Fast foldable tent domes

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ABSTRACT

In the near future ELTs (Extreme Large Telescopes) will be built. Preferably these telescopes should operate without obstructions in the near surrounding to reach optimal seeing conditions and avoid large turbulences with wind-gust accelerations around large obstacles. This applies also to future large solar telescopes. At present two foldable dome prototypes have been built on the Canary Islands: the Dutch Open Telescope (DOT, La Palma) and the GREGOR Telescope (Tenerife), having a diameter of 7 and 9 meter, respectively. The domes are usually fully retracted during observations. The research consists of measurements on the two domes. New camera systems are developed and placed inside the domes for precise dome deformation measurements within 0.1 mm over the whole dome size. Simultaneously, a variety of wind-speed and -direction sensors measure the wind field around the dome. In addition, fast sensitive air-pressure sensors placed on the supporting bows measure the wind pressure. The aim is to predict accurately the expected forces and deformations on up-scaled, fully retractable domes to make their construction more economically. The dimensions of 7 and 9 meter are large enough for realistic on-site tests in gusty wind and will give much more information than wind tunnel experiments.

Keywords: foldable tent domes, wind field measurements, wind load, deformation measurements of large structures, optical displacement sensors, three-dimensional displacement sensors

1. INTRODUCTION

The fast foldable dome design consists of two electrically actuated steel bows (the grey frame-work bows in fig. 1). To create an arc shaped form and allow a higher closing wind-speed limit (up to 25 m/s) additional bows are added (the red and green single bows in fig. 1). Between the bows cloth is tensioned if the dome is closed. The cloth has a saddle shape form after tensioning. Due to the saddle shape there is in every direction a pulling force, giving a strong foldable dome structure to withstand storm conditions. The 9-meter dome on Tenerife survived a recorded wind speed of 68m/s (1-minute average) during the storm Delta on 28-11-2005. A more extensive description with technical details of the design of the foldable tent domes is given in ref[1].

When the dome is retracted the telescope is standing free in the surrounding area. On the one hand, the telescope and main mirror must be stiff enough to withstand the wind pressure. On the other hand, temperature fluctuations of the air around the main mirror are minor. The open principle applied to solar telescopes is explained in ref[2] and references therein.

In the next section the development of a three-dimensional sensor to measure the bow and cloth deformations of the dome is described. Section 3 gives more details about instruments for wind measurements to support the 3-D sensor data. The pressure sensor units are described in section 4. In section 5 we summarize our conclusions and comment on future work.

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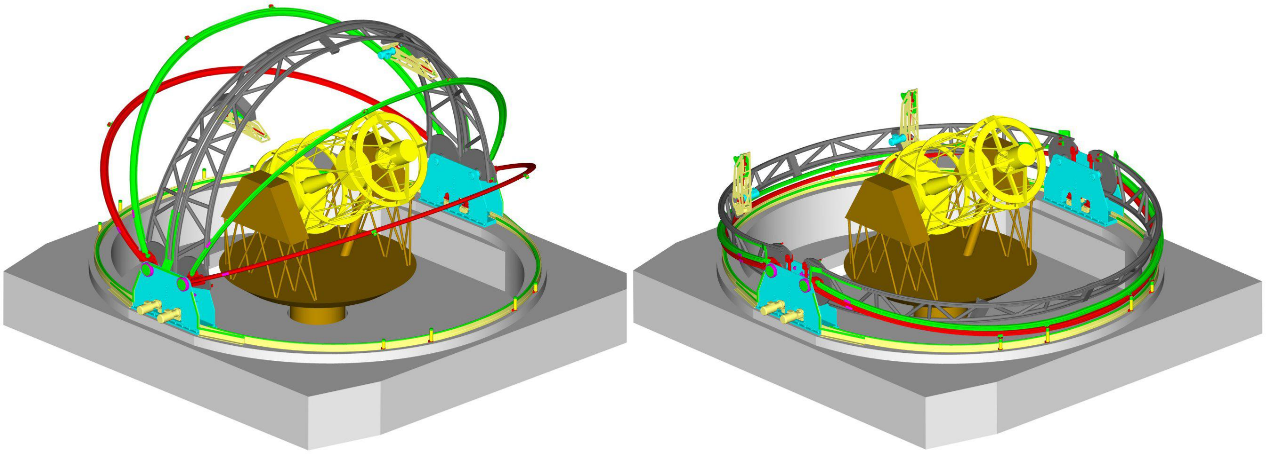

Fig. 1. Dome sketch around the GREGOR telescope: closed at left, open at right.

