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# Heat dissipation tests on the titanium Junction Box of the ANTARES experiment

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## Abstract

The Junction Box is the part of the ANTARES project where the main electro optical cable from the shore is splitted into the 13 lines that power the detector strings. The different active components housed inside will produce a total amount of heat greater than 1 KW; it is therefore important to guarantee a good heat dissipation to avoid damages to the instrumentation due to local overheating. This report describes the test performed in our laboratory using the titanium box equipped with different heaters and submerged in a water bath at 15°C to simulate the real conditions. The results have defined the optimal configuration in order to guarantee a safe margin with respect to the maximum temperature allowed by the instrumentation; simulations performed with the FEA code show good agreement with the measured temperatures.

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## 1 INTRODUCTION

The aim of the international ANTARES (1) collaboration is the realization of an undersea detector to measure high-energy neutrinos. The detector, ready to take data starting from the year 2003, will be located on the bottom of the Mediterranean Sea at 2500 m depth, close to the town of Toulon in France (2). When completed, the effective area of the detector will be 0.1 $Km^2$, sufficient to measure fluxes of cosmic neutrinos. The configuration of the detector is shown in fig.1: 13 flexible strings support different optical modules (OM) to form an array of a total of 1000 PMTs to sense the Cherenkov light produced by the muons in the sea water. Starting from the bottom each string includes:

- a socket with the electro optical connection to anchor the string in the sea bed (BSS),
- 100 m of electro-mechanical cable,
- 30 segments each composed by a frame to support the three PMTs, a local control module (LCM) to house the read out electronics and 12 m of electro-mechanical cable,
- a top buoy to keep the string in the vertical position.

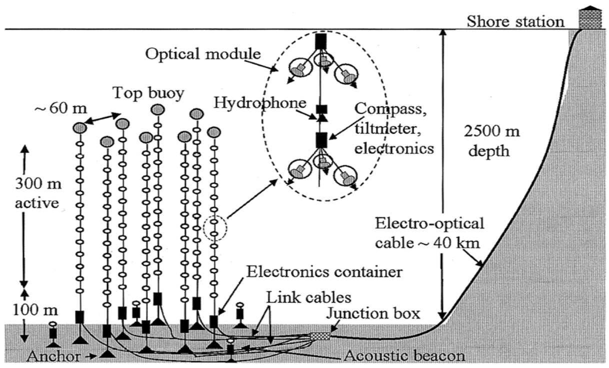


**FIG.1:** The ANTARES undersea detector

Each string is connected by an electro optical cable to a junction box (JB), which ensures the link to the shore station via a 40 Km long cable containing a 5 KV line and 24 optical fibers. The JB is an extremely important component: it represents, in fact, the ‘ single point failure’ of the apparatus and a possible malfunctioning would compromise the results of the experiment. The JB, shown in fig. 2, is composed by a container and a frame for support and handling. The design and the realization of the JB have been performed by our group, using two titanium hemispheres provided from the Moscow University collaborators. The volume inside the two hemispheres was found to be largely insufficient to house the required instrumentation and cable connections (penetrators): the final design includes therefore a specially-machined titanium spacer, the two hemispheres, a small box for the plug-in of the main cable and a large number of seals; a detailed description of the mechanical executive design can be found in ref (3).

