurements.

3.4. Manufacturing results

At the initial manufacturing of the mechanical parts there were some limitations of the machine able milling angles of the mechanical structures, because the angles were defined by the geometry of the milling tools. Through the use of ball milling tools and the 3-dimensional CAM-software, the realization of any angular structure is now possible. The achieved manufacturing uncertainty of less than 10 µm and a yield of 75 % were the result of the very intensive process optimization and the validation of the process results.

Because of the material properties of titanium alloys, the deburring will be an issue for further optimizations. Further options, such as the use of different milling tools for deburring and the possibilities of automatic deburring processes will be tested and validated.

4. Summary

The mechanical parts for Sentinel 2A and 2B were successfully manufactured; the filter arrays were integrated into the Sentinel 2A and 2B Satellites. All necessary requirements were met. The established manufacturing, measuring and integration procedures enable the realization of high precision mechanical structures in titanium alloys with manufacturing uncertainties less than 10 µm.

5. Acknowledgements

The Sentinel 2-A satellite was successfully launched in May 2015. The launch for the Sentinel 2B Satellite is scheduled for June 2016. The Sentinel 2 Filter arrays have been developed and manufactured with the financial assistance of the European Union and/or ESA.

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