2. THREE-DIMENSIONAL DOME DISPLACEMENT SENSOR (3DD3)

The deformation of domes, even due to high wind speeds, is small. In order to get suitable information we can measure the displacements of several points on the bows and cloth of the dome relative to the stiff dome floor and later convert these displacements back into the general deformation of the dome.

Measurements at domes of telescopes need to overcome some obstacles. Because the telescopes are used for astronomical observations, the deformation measurements are not allowed to interfere with these observations. As a consequence, the measurement units should not obstruct the use of the telescope. Also, because the dome must be able to open completely, a measurement unit cannot be placed too close to the dome. For this reason it is not possible to use tripods with a contact measurement unit.

For contactless displacement measurements a laser distance sensor is a readily available measurement device. Although these devices can have a very good resolution when pointed at a (nearly) flat surface, they can only detect movement perpendicular to the plane of the surface. For the case of three-dimensional measurements at distances of up to 8 meters with a resolution of less than 0.1 mm, no commercial devices are available.

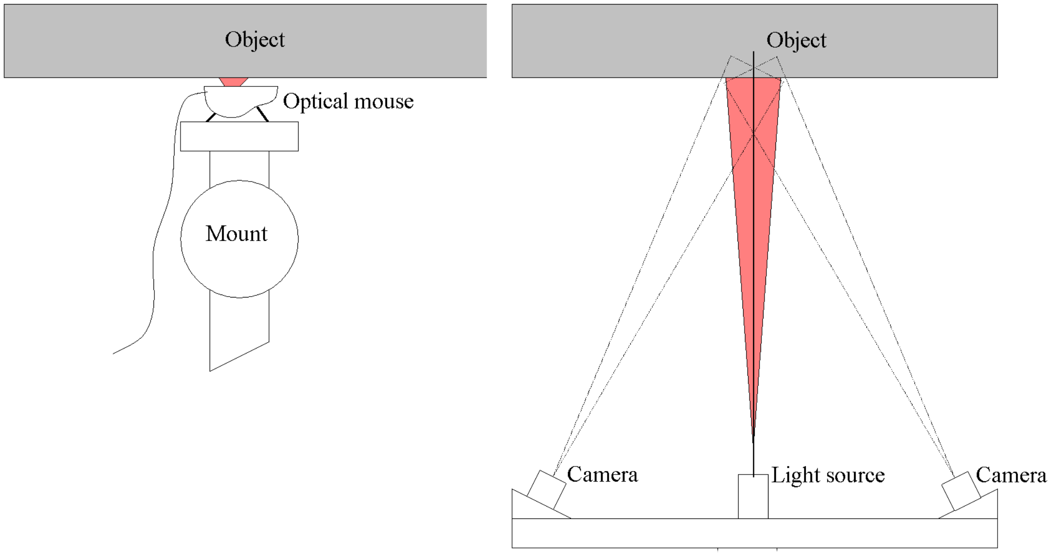

Fig. 2. Principle of the deformation measurements.

We developed a three-dimensional measurement unit (3DD3) for bow and cloth deformations of retractable domes. The working principle is as follows. The unit works in a similar way as an optical computer mouse. In fig. 2 on the left an optical mouse is shown, which can measure translations in 2 dimensions. A highly stable mount has to support the mouse. On the right of fig. 2 a distant camera images the light spot region of the object. Translations in 2 dimensions perpendicular to the line of sight are measured using correlation techniques similar to the mouse technology. With two cameras a stereo system is formed and the object translations of the spot region can be calculated in three dimensions.

