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Advanced Virgo, task list of the Optical Simulations and Design system

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1 Introduction

In the work breakdown structure of the Advanced Virgo design process the term subsystem refers to an organisational structure rather than a technical one. Here the *Optical Simulation and Design* (OSD) subsystem plays the role of a central hub linking the design activities of other subsystems together. In particular OSD should try to implement new subsystem designs into a reference simulation. It should further be able to use that standard simulation to provide input for trade-off analyses between different design options. Further, the OSD should compile an optical layout of the core interferometer, specifying the parameters of the optical beam at each point as well as the locations of all optics. Additional technical tasks are the definition of the critical optical design parameters such as the requirements for flatness, absorption for the mirror substrates, the arm-cavity finesse, SR mirror characteristics, mirror wedges etc.

This documents provides a list of tasks related to the OSD subsystem. A brief description of each task is given as well as a potential break-down in subtasks. The following section 2 provides an overview of what tasks relate directly to OSD and the baseline design of Advanced Virgo. Section 3 describes tasks that are related to alternative design options or noise sources for which it is not yet clear whether they will have an impact on the Advanced Virgo detector. Section 4 provides some information about OSD related input to tasks that are lead by other subsystems. Finally a timeline for this work shall be provided in section 5 in future issues of this document.

2 OSD core tasks

This section describes the core tasks of the OSD system and gives a general description of the work to be done. The tasks are further divided into subtasks with milestones, deliverables and involved persons are listed when applicable. OSD tasks deal mainly with the core optics (IMX, IMY, EMX, EMY, BS, SRM, PRM as given in [1]).

All subtasks defined below will first provide initial results based on best estimates of a probable Advanced Virgo design. In a second iteration, when the actual Advanced Virgo design is derived, the tasks will provide new results, taking into account results from other tasks and other subsystems.

2.1 Beam size and geometry

The size of the beam at the main test masses strongly influences the thermal noise of the detector and the optical losses (due to clipping). In addition the beam size has a large impact on the design of the optical layout for the auxiliary beams and the input/output telescopes.

The beam size is defined by the radii of curvature of the main optics and recycling mirrors. This task is to compute for a given spot size on the arm cavity mirrors, the beam size everywhere in the main interferometer as well as the corresponding radii of curvature.

- draft layout with beam waist in the centre of the arm cavities [1]
- define the beam size in all parts of the core interferometer, compute corresponding radii of curvature for all core optics [2].

2.2 Geometry of main mirror and beam splitter substrates

The substrate shape (diameter, weight, wedges, material, etalon, etc.) can influence the optical design in various ways and needs to be designed carefully.

- Wedges: analyse the requirements for wedges, derive the wedges size, understand their influence on noise couplings and their relevance to auxiliary beams [3].
- Etalons in arm cavity mirrors: analyse the performance of etalons, compute requirements [4].
- Arm cavity mirror substrate diameter: Compute clipping losses, compare to requirements for cavity finesse (OCA Nice?)
- Beam splitter diameter: The beam splitter has different constraints, probably mostly mass and availability of large substrates
- Substrate quality: Computer losses due to scattering, compare to cavity finesse requirements (LMA Lyon ?)
- Substrate changes due to thermal effects: Compute the losses and scattering into higher order modes due to residual surface imperfections that are not compensated by the TCS (OCA Nice?)
- Resonator robustness: quantify the influence of radii of curvature on resonator stability

2.3 Auxiliary beams

The name 'auxiliary beam' refers to any beam other than the main input and output beams of the Michelson interferometer. The most important auxiliary beams are that ones originating at the BS AR surface, the IMX AR and IMY AR surfaces and in transmission of EMY and EMX.

Some of the main optics might have AR coated surfaces which are hit under an angle (not normal incidence). This is the case for the main beam splitter and also for the input mirrors if these feature wedges. Such an AR coating creates one or several auxiliary beams which need to be carefully treated. At least the beams should be properly dumped. In many cases these beams are required or at least of interested for interferometer control systems. In that case one must determine the required reflectivity of AR coatings and design an optical layout which allows to separate these beams from the main beam and to steer them to a detection system (steering mirrors, telescopes).

