A retrospective study on the construction and installation of the New Injection Bench (After STAC recommendation in June 2006)

1. Overall organization

After the decision to start an activity devoted in changing the VIRGO Injection Bench, on 27th of July 2004, the VSC selected a team of persons involved on the study and design of a new/updated bench:

M. Punturo (INFN-Pg), Coordination
P. La Penna (EGO), Optics coordinator
F. Cleva (OCA), Faraday Isolator
H. Heitmann (OCA), Controls
F. Frasconi (EGO/INFN-Pi), Mechanics coordinator
F. Richard (EGO), Finite Element Modeling
R. Flaminio (EGO/LAPP), EGO relationships

A team of researchers was charged to prepare a set of tests to be done on the current IB, to fully understand its behavior, coordinated by F.Fidecaro (INFN-Pi) (meeting every 15 days, open to all the Virgo commissioners).

The design and selection process of the bench components started in August 2004 (Faraday isolator, overall bench layout, telescope simulations). The components purchasing started in September 2004 and as soon as the Faraday isolator was available, it was tested in Nice by F. Cleva. All the other components were assembled and tested at EGO site. Experience with off axis parabolic telescope was acquired through a visit of P. La Penna and F. Olivier to LIGO-Caltech in January 2005 (thanks to Mike Smith).

The design and planned implementation were discussed every month within the collaboration meetings. Significant activities were discussed at the weekly meetings.

The planning was drawn by M. Punturo, after periodic meeting with the people involved in the bench design and construction. Once the construction of the bench had started (end of August 2005) a weekly report was written by every group involved in the activity (optics, mechanics, vacuum).

The largest part of the bench was ordered outside EGO. A part of the mechanical and electric components (mounts for optics, cables, connectors, etc.) were machined and prepared by the EGO personnel.

2. Modeling/pre-experiments

A big effort has been done in developing optical and mechanical models of the bench. In particular, a complete optical simulation of the bench was performed using the optical software Zemax (3D simulation), which allowed to decide between different configurations (simulations performed by O. Francois, P. La Penna, E. Genin). 2-D designs of the bench were drawn using Optocad (paraxial optical simulation, specifically adapted to VIRGO, performed by J. Marque) and Autocad. The mechanical design of all the components of the bench was performed with Autocad (3D).
F. Richard performed a detailed simulation of the old bench with ANSYS (finite elements): this allowed the identifications of many of the measured resonance lines. In addition, as soon as the preliminary mechanical design of the bench was available, a second simulation (finite elements – ANSYS) of the new geometry chosen has been done to optimize the mechanical performance of the structure (relevant activity performed with F. Frasconi).
It should be put in great evidence that, during this phase, it has been given the opportunity to develop important expertise on simulation tools which were not available before.
By the end of May 2005, the bench final design with the monolithic suspension wires was ready to be ordered to an external firm (outside the EGO workshop) for its final machining.
A relevant effort has been done also in the design and construction of all the mechanical tools necessary for the bench assembling in cleaning room and its final installation within the vacuum tower.

The largest part of the optical components was not tested before their installation on bench in clean room. The only tested component was the Faraday isolator (February 2005): it was sent to Nice, where F. Cleva performed a set test in air by using a 20 W spare laser available there. The results of the tests were satisfactory and finally the Faraday was sent back to EGO for its final installation.
The test on the bench was scheduled to take place in class 10 clean room (September-October 2005) where the bench was assembled on a dedicated mechanical structure. On top of this structure a nominal 700 mW Nd:YAG laser (having approximately the same size of the VIRGO 20 W laser) mounted aside the bench was used for the alignment purpose of the Faraday and all optical components. This allowed a rough alignment and centring of the bench optics as well as the Faraday isolator tuning.

During this phase some problems have been encountered: several mechanical components, in particular those ordered outside EGO, did not fit correctly the specifications (did not correspond to the design) or had to be modified. The intervention of the EGO and, sometimes INFN, mechanical workshops was necessary and very useful.