The actual unit consists of two Firewire cameras, one LED, three lenses and three flat mirrors (see fig. 3). The lenses (L1 and L2) can be exchanged to obtain a longer or shorter focal distance. The function of the adjustable mirrors (M1 and M2) is to make compact flat units. Each camera (C1 and C2) has its own lens and mirror, as does the LED (S). Each camera measures the in-plane displacement of the target. Because the two cameras of one unit look at the target under different angles, stereo decomposition can be used to determine the out-of-plane displacement as well. Specifications for these units are given in table 1.

The unit has been designed to be placed on the floor instead of on a mount, so less space is needed and it has the additional advantage to be more stable. This allows us to place multiple units inside a telescope dome without interfering with its operations. An additional option is to place the units under the dome floor with holes for the light beams, leaving more floor space free. This option will be used at the GREGOR telescope, see the end of section 2.2.

Table 1. Specifications for the 3DD3 units.

	3DD3 unit
magnification	about 10 between camera and target plane by choice of focal length of lens
in-plane measuring accuracy	1/10 pixel = 5.6 micrometer at target in case of magnification 10
out-of-plane measuring accuracy	88 micrometer at 5 m distance of target and magnification 10
light source	LED (622 nm)
camera	Unibrain Fire-I
CCD dimension	640 x 480 pixels (pixel size 5.6 x 5.6 micrometer)
overall dimensions (LxWxH)	1200mm x 100mm x 300mm

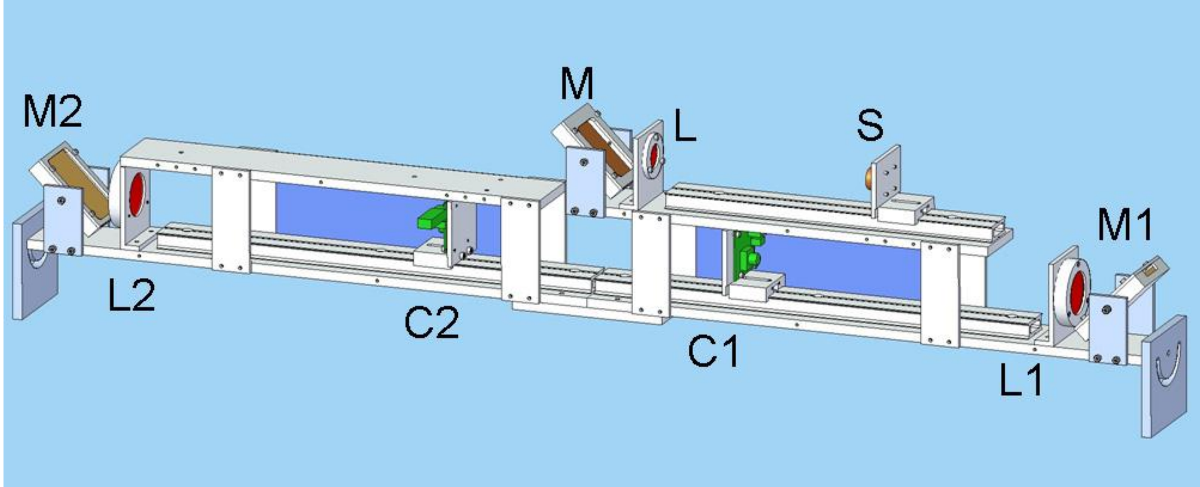

Fig. 3. Design of the 3DD3 units, version Mk3.

2.1 Data Processing 3DD3

The raw images from the cameras of the 3DD3 units are processed by small form-factor computers, so-called 'Barebones' (see fig. 4). Software has been written that uses Fourier transformations to pre-process the images and to calculate the correlation function. The correlation function on its turn is used to calculate the displacement. Each computer is powerful enough to process the images of four cameras running at 15 frames per second in real time, reducing a data stream of 17 MB/sec to 0.5 kB/sec. The cameras have a maximum speed of 30 frames per second, which needs one computer for each two cameras. A series of lower speeds can be used, including the 15 frames, which is fast enough for the foldable dome application. More information about the data processing is given in ref[3].

Fig. 4. Barebone computers on the platform for the data processing of the 3DD3 units. Two of these computers are visible in vertical position on the platform floor in the space under the cabinet at left.

