QUALIFICATION TESTS OF THE SOLEIL STORAGE RING HLS

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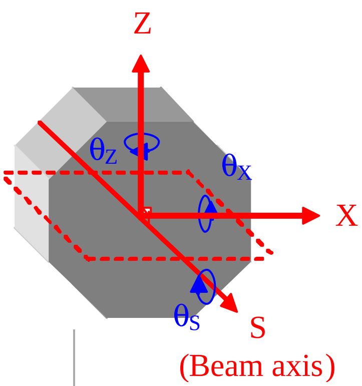
1. PRINCIPLES OF MEASUREMENTS:

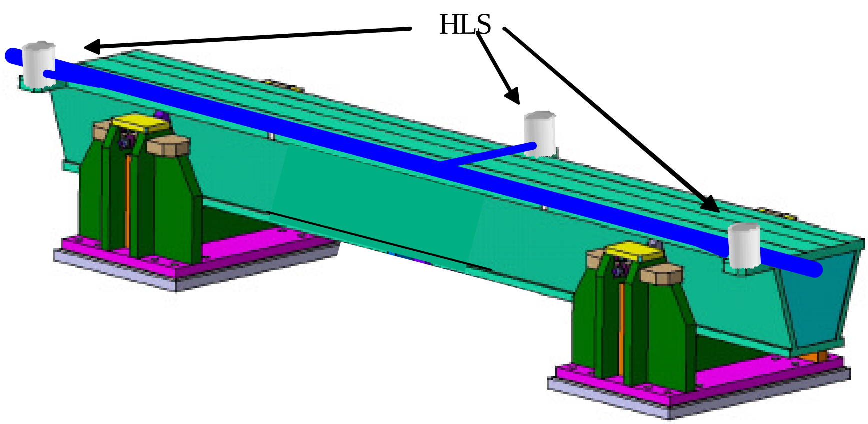
Figure 1: Fogale HLS system

The HLS (Hydrostatic Levelling System) is a system based on the measurement of the displacement without any contact (capacitive effect) and the water gauge system. An electrode can measure the electrical capacity of the dielectric made by the air located between the electrode itself and a conductive material. The water represents the conductor in the HLS case. If these three sensors are installed on the same structure, then their reading variations allow to easily find the angle variation of the structure (it is an inclinometer). If three other sensors are installed on a second structure and connected to the same fluid system, then we can determine the relative position of both structures for the three degrees of freedom (Z), (θ_X) et (θ_S).

Figure 2: The machine reference triedre



The HLS system is planned for the vertical alignment (Z) of the storage ring as well as for the definition of the magnet horizontal positions (θ_X) et (θ_S). Each girder will be equipped with three sensors thus defining a plane. So, the adjustment consists in merging the 56 planes in only one. A set of HLS manufactured by Fogale based at Nîmes, France (fig. 1) has been for all the presented tests in this paper.



2. BANDWIDTH:

The HLS system is planned to detect the variations on an hour scale that represents the upper limit of the measurement bandwidth. On the other hand, the aim is to reduce the maintenance operation at only once a year: that represents the lower limit of the measurement bandwidth.

The physical parameters determining the bandwidth have essentially the following origins:

- Thermal : fluid expansion, mechanical assembly, measurement sensitivity

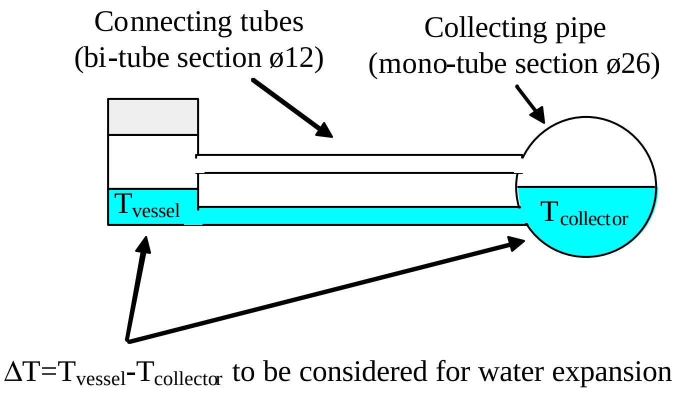
- Mechanical : fluid movements, mechanical stability of the sensor

- Electronic : A set of parameters influencing the capacitive measurement and the signal conditioning stage other than the thermal one will be considered.

In standard conditions of use, the upper limit of the bandwidth essentially depends on the stability of the fluid defining the horizontal. The lower limit represents the system drifts on the whole (sensor, mechanics, fluid).

3. SETTING THE FLUID SYSTEM:

Figure 3: Water expansion effect



The fluid is distributed between the vessels keeping their free surfaces and at the same atmospheric pressure. Two topologies exist: the first one consists in connecting together the vessels with only one tube containing both air and water. The second one is made of two tubes: one for the water, one for the air. The latter topology presents the followings drawbacks: the need to use a temperature sensor at each pot in order to master the water expansion, the risk of blocking in each tube (air bubbles in the water, water bubbles in the air) and important charge losses (friction) in large lengths.