- design of the auxiliary beam layout. **Milestone**: Draft design, J. Marque, middle of August; preliminary costing, J. Marque, end of September.
- Requirements for 'windows' separating different sections of the vacuum system.**Milestone**: Review of the experience in Virgo, J. Marque, end of August.

2.4 Arm cavity finesse

The finesse of the arm cavities is defined by the reflectivity of the cavity mirrors and the intra-cavity losses. On the other hand the cavity finesse influences the cavity losses, i.e. if the loss per reflection on the arm cavity mirrors is given, the total loss increases with increasing finesse. Therefore, given other parameters of the optical system, an optimization can be performed to find the optimal finesse for the arm cavities, see [5] for a similar analysis related to Virgo+.

- estimate the optical losses upon reflection of the arm cavity mirrors
- optimisation of arm cavity finesse based on an astrophysical figure of merit, see 2.6.

2.5 Scattered light

Scattered or diffused light that re-enters the main interferometer beam can easily limit the detector sensitivity. Investigate the effects of scattering on the optical benches are part of the DET and INJ tasks. However, there is also the possibility of scattered light being created or coupling in the main interferometer itself. Designing the optical layout to avoid this is a task of OSD.

The two approaches for reducing stray light effects are: a) reduce the generation of stray light (either by improving the quality of the optics and or by reducing the movement of the components in the scattering path) b) reduce the coupling of stray light into the interferometer

- Specifications of core optics for roughness, flatness, point defects (MIR)
- Requirements for auxiliary (probably not suspended) optics (J. Marque)
- Draft design for baffles (VAC)

2.6 Sensitivity optimisation

In order to derive an optimised sensitivity for Advanced Virgo we must perform a trade-off investigations regarding the different interferometer options, see for example [6]. The trade-off will probably be iterative, i.e. all other tasks provide information for this one, and the results from here will be fed back into all other tasks. This task will be led by the Advanced Virgo coordinator together with OSD.

- define figures of merit for different types of astro-physical sources
- define optical power in the arm cavities
- operating point, especially SR tuning and SR reflectance

3 Additional OSD tasks

The following tasks currently are not part of the OSD core activity. However, some of these will potentially become a core task, depending on results from ongoing research. Others, like the compatibility with higher-order modes, concern optional functions or features of the detector and should be followed in parallel to the design of the detector baseline.

3.1 Impact of TCS on optical layout

Not a OSD core task as such but it can have a potentially huge impact, especially compensation plates. This is not clear at the moment. A general decisions of what type of TCS systems will be developed must be taken before this task can start.

3.2 Compatibility with higher-order Laguerre-Gauss modes

The use of higher-order Laguerre-Gauss modes has been proposed as a later upgrade to Advanced Virgo. This could potentially increase inspiral ranges by more than 30%. If possible the Advanced Virgo baseline should allow for such an upgrade with minimal extra costs.

3.3 Squeezed light

Injection of squeezed light into the dark fringe is a very likely technique to be used with advanced detectors after the first science run. The GEO project is planning to demonstrate the use of squeezed light in a large-scale detector during 2009. The Advanced Virgo detector design should allow for a later use of squeezed light if possible.

3.4 Parametric instabilities

Parametric instabilities [7] could potentially be a huge problem for all advanced detectors but currently not all experts agree on this. Need to monitor progress and eventually investigate.

3.5 Holographic noise

Holographic noise [8] is a recently predicted fundamental noise source that would limit the Advanced Virgo sensitivity. We need to monitor the process and if it turns out to be a real threat, this needs to be investigated.

4 Connected tasks not lead by OSD

This section is meant to collect some OSD related information on tasks that are lead by other subsystems.