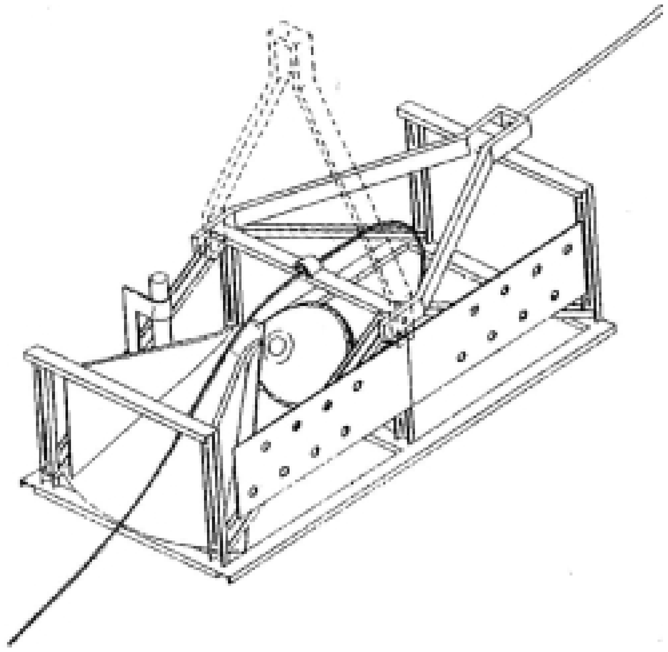

**FIG. 2:** The Junction Box and the frame.

The JB will contain different items including a transformer to lower the 5 KV AC from the shore down to 1 KV AC and 25 V DC, the splitter to power the 13 strings with the possibility to switch off a single line, different optical connections for data transmission and multiplexing, an intelligent unit to drive the slow controls and to generate a fast trigger to the DAQ. For the purpose of this note, the main issue is the total amount of power dissipated by these components (see table 1): 900 mW by the transformer and 250 mW by the other elements.
The JB is expected to continuously operate for a nominal 10-year period and consequently any local overheating of the electronics should be carefully avoided. We have therefore decided to perform some measurements on the heat transmission using the JB in the configuration described in section 2; the results of these tests confirm that the total power listed in table 1 can be safely dissipated provided that the geometrical configuration where the main transformer is located in the top region of the JB is chosen. These results have been successfully compared with the simulations of the FEA program, as discussed in section 3.

**TAB. 1**

| **designation** | **quantity** | **total dissipation (W)** |
|---|---|---|
| *main transformer* | 1 | 1000 |
| *clock+ROR module* | 1 | 10 |
| *output breaker* | 7 | 50 |
| *output breaker/switch* | 16 | 50 |
| *low voltage supply* | 1 | 50 |
| *JB control module* | 1 | 50 |
| *timed relay* | 2 | 2 |
| *short mode relay* | 1 | 2 |

## 2 THE EXPERIMENTAL APPARATUS AND THE MEASUREMENTS.

The JB in its final configuration will be mounted by October 2000 since the titanium spacer needs a dedicated time to be produced and machined while the inner components are expected to come a bit later. We therefore decided to start our test for heat dissipation using the JB in its simplest configuration where the two available hemispheres are separated by a stainless disk to generate two regions: region A to house the transformer and region B for the electronics. The general layout of the apparatus which has been mounted in our laboratory in Genova is shown in fig 3 and includes:

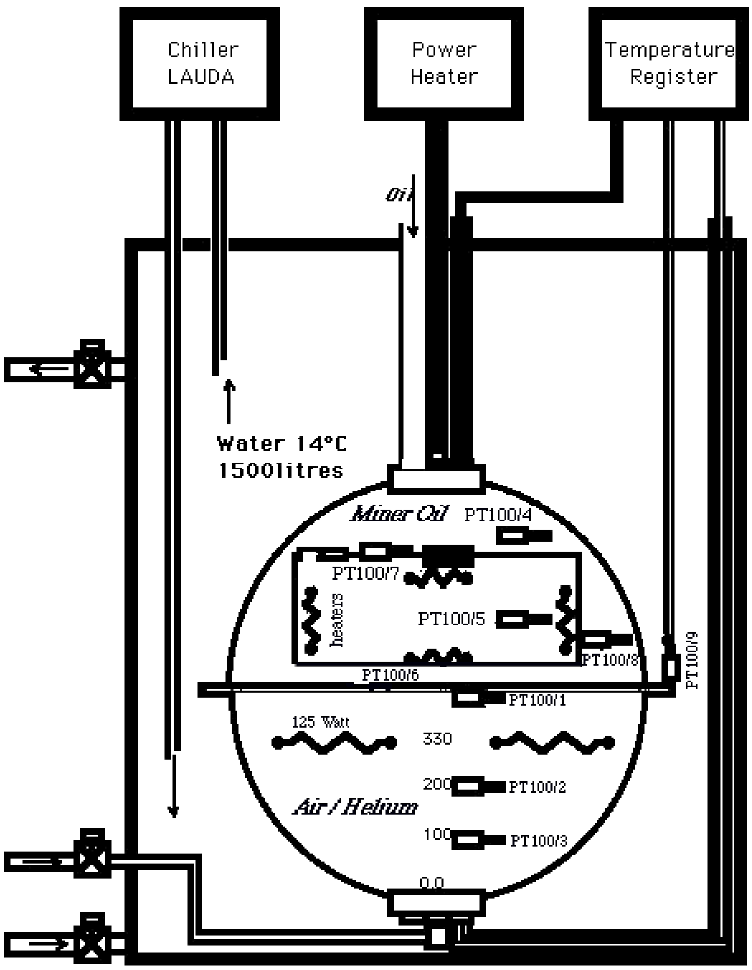


**FIG. 3:** The experimental apparatus for the test.

- a box of 30x30x50 cm made by a 0.3 cm thick copper sheet with dimension very close to the real transformer. Six flat heater resistors of dimension 2x20x0.1 cm are located in the inner part of each side of the box; each resistor is supplied with 250 V AC to give a power of 150 mW: the total amount of heat released in the box is therefore 900 mW as in the 40 KVA transformer. The box is fixed by a support at 5 cm from the disk; this clearance is necessary to insulate the transformer from metallic components surrounding it. Both the inner part of the box and the volume of region are filled with 100 liters of mineral oil (Total Fina "Diekan1640") using an external tube connected to one on the three holes already present in the top of the hemisphere. The remaining two holes are used for exhaust and to power the heaters;

- a stainless disk of 80 cm diameter and 1.5 cm thickness to separate the two regions. The disk is sandwiched between the 2.5cm large flanges present in the hemispheres. Only the flange of region A has a slot carved on it: to ensure sealing we used an o-ring while glue was used for region B;
- two cylindrical heaters 1cm diameter, 20 cm length located in region B. The heaters are located in the central region with a support fixed on the disk and produce 250 mW to simulate the heat from the electronics of table 1. Region B is filled with air at atmospheric pressure; however a tube connects this region with a pumping system located outside, which can be used to make a low vacuum before filling with another gas.

In order to be able to monitor the temperature at different locations, 8 platinum resistors are located in the system as shown in fig. 3: 3 in the oil bath (PT6,PT8,PT4), 1 on the surface(PT7) and 1 in the inner part of the copper box(PT5), 2 in the air region B(PT2, PT3) and 1 on the stainless disk (PT1). The sensors (PT100 mod) are read out by an Ascon controller mod. MLM-8/33, which scans up to 8 different channels.

The JB was located in the middle of a big cylindrical tank containing 1500 liters of tab water maintained at constant temperature in the range 14 +/- 1.5°C by a chiller. The same temperature was measured in the seawater at 2500 m depth in the location where the JB will be positioned: we are therefore confident to realistically simulate the real conditions of the experiment.

When all the parts of the system had reached the temperature of the water, we switched on the power and recorded the 8 temperatures in 5-30 minutes intervals up to the equilibrium value. This procedure was repeated in three different conditions:

(a) the transformer is in the upper region ; region B is filled with air at 1 atm

(b) the transformer is in the lower region; region B is filled with air at 1 atm

(c) the transformer is in the lower region; region B is filled with helium at 1 atm

The temperature $T_n$ of the n-th sensor was fitted as a function of the time (t) from the initial temperature $T_0$=14 °C, using the following expression:

$$T_n=T_e-(T_e-T_0)\, e^{-t/A} \qquad (1)$$

where $T_e$ and A are free parameters representing, respectively, the final temperature and the half time needed to reach it. The values of $T_e$ and A for the (a), (b) and (c) conditions are listed in table 2.

**TAB. 2**

| **sensors** | **PT1** | **PT2** | **PT3** | **PT4** | **PT5** | **PT6** | **PT7** | **PT8** |
|---|---|---|---|---|---|---|---|---|
| *Te (a)* | 36 | 30 | 30 | 39 | 58 | 28 | 49 | 34 |
| *A (a)* | 18 | 12 | 10 | 70 | 88 | 90 | 30 | 92 |
| *Te (b)* | 55 | 42 | 42 | 17 | 70 | 57 | 54 | 42 |
| *A (b)* | 70 | 12 | 11 | | 74 | 73 | 41 | 100 |
| *Te (c)* | 50 | 35 | 32 | 17 | 73 | 60 | 55 | 44 |
| *A (c)* | 125 | 8 | 18 | | 100 | 96 | 53 | 145 |

The fit is generally good as shown in the example of fig 4.