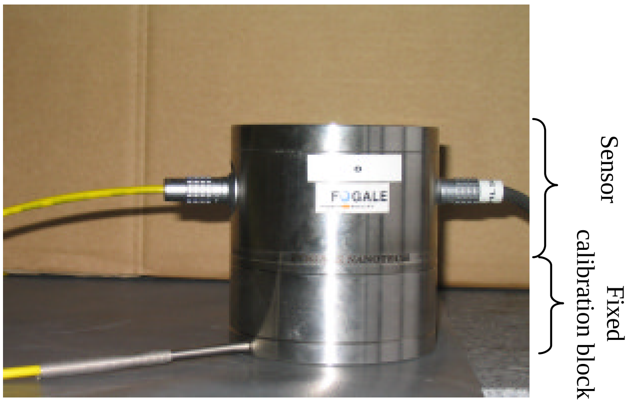
The test bench installed at the CEA is made of a single collecting pipe (110m linear) on which is connected a couple of tubes per sensor on a 30 cm length. Thus we need to know the temperature differential between the water in the vessels and the water in the collecting pipe at the level tap. Further tests have been carried out with whole in mono-tube.

4. TEST DEFINITIONS:

The led tests must determine more precisely the bandwidth as well as the main parameters of its modification.

4.1. - sensor on a fixed calibration block :

Figure 4: HLS assembly with the fixed calibration block



The sensor stands together with a fixed stainless steel machined calibration block. We register the function measurements of thermal variations on the scale of roughly 24 hours. It allows revealing the thermal dependence of the sensor mechanics. This mechanics is correctly mastered by the expansion coefficient of the calibration block. After subtracting its effect, we can deduce the thermal dependence of the measuring electronics. We could be induced to exploit this function if necessary. This test is led again after a space of several months. Thus we obtain a good estimation of the drift of these parameters.

4.2. - System extended on a monolithic structure :

Figure 5: Layout of the five HLS in Hal HE3, CEA St Aubin

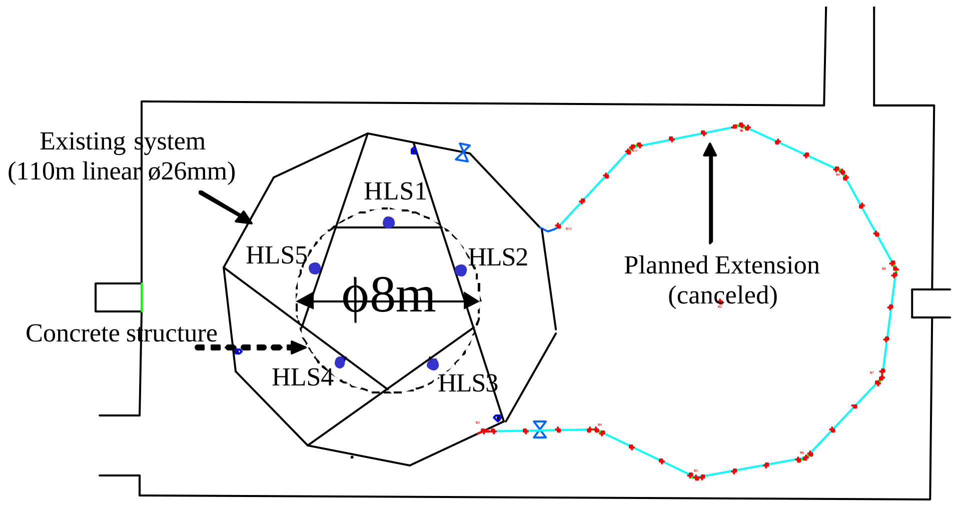
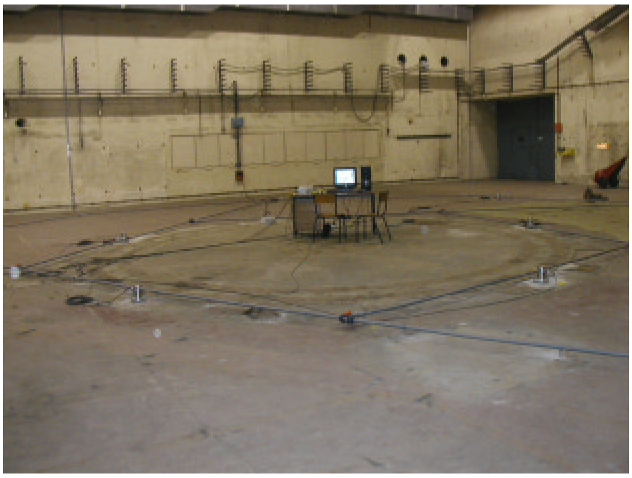


Figure 6: Overview of HE3

5 sensors are fixed on a concrete structure with a 8 m diameter and more than one meter thickness. Its dimensions and age (more than 20 years old) allow us to theorize a large stability: this concrete foundation can tilt but not distort. Therefore, we can calculate at any moment a medium plane by the criterion of the least squares coming from the measurements of the 5 sensors. The remainder, after subtracting the plane position, allows us to describe the precision of the whole system. The recording with a 5 mn period during several months integrating almost all the physical parameters gives us a good estimation of the bandwidth. The sensors are

connected together with a fluid system made of a PVC tube of ø26mm inside. The developed front line constitutes 100m of water circulation with free surface.