2.2 Deployment

At the moment seven prototype units are installed at the DOT (see fig. 5) and the aim is to use at least three measuring points per bow. With three points per bow it will be possible to determine its deformation and consequently also the stress in the bow. If we combine the data from several bows it will be possible to determine the stresses in the cloth.

The seven units manufactured in the first series are used to do first tests with 3D dome measurements. The results are very good and show a clear correlation with the wind load on the dome.[3] We experienced that the powder-coating paint shows a too small structure to be used for target points. Instead we fixed with tape small sheets with a random pattern to the bows, see fig. 6. The cloth on its turn shows enough pattern to be used as target.

Furthermore, we found that the displacement measurements using correlation techniques are precise to such a degree that the maximum needed focal length of the lenses certainly is not more than 500 mm. This made the way free for a new design of the 3DD3 units (3DD3, version Mk3, see fig. 3), which is much more slender than the one used before at DOT. Currently 20 units of the Mk3 design have been manufactured and will be installed at the GREGOR telescope.

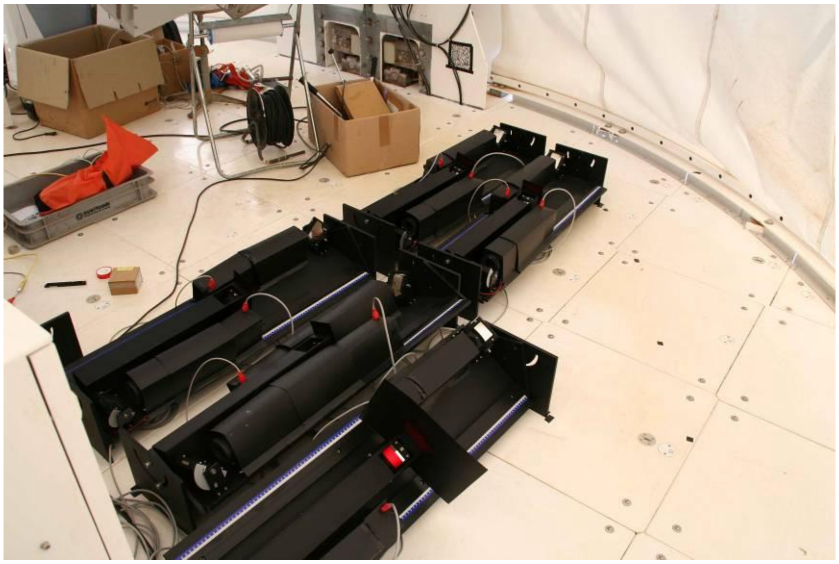

Fig. 5. 3DD3 prototype units on the DOT platform. In this photo 5 units are visible.

Fig. 6. Left: Measuring activity on the platform. 2 target points on a bow are visible.
Right: Close-up of target point with light spot.

3. WIND MEASUREMENTS

To verify the 3DD3 measurement data, actual data from the wind field and wind direction around the telescope must be obtained. On the fence of the telescope platform wind vanes and rotating cups are installed, see figs. 7 and 8. They are installed on the height of the main mirror, thus it is possible to get data from the wind flow around the main mirror when the dome is open and the telescope is pointed to the sun. Also on the top of the dome a wind vane and rotating cups are mounted. In this way it is possible to determine the wind flow around the dome and compare it with the data from several 3DD3 units. PC104 computers process the data of the wind measurements. All the electric cables of the wind devices go to a connection enclosure under the platform (see fig. 9).