The Reference Cavity was not aligned in clean room (lack of time). Moreover, even the Faraday Isolator fine tuning with a full power laser (10 W) was not performed within clean room, this test being scheduled to be done within the vacuum tower (after the bench installation) by using a fake dihedron. Unfortunately it has been skipped, owing to time constraints (this was probably a mistake, since this test was critical, as later experience demonstrated).

3. Costs and human resources

In the following table a summary of the expenses for the suspended IB is reported:

Component	**Cost [€]**
Faraday isolator	11332,95
2 off-axis parabolic mirrors	27295,03
Additional coating for optics of the new IB	432,00

Optics for new IB	14880,00
Optical elements acquisition for new IB following VSC decision	7087,65
Optical components for new IB	704,22
Lens for telescope	1284,00
Lens for telescope	388,18
Lens for RFC telescope	384,00
Miroros for new IB	2318,93
Waveplates and lenses	6072,91
Beam Splitter for new IB	437,00
2 mirrors (SILO)	3846,00
Optical storage boxes	221,57
Sub-total Optics	**76684,14**
Picomotor actuators vacuum compatible	8400,00
Closed loop picomotor actuators	15177,96
PI closed loop actuators	65598,00
Position sensors	7618,52
Photodiodes (DPS)	1594,08
Photodiodes (DPS)	1605,13
Sub-total Actuators/Sensors	**99993,69**
Mechanical machining of the new IB	7518,00
Marionette cable mechanical support for new IB	720,00
Design of 2 motorized supports for parabolic mirrors	1800,00
Supports for parabolic mirrors	2760,00
Optical mounts construction	3242,16
Optical mounts for flat optics	6887,82
Mechanical elements for optics	2976,00
Security supports for mounting the new IB in the tower	1278,00
Tools construction for new IB assembling	5247,60
Sub-total Mechanics	**32429,58**
TOTAL new suspended IB	**209.107,41**

The table above reports the cost of the bench itself, together with some additional optics to be used as back-up solutions in case of difficulties during the assembling and operation phases of the new project (in accordance with a VSC decision). Additional expenses concerning the changes in the Brewster link and the External Injection Bench (EIB), which are connected to the changes on the suspended IB but only partially to be put in relationship with the installation of the new bench (many changes in the EIB were an optimization of what already existing and regarding the installation of the Beam Monitoring System), are reported in the table here below:

Component	**Cost [€]**
Construction of 4 absorbing glass baffles for UHV	758,40
Coater supports (LMA) per specchi parabolici	6879,39
Coater supports (LMA) for parabolic mirrors	1863,37
Brewster plate	11721,56
System of wave plate + mounting + polarizer (for B2)	3602,61
Machining of a big flange (1100 mm diameter) for the IB tower	6768,00
Construction of the metallic support of the new Brewster	4860,00

Windows for Brewster	3960,00
Construction of optical supports for the new EIB	1587,60
All mirrors for the new EIB	11952,00
Beam dumps for new EIB	987,60
Lens mounts for telescope collimating laser beam (EIB)	741,60
Optical components for the BMS	3331,20
Total EIB and Brewster	**59013,33**

The design, assembling and installation of the new suspended IB have been mainly carried out by EGO personnel. The EGO optics group was strongly involved in the design, ordering, construction, commissioning of the bench. The technical design was drawn by EGO personnel, the mechanical design by EGO/INFN Pisa personnel, electronics and vacuum by EGO personnel. The VIRGO collaboration has essentially given help as far as the Faraday and IB local controls were concerned (Nice group). The LMA has provided coatings for part of the mirrors (namely the parabolic mirrors).

The involvement of the people was in average of the order of 50 %, two-three members of the EGO working group were involved by a larger fraction of their working during 2005 (full time during the months of the integration and commissioning of the bench).