4.3. - Setting the fluid in motion:

Several tests of partial water filling and purging were led in order to determine the time taken by the fluid to stabilize in accordance to the length and the topology of the tube network. The definition of the medium plane must be independent to the quantity of the water used.

Setting the network into motion without modifying the water level allows us to ensure no dependence of the fluid mechanical stability in the definition of the horizontal.

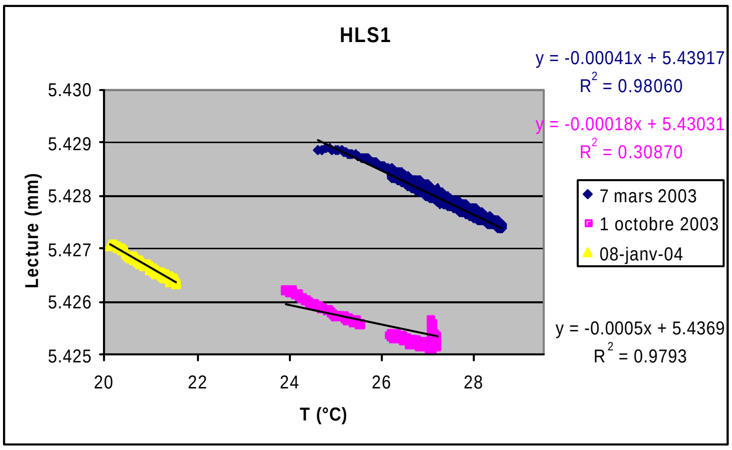
4.4. - Modelling the mechanical response of the fluid :

The knowledge of the mechanical response of the fluid could permit to estimate the time it takes to stabilize in accordance to the topology and the dimensions of the tubes used in the storage ring. So we need to model its performance with the fundamental equations of the fluid mechanics (Navier-Stockes, Bernoulli, etc.). The mere estimation of the surface wave attenuation law according to the tube diameter for a given length (354m) could be enough to choose the collecting tube.

5. SENSOR ON A FIXED CALIBRATION BLOCK, RESULTS:

Each sensor is used with a set of two calibration blocks, one permitting a reading close to the minimum, the other allowing a reading close to the maximum. The difference of performance being negligible, we can consider that in fact the test is doubled. Fig. 7 represents the result for one of the sensors. We can notice three scatter plots at three distinct dates. Each plot bore a gradient representing the thermal dependence, from whatever origin (stainless steel block expansion, electronic, mechanical).

Figure 7: HLS on the calibration block



The analysis of the measurements made in Mars 2003 and January 2004 allow us to conclude the following points:

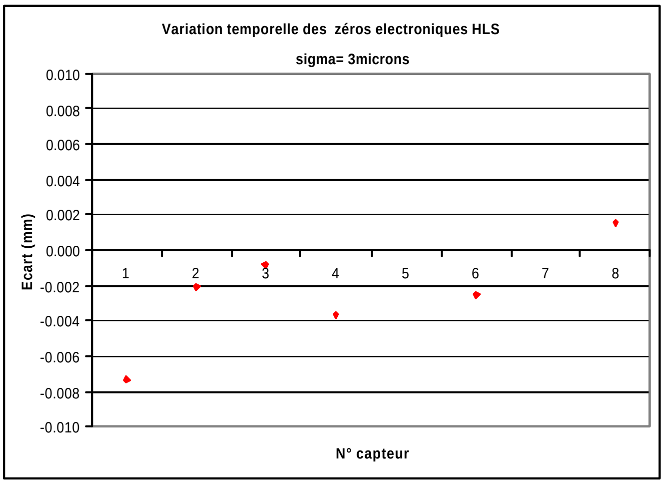
5.1. - Thermal dependence:

It is inferior to 0.80µm/°C in any case (σ=7µm/°C). Its drift (after 10 months) is roughly 0.34µm/°C.

5.2. - Electronic zero in relation to the mechanical reference:

All the measurements having been made with the same mechanical calibration sets, we can compare the position value of the electronic zero of the sensors between them. We notice a dilution of standard deviation σ=7.7µm. The origin of this value is essentially the calibration curves of the supplier. The whole drifts noticed during 10 months represent a standard deviation σ=3µm. However we will notice that the statistical parameters are calculated on a series of only 6 sensors (small quantity).