Table 2. Specifications for the anemometers.

	simple anemometer	**advanced anemometer**
operating range	0 - 30 m/s	0 - 75 m/s
resolution	0.07 m wind run	0.04 m wind run
inaccuracy	< 0.9 m/s	< 0.8 m/s
measuring principle	optical 12 pulses	digital (analog output)
heating	no	internal heater
overall dimensions (HeightxDiameter)	85mm x 120mm	265mm x 150mm

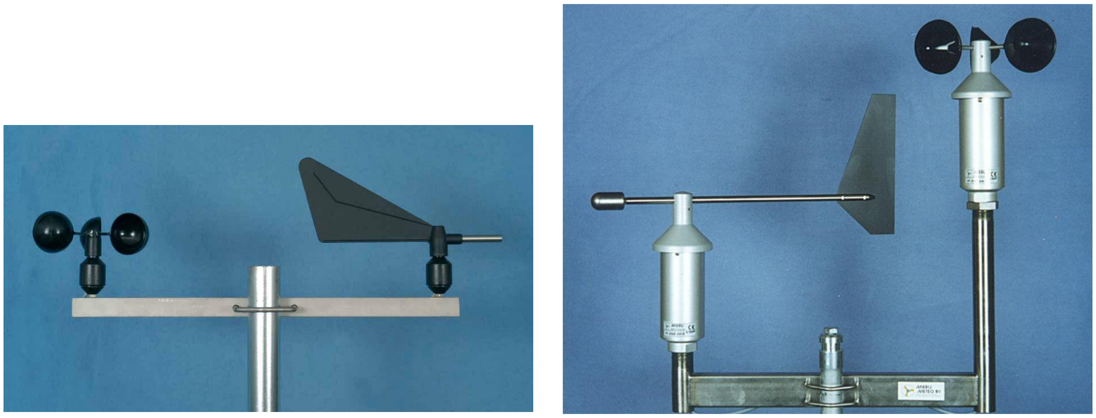

Fig. 7. Left: low cost anemometer (cups) and vane. Right: heated advanced anemometer (cups) and vane.

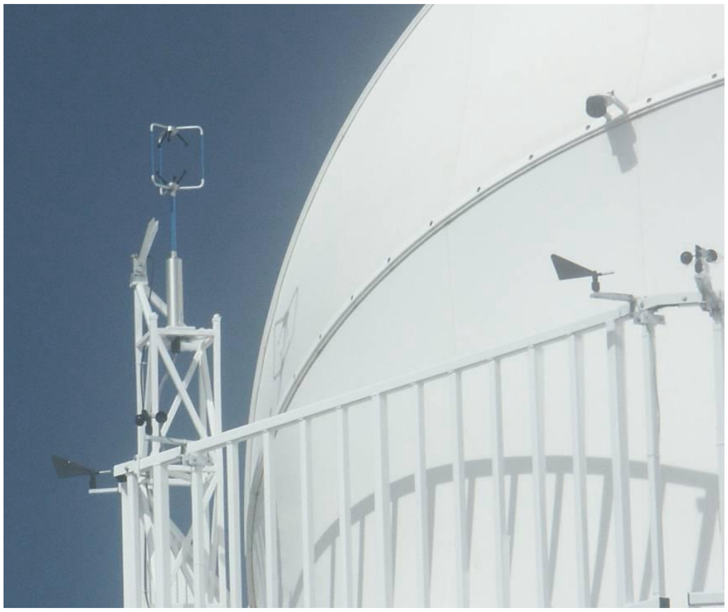

Fig. 8. 3D ultrasonic anemometer and 2 of the 8 small-size setups of cups and vane.

The advanced cups and vane are mechanically more robust and have an incorporated heating, which guarantees operation in case of frost. However, the simple cups and vane have a faster response and up till now also functioned without problems in high wind. Tables 2 and 3 show the specifications for both simple and advanced anemometers and vanes, while the ultrasonic anemometer is specified in table 4.

Table 3. Specifications for the vanes.

	simple vane	**advanced vane**
operating range	0 - 360 degrees	0 - 360 degrees
resolution	22.5 degrees	5.6 degrees
inaccuracy		< 3.8 degrees
measuring principle	optical (4 bit Gray-code)	digital (analog output)
heating	no	internal heater
overall dimensions (LxWxH)	155mm x 28mm x 120mm	370mm x 53mm x 265mm

Table 4. Specifications for the 3D ultrasonic anemometer.