4.1 Degenerate vs. non-degenerate cavities

Degenerate recycling cavities have caused many problems during the commissioning of first generation detectors due to the fact that those RF sidebands that do not enter the arm cavities have no preferred transverse mode and can ‘hop’ between different shapes upon very small changes in the shape or alignment of the mirrors. In consequence Advanced LIGO plans to use telescopes within the recycling cavities in order to make the recycling cavities non-degenerate. This has three advantages:

- RF sidebands in recycling cavities have a better defined mode shape, this will reduce a number of noise couplings (power noise, frequency noise) and reduce the requirements for the TCS
- the beam in the injection and detection port will be much smaller making the design of the optical benches much simpler
- the separation of the auxiliary beams from the main beam will become very simple and can be done at various places in the vacuum system

The main problem is the need for a new type of suspension system for the telescope mirrors and/or possibly extra vacuum tanks.

Advanced LIGO believes that non-degenerate cavities are *required*. Therefore we should carefully study the potential problems of the current Advanced Virgo baseline with degenerate cavities. Probably led by ISC in combination with TCS. In case the non-degenerate cavities become the baseline of Advanced Virgo, OSD will perform the design of the telescopes inside the recycling cavities.

4.2 Noise couplings

Optimise optical layout for low noise-coupling transfer functions. This is a core task of the ISC. This will sometimes need support or input from OSD, for example regarding resonances of higher-order modes.

4.3 Dark fringe light power and quality

The beam shape and power of the main beam needs to be specified by DET in terms of 'waste' light or higher-order mode contribution. This is directly connected to the TCS specifications and the beam size and mirror geometry.

In case of degenerate recycling cavities the specifications must be done separately for the carrier and sidebands.

5 Timeline

The following texts are derived from statements in official Advanced Virgo design documents. A more detailed description of how this overall timeline is represented by milestones in the OSD system will be added later.

5.1 Overall timeline

The realization of Advanced Virgo is made in 4 steps:

- The realization of the Conceptual Design and Project Execution Plan (2006-2007).
- The setting up of the Work Breakdown Structure (WBS) and the realization of a Technical Design (2008-2009).
- The completion of R+D and the procurement of the parts for the construction (2009-2011).
- The assembly and integration (2011-2012).

5.2 Review 2008

The AdV phase two should last 2 years and will end with the completion of the AdV technical Design. By mid 2008 each SM must present the subsystem plan and the list of task managers must be defined. In fall 2008 the 1st AdV review must be held with the aim of: review the subsystems plans and activities; and take a final decision on the open options with the biggest impact on the design.

As recommended by the STAC, the Advanced Virgo project will be reviewed by an external panel. The review would proceed in 2 steps: a first meeting end October early November 2008, and a second meeting early spring 2009.

5.3 OSD timeline

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References

[1] A. Freise and M. Mantovani. Initial set of optical parameters for numerical simulations towards advanced VIRGO. Technical Report VIR-NOT-EGO-1390-330, Virgo, 2006. 2

[2] S. Hild and A. Freise. Advanced virgo design: Preliminary revision of the beam size and the test mass curvatures. Technical Report VIR-038B-08, Virgo, 2008. 2

[3] S. Hild and A. Freise. Advanced virgo design: Differential arm length noise from vertical movement of wedged input mirrors. Technical Report VIR-037A-08, Virgo, 2008. 2

[4] M. Mantovani, A. Freise, and S. Hild. The consequences of using the etalon effect to tune the arm cavity finesse on the alignment signals for advanced virgo. Technical Report VIR-027A-08, Virgo, 2008. 2

[5] R. Flaminio. Virgo+ sensitivity vs fabry-perot finesse. Technical Report VIR-NOT-EGO-1390-324, Virgo, 2006. 3

[6] S. Hild and G. Losurdo. Advanced virgo design: Comparison of the advanced virgo sensitivity from bench 4 and bench 7.0. Technical Report VIR-055A-08, Virgo, 2008. 3

[7] A. G. Gurkovsky, S. E. Strigin, and S. P. Vyatchanin. Analysis of parametric oscillatory instability in signal recycled LIGO interferometer. *Physics Letters A*, 362:91–99, February 2007. 4

[8] C. J. Hogan. Measurement of quantum fluctuations in geometry. *Phys. Rev. D*, 77(10):104031–+, May 2008. 4