Figure 8: electronic Stability test after 10 months

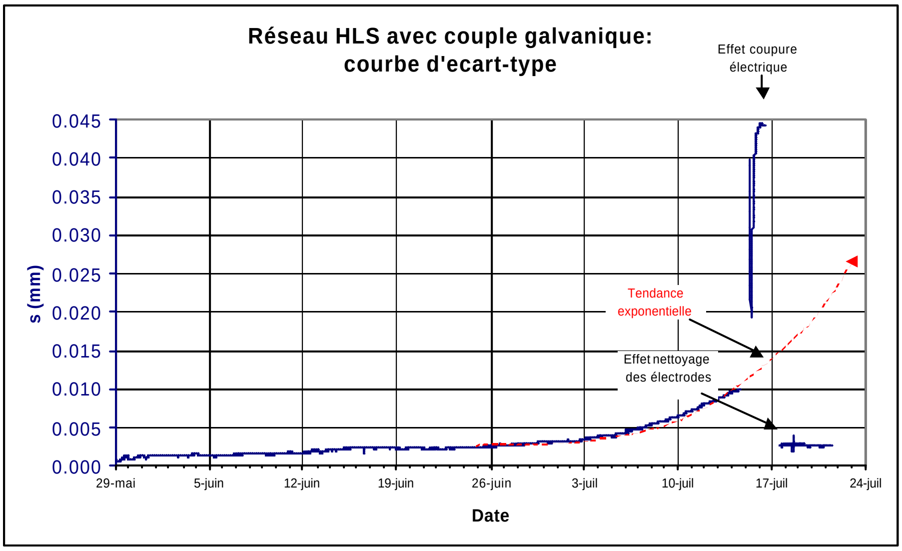


6. SYSTEM EXTENDED ON A MONOLITHIC STRUCTURE, RESULTS:

6.1. The first sensor version:

Chronologically, we obtain only three results spaced out on a 10-month measurement period. A first measurement period has been launched with water from the water supply network, therefore full with mineral salts. Yet, the technology used for the electrode integrates a front glass plate on its electrode. This kind of assembly is sensitive to the mineral deposits obtained by water evaporation; the drift is marked and important.

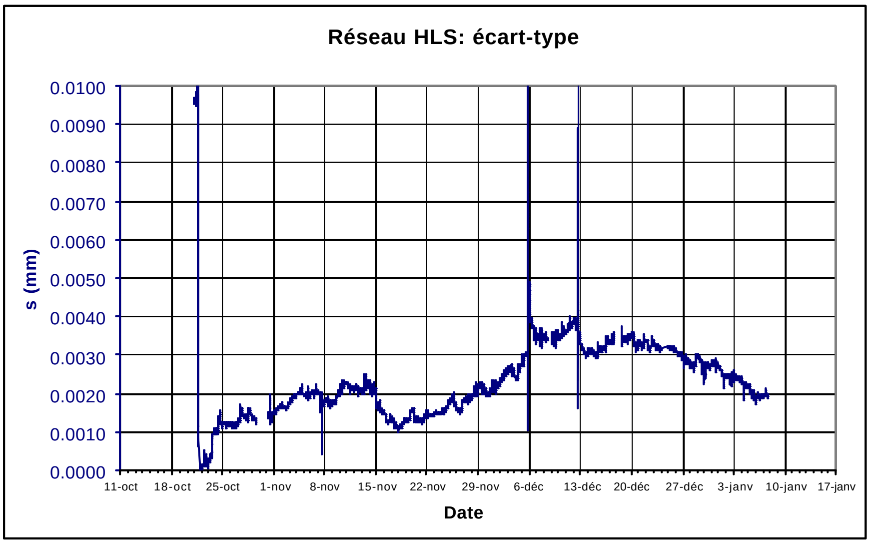
Figure 9: Results with galvanic couple



The second period corresponds to the same network but with deionised water. Despite this precaution the results are bad as well. In fact, the parasitic phenomenon came from the existence of components of the fluid network of different kind: stainless steel vessels and brass pipe fittings produce a galvanic couple attacking the brass pieces and polluting the water by filling it with metallic salts (fig. 9). The cleaning of the electrodes has the effect of decreasing considerably the parasitic effect.

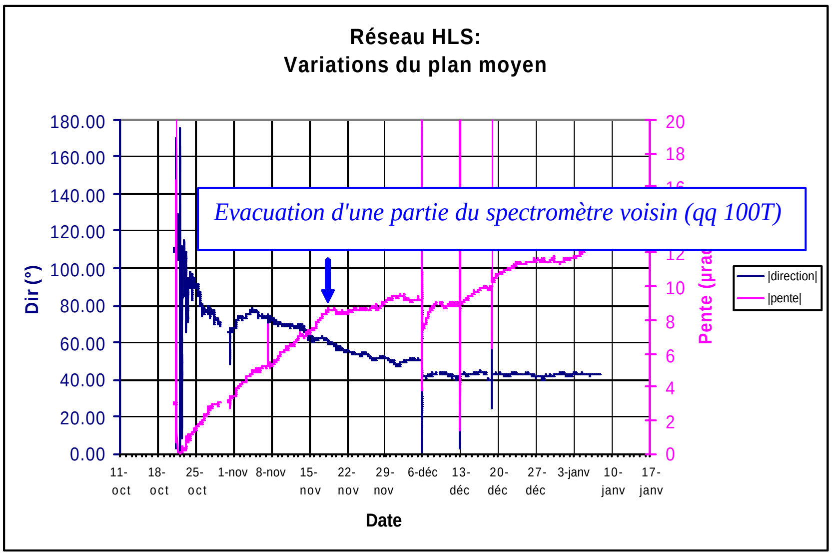
An electrical power cut during few hours reveals the existence of the deposits on the electrode that therefore charges with humidity from condensation and leading to a serious modification of the capacitive measurement. The cleaning of the electrode makes the phenomenon disappear.