The following lists concern the people most involved in the IB design, construction, installation and commissioning of the new IB bench. In the right column there is an indicative quantification of their time involvement (Eric Genin started working at EGO in September 2005; Olivier Francois left EGO in November 2005):

Most involved people in new IB design:

Paolo La Penna (EGO)	80%
Franco Frasconi (EGO-INFN Pi)	60%
Oliier Francois(EGO)	60%
Julien Marque (EGO)	30%
Frederic Richard (EGO)	20%
Tatiana Zelenova (EGO)	40%
Vincenzo Dattilo (EGO)	20%
Frederic Cleva (OCA Nice)	30%
Antonio Pasqualetti (EGO)	30%
Carlo Bradaschia (INFN-Pi)	20%
Michele Punturo (INFN-Pg)	40%
Raffaele Flaminio (EGO)	20%
Francesco Fidecaro (INFN-Pi)	20%

Most involved people in new IB construction and installation:

Paolo La Penna (EGO)	100%
Olivier Francois (EGO)	90%
Eric Genin (EGO)	90%
Franco Frasconi (EGO-INFN Pi)	70%
Julien Marque (EGO)	40%
Salem Hebri (EGO)	40%

Vincenzo Dattilo (EGO)	40%
Flavio Nocera (EGO)	30%
Federico Nenci (EGO)	30%
Marco Ciardelli (EGO)	40%
Antonio Pasqualetti (EGO)	30%
Roberto Cosci (EGO)	30%
Paolo Ruggi (EGO)	30%
Michele Punturo (INFN-Pg)	40%
Henrich Heitmann (OCA Nice)	40%
Frederic Cleva (OCA Nice)	30%
Maurizio Perciballi (INFN Roma1)	20%
Piero Rapagnani (INFN Roma1)	20%
Paola Puppo (INFN Roma1)	20%

4. Fabrication schedule

July 2004:	Approval by VSC of the study of a new IB;
July 2004-November 2004:	First proposal design of the new IB, approval of the basic design of the new bench (flat PR, off-axis parabolic telescope) by the VSC in November 2004;
November 2004-May 2005:	Finalization of the design, placing of orders;
August 2005:	Arrival of the last components (delayed, 50 mm diameter parabolic mirror)
September-November 2005:	Assembling of the new IB in clean room, with parallel dismounting of the old one. Changes of the IB vacuum tower (input flange, Brewster link). Tuning activity of the IB Suspension (compensating the difference of the total payload weight). Changes of the EIB layout and new PR payload installation.
Begin November 2005:	New suspended IB installation within the vacuum tower.

(see planning by Michele Punturo for more details)

QA/QC

The main alignment of the bench was tested in clean room. In particular, in clean room it was tuned:

- The length of the short telescope after the IMC
- The tuning of the Faraday isolator
- The alignment of the off-axis parabolic telescope

It was not tested:

- The alignment of the RFC
- The isolation of the Faraday isolator with full power (500 mW instead of 10 W)

The alignment of the RFC and the isolation of the Faraday isolator should have been tuned in air in the tower.
- For the Faraday isolation test it was necessary to use the fake dihedron: this test was skipped for time constraints.
- For the alignment of the RFC it would have been necessary to lock the IMC in air: also this test was skipped for time constraints (it was even not sure that it was possible to lock the IMC in air, it has never been tried).

Some important parameters of the new IB:

- Power on the PR mirror: about 8 W (ten times more than before shutdown)
- RFC alignment: matching more than 75% (same level as before shutdown, satisfactory)
- Beam-ITF matching: more than 96%, possible to improve (better than before shutdown)
- Faraday isolation: about 100 (same level as before shutdown, but with ten times more power; it should be of the level of 10,000). Probably due to the tuning of the Faraday with too low power (could be improved by a better tuning to be done within the tower).

5. Commissioning schedule

November 2005-January 2006:	First phase of the new IB commissioning (IB local controls, IB in vacuum, IMC locked, beam in the ITF, ITF locking);
February-May 2006:	Second phase of the new IB commissioning (RFC locking, beam quality improvement, automatic alignment of the IB implementation);
Begin June 2006:	Suspension trouble fixing, RFC transmission steering mirror alignment, Faraday isolator reflection steering mirror centring, IB balancing improvement.

Several delays and problems came out from the aforementioned missing tests, in particular:

- RFC alignment (required in-tower interventions);
- Faraday isolator isolation (lower than expected, still to be fixed).