These results clearly indicate that in condition (a) where the transformer is in the upper region of the JB the heat exchange with respect to the water is optimized and the temperature of both the oil and air are minimized. Indeed we tested also conditions (b) since this

geometry would avoid possible oil leakage from the transformer to the electronics in the lower region. However, the values obtained in (b) are too close to the limit allowed by the instrumentation: 65°C for the transformer, 40°C for the optic fiber in region B and 40°C for the switches. An improvement is obtained in condition (c) where the helium is used to improve the thermal exchange with the titanium shell.
Of course the two heaters in region B are only a crude approximation of the real electronic configuration; in particular, being our empty volume much higher than the real conditions, it might be possible that our results for conditions (b) and (c) are optimistic; moreover it is not know the effect of the use of helium gas in electronic devices for a long period . All these considerations support our decision to choose configuration (a) for the JB; of course a lot of attention will be paid for the design and choice of the feed through to be located in the separation disk to allow the transmission of the voltage and anode cable connected to the transformer.

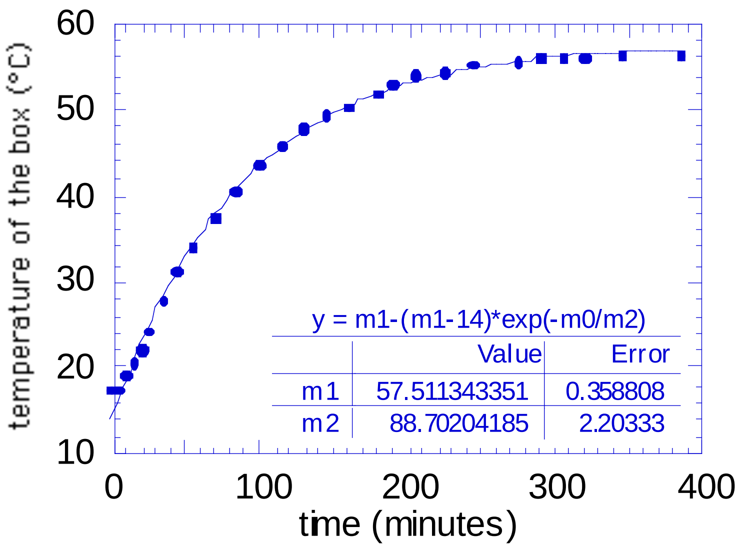


**FIG. 4:** The fit of the temperature in the copper box in condition (a) as a function of time.

## 3 THE SIMULATIONS

In our simulation base on the FEA fluodynamic computational model we considered a two dimensional symmetric model of the Junction Box.
We simulated the convective motion of the dielectric oil in two different layouts:

- transformer and dielectric oil in the upper compartment of the JB,
- transformer and dielectric oil in the lower compartment of the JB,

taking into account the characteristic of a standard dielectric oil for electric transformers and their variations with temperature as shown in the table below:

| **Temperature [°C]** | **Density [Kg / $m^3$]** | **Viscosity [$m^2$ / s]** | **Thermal conductivity [W / m °C]** | **Specific Heat [J / Kg °C]** |
|---|---|---|---|---|
| 0 | 890.0097 | 0.09 | 0.145 | 1080.352 |
| 20 | 889.9968 | 0.03 | 0.143 | 1996.500 |
| 50 | 889.9774 | 0.01 | 0.1401 | 1996.722 |
| 100 | 889.9452 | 0.003 | 0.136 | 2185.092 |
| 150 | 889.9129 | | 0.131 | 2373.462 |
| 200 | 889.8807 | | 0.126 | 2561.832 |

In the simulation we took into account the empty volume in the upper compartment of the JB. We then found the velocity and temperature distribution of the fluid inside the vessel (see fig. 7,8); the results of the simulation showed that:

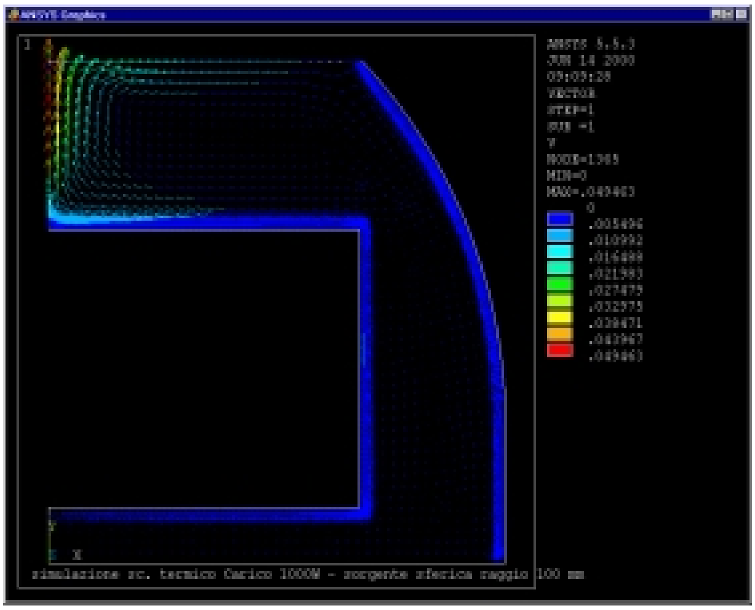

**FIG. 5:** Velocity distribution [m/s] of the oil inside the vessel – oil in the upper hemisphere.

- The transformer and the dielectric oil in the upper hemisphere of the JB is the best layout for power and temperature dissipation; the maximum temperatures calculated on the surface of the transformer in the two layouts are 44°C and 73°C respectively.
- The heat is easily drained out through the walls of the Junction Box.

As transformers are usually expected to operated in the range 70-80°C, both layouts look to be satisfactory; although a lower temperature profile is always preferable.

The temperature of the surface below the transformer didn't rise more than 10°C above the external wall temperature; as heat (around 200 W) is dissipated also in the electronics compartment, we don't expect the temperature on that compartment to be below 25°C; then the heat transfer from the transformer to the electronics compartment shouldn't be very important.

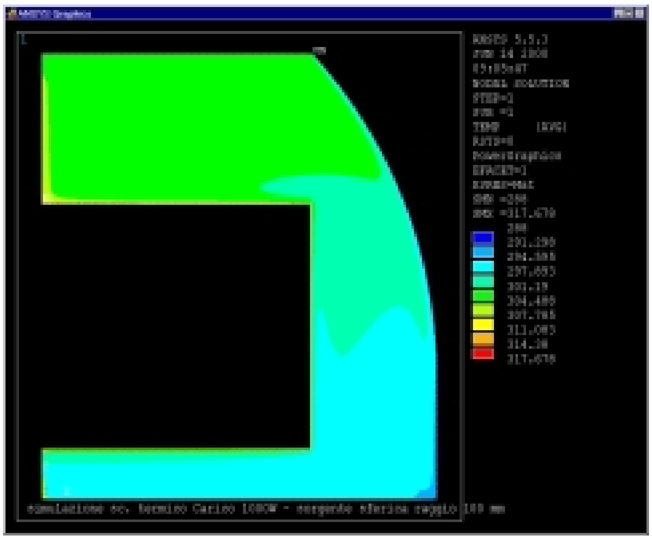

**FIG. 6:** Temperature distribution [K] of the oil inside the vessel – oil in the upper hemisphere.

Nevertheless, the heat dissipation in the electronics compartment is not a negligible matter, as reliability reasons strongly suggest not to trespass the commonly accepted upper value of 50°C of environmental temperature. As the layout in that volume hasn't been fixed yet, we couldn't simulate accurately enough the thermal distribution and the fluid motion there. The first results just showed the heavy influence of the layout of the components that should be studied in order to help the gas circulation, as well as the opportunity to foresee thermal bridges and shields. A forced cooling system, though greatly beneficial, wouldn't be advisable from the reliability point of view and should be considered as a last chance.
The measurements made in the Genoa Lab on a real scale system validated the model.

## 4 REFERENCES

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