Figure 10: Results with normal conditions



The third period gives better results, the installation respecting the supplier's instructions. It enhances a drift of the system of $\sigma=4\mu m$ for 2 months and a half (fig. 10), without any marked exponential trend. These results appear to be very promising. Nevertheless, a modification of the electrode technology has been asked to the manufacturer because the technology with the glass guard appears to be a little too much sensitive to the deposit phenomena: One of the sensors has once again been a victim of this phenomenon after the fluid network clean-up. Furthermore, the objective is the maintenance once a year, so we can't take any risk about it.

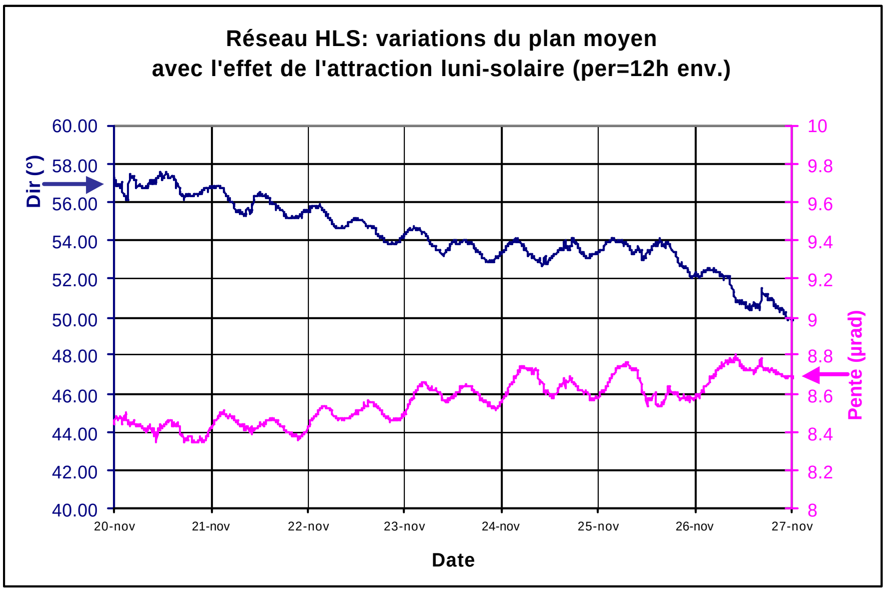
Figure 11: Mean plane evolution



The analysis of the medium plane variation in direction and angle bow (fig. 11) is much more delicate to make: theoretically, these variations should be interpreted as a real tilting of the structure. Nevertheless, we will keep prudent on this interpretation. However, the bend appearing on November the 19th can be induced by the dismantlement of a heavy spectrometer piece near the HLS hall that has been carried out at this date.

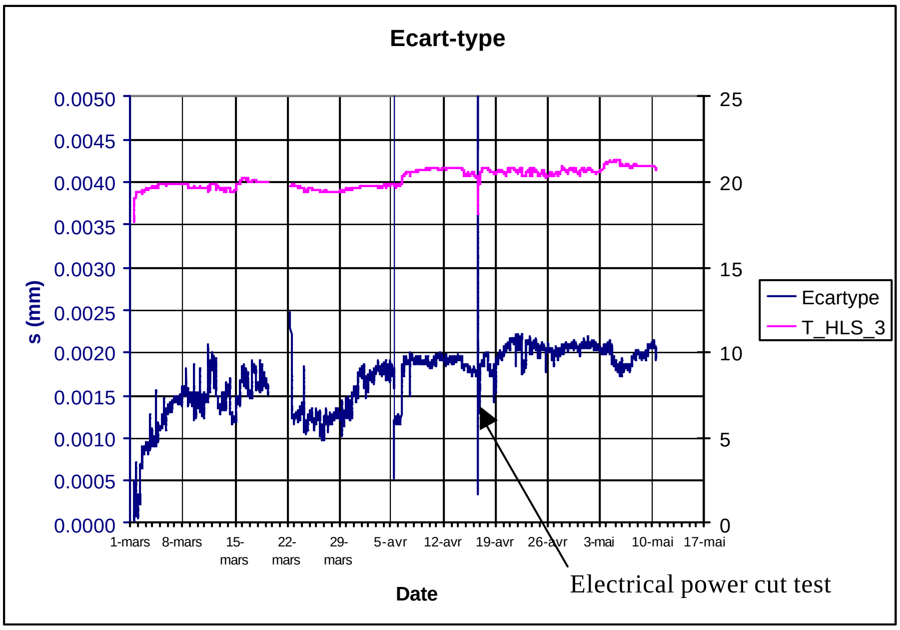
On can notice the variations of the least square mean plane revealing the lunar-solar tidal effects (fig. 12). The theoretical half-day period is very visible, in spite of the tiny amplitude (0.2µrad).

Figure 12: Zoom on the lunar-solar tidal effect



6.2. Ceramic electrodes version:

Figure 13: Results with electrode without front glass



A test in similar conditions gave a standard deviation equal to 2µm instead of 4µm for same period (2 months ½). The fig. 13 doesn't show any exponential tendency, the HLS readings are exceptionally stable during the 9 last weeks since we achieved σ<1µm. The electrical power cut test doesn't show anymore the deposit effect on the electrode.

6.3. ceramic electrodes & full mono-tube network:

Figure 14: full mono-tube configuration

All the previous tests were made with the connecting pipes in bi-tube configuration. We have modified them in mono-tube configuration.

In this case, any water expansion effect can affect the HLS measurements. As a consequence, the noise measurement decreases; it can be seen (fig. 15) in the comparison of the noise numerically extracted from the two sigma-functions (σ) of fig. 13 and fig. 16.

Figure 15: noise comparison versus connecting pipe configuration

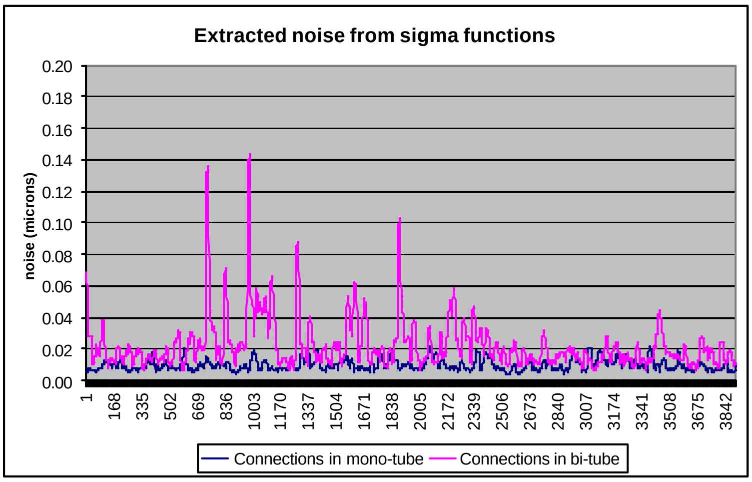
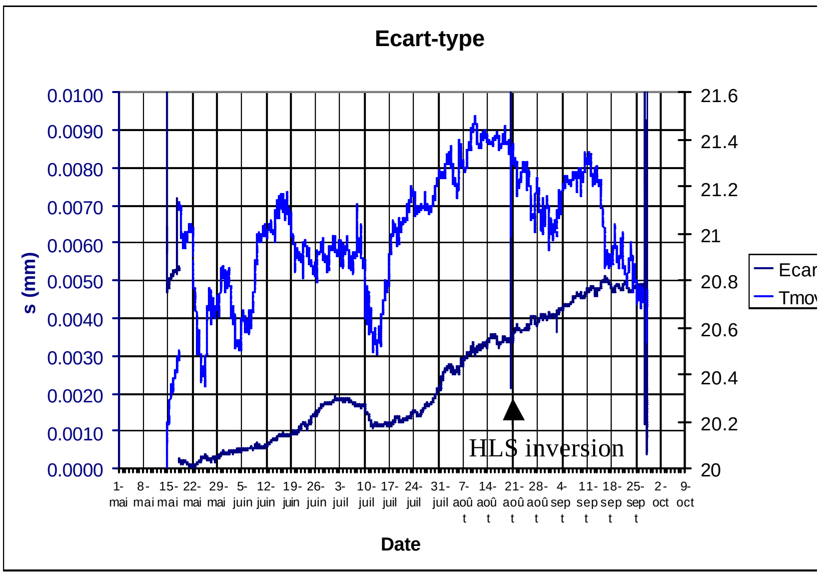


Figure 16: Results with full mono-tube configuration



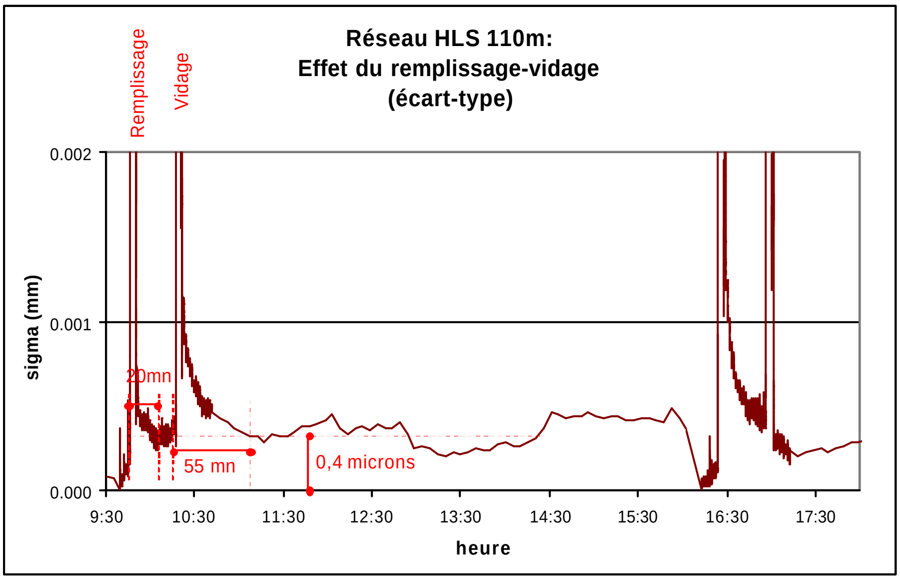
The good results obtained in the previous paragraph (σ=2μm) are not confirmed during the 15 weeks of measurement in full mono-tube setting. Therefore we decided to invert two suspicious sensors on the concrete structure: it allows dissociating a sensor drift to a structure deformation. The behaviour slightly changed: the sigma function did not (see fig. 16), but the system stored a change in the mean plane slope. More investigations are necessary to solve that problem. Nevertheless, the achieved accuracy (σ=5μm in 4 months) is satisfactory.

7. FLUID MOVEMENTS, RESULT:

The presented results in following section have been realised with the bi-tube connecting pipe configuration.

7.1. Filling-purging test:

Figure 17: Filling-purging test

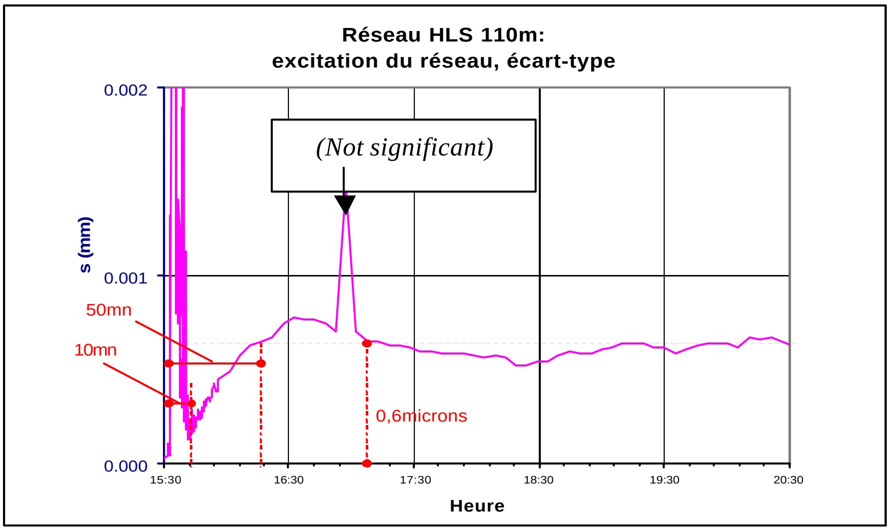


Several filling-purging tests have been carried out in order to detect any influence on the horizontal definition of the fluid. It consists in injecting a water excess to increase the sensor reading of about half a mm. Firstly, one can observe the necessary delay to recuperate the fluid stability, then one can store an offset related to the origin value. The fig. 17 shows the achieved results on the whole pipe network (110m length). The stabilization delay is about 20mn for the filling phase and 55mn for the purging one. The dispersion of the readings increases with these interventions on the network: it means that they move away from the initial readings. One records an acceptable 0.4µm increase (1σ). One can attribute that variation to the thermal dilation of the water. Its movement slightly changes the temperature difference between the vessel and the pipe (0.4µm should correspond to 0.07°C). There is no satisfying explanation to the differential behavior between filling and purging phases.

The test carried out on the reduced network (26m ring, linear) gives a stabilization delay about 20mn (purging phase) instead of 55mn for the whole network (110m, non linear).

7.2. Excitation pipe test:

Figure 18: network excitation



The pipe network is manually and slightly excited in many different points without any water level modification. The stabilization delay splits in two parts: firstly, the free surface of the fluid becomes stable with a 0.2µm dispersion (1σ), then a slow drift appears during 50mn giving a 0.6µm dispersion. This phenomenon doesn't exist with the full mono-tube configuration. Therefore it can be attributed to the thermal dilation to the water insufficiently mastered as previously seen (0.6µm represents $\Delta T \approx 0.07°C$).

This test was realized after seven weeks of absolute motionlessness of the network. The aim was to try to reveal disrupted effects on the horizontal definition of the fluid due , for example, to the forces created by the capillarity effect of the fluid. (The capillarity length of the water is about 2mm [3], our tubes have respectively 13 & 6mm ray).

8. MODELING THE HYDRODYNAMIC BEHAVIOUR OF THE FLUID:

C. Zhang *& al.* [1] carried out a hydrokinetic study of the fluid in a half-filled single tube applied to the HLS network configuration. They described the behaviour of the fluid surface inside a linear and rigid tube closed to their both ends. The study leads to a law, describing the damping behaviour as a function of the tube diameter and its length.

We applied that result to storage ring network configuration. As a consequence, we decided to split the collector pipe in many parts, each of them corresponding to the cells. At both ends, the pipe will be reduced in diameter in order to cut the low frequencies of the fluid surface that are the most negative for the fluid stability since they present the higher amplitude.

The use of the very interesting Zhang's works is for us, in a first time, to avoid any negative effect on the network setting. Later, we hope to be able to simulate a complete ring network with 1D Saint-Venant equations taking into account the fluid viscosity. In any case, modelling the hydrodynamic behaviour of the fluid will stay qualitative.

9. SYNTHESIS OF THE RESULTS:

The synthesis of the stored values during these tests should allow estimating the expected performance of the 354m storage ring HLS network. In this chapter we will present successively the bandwidth limits and the consequences on the network infrastructure.

9.1. Bandwidth upper limit:

The linear extrapolation of the stabilization delays we stored (as a function of the tube length 26 & 110m) gives a delay approximately equal to 2 hours and half for a 354m-circumference pipe. This value corresponds to the same pipe diameter (ϕ20 inner tube). As a precaution, we will choose an upper diameter to enhance the response delay. One notices that any drastic parasitic effect on the horizontal definition of fluid surface could be seen during these tests.

9.2. Bandwidth lower limit:

9.2.1. electrode with front glass:

The achieve results in a normal condition (σ=4µm in 2 month ½) should allow to hope that aiming 20µm stability in a year is possible. Nevertheless, the tests carried out at ESRF [2] with sensors equipped with electrode without front glass give a better accuracy (1.7µm in the same delay). It is true that the size of the fixed structure is not the same but we have no reason to think that there is a relation between the accuracy and the network size (for this dimension range).

9.2.2. electrode without front glass:

We achieved good results with the last version of Fogale sensor without front glass on the electrode: 2µm instead of 5µm with the previous version (1σ). In addition, the electrical power cut test does not show any negative effect due to the deposits on the electrode.

9.2.3. electrode without front glass & with a whole network in mono-tube:

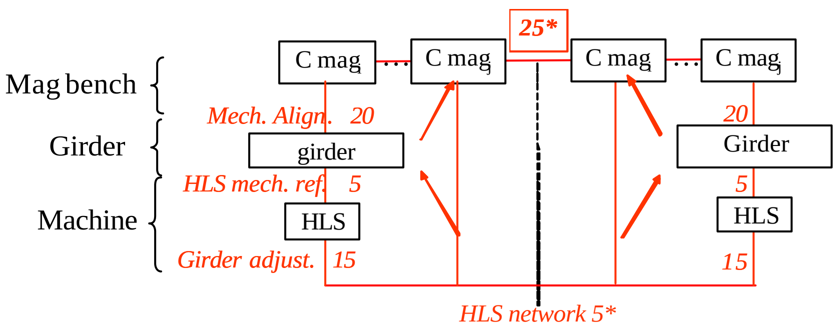
That configuration reduces the noise measurement due to water expansion in the connecting pipes. The long term test gives a value a little bit worse than to the previous one but we cannot attribute the difference to the connecting pipe modification.

9.3. Setting the HLS as an absolute vertical reference:

The HLS has been designed originally for a differential use: it is first, an inclinometer. We intend to use it as an absolute vertical reference in order to align the quadrupoles of the storage ring. For that, it is necessary to accurately measure the offset between the mechanical reference of the girder supporting the Qpoles and the electronic zero of the sensor. The following actions must be led:

- Manufacturing with accurate machining of the vessels
- Binding the vessels directly on the upper face of the girder that is a machined mechanical reference for the adjustment shims of the Qpoles.
- Ensure of the electronic stability of the sensor related to the mechanics. This last point seems to be easily realised (σ=3µm for 10 months): see the achieved results in the paragraph N°5.

Figure 19:Radial Vert. (1 s Z) Error budget: girder/girder



The fig. 19 shows the expected error budget by applying these precautions. The term corresponding to the HLS measurements (σ=5µm) is subject to long-term variation, due to slow drift. Therefore, the resulting 25µm value can vary along the year to about 30µm.

9.4. Infrastructure:

The thermal water expansion influences the measurement as the fluid free surface is not continuous (see par. N°3). Therefore, we propose a whole network in mono-tube configuration, included the connecting pipes.

The collecting pipe will have inner & outer diameters respectively equal to ϕ39 & ϕ45mm. The connecting pipes: ϕ19 & ϕ22mm. The whole network (pipes & vessels) will be realized in 316L stainless steel and connected together with fixed or flexible joins, depending on its location on the machine. A valve at both ends of the 16 cells should segment the whole storage ring to permit insertion device installation on the straight sections.

10. CONCLUSION:

As a conclusion, we would like to draw critics up from a long period of tests that have led for more than a year:

- Our test bench has to be improved by increasing the quality of the vessel binding on the concrete structure, including both, mechanics & sealing. We cannot really reach an estimation of the HLS accuracy better than few microns in terms of long-term stability.

- Height sensors should be better than five to define accurately the mean plane.

Nevertheless, the achieved results for 4 months (σ=5μm) is satisfactory because that figure includes the uncertainties due to our bench. The HLS installation on the storage ring is now starting. More investigations are planned for the 2005-year.

11. REFERENCES:

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