	3D ultrasonic anemometer
direction operating range	0 - 360 degrees
wind speed operating range	0 - 45 m/s
direction resolution	1 degree
wind speed resolution	0.01 m/s
measuring principle	digital (analog output)
overall dimensions (HeightxDiameter)	750mm x 240mm

Fig. 9. Anemometer (cups) and vane connection box mounted under the platform floor of the open DOT tower. When closed, the inside of the box is protected against the heavy weather situations of storm combined with rain, snow or ice.

In March 2008 measurements at the DOT were started. Fig. 10 shows a scheme of the setup of the 3DD3 units and wind sensors on the DOT platform. As already mentioned in section 2.2, the results show a clear correlation between the measured dome deformations and the wind field. The results are presented in ref[3].

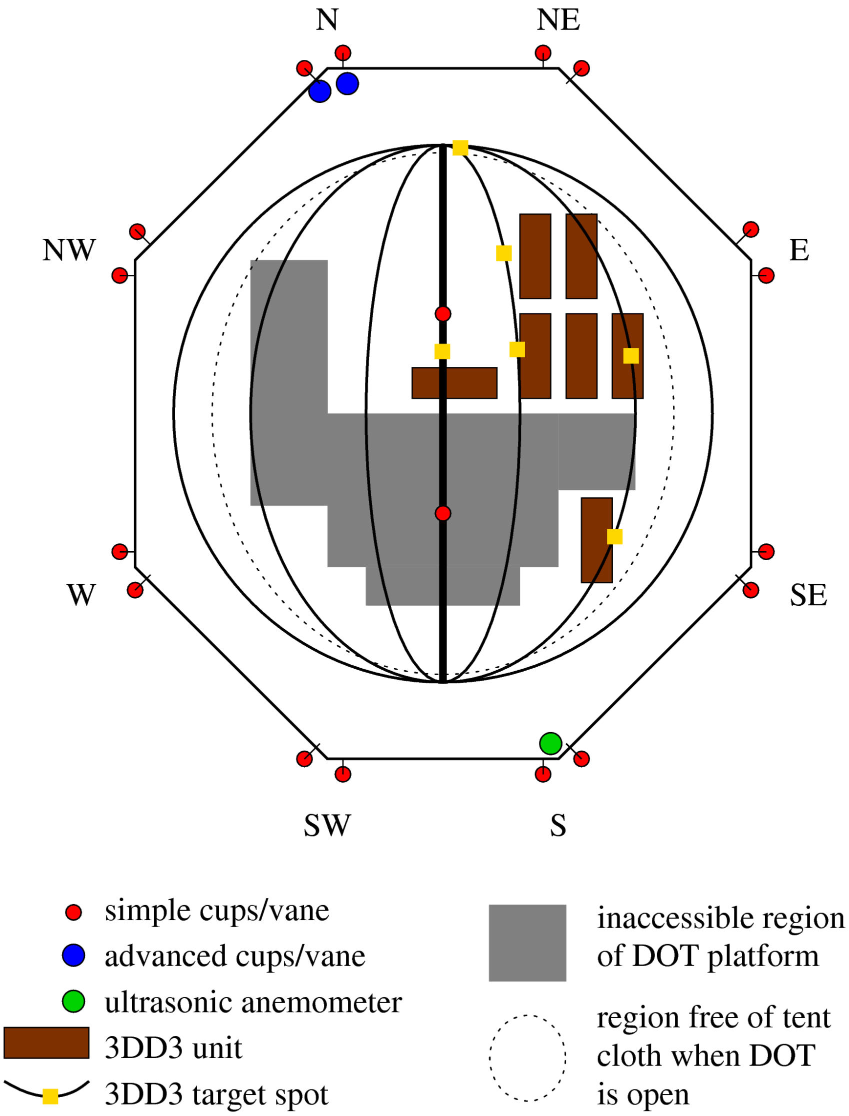

Fig. 10. Schematic overview of the initial setup of the 3DD3 units and wind sensors on and around the DOT at the time of the measurements. In the overview, the bows of the DOT dome are solid lines. When the dome is completely opened, part of the tent cloth lies folded on the inside of the platform; this is denoted by the dashed line. The elevator, staircase, telescope mount and various equipment boxes occupy parts of the floor that are for this reason not available for 3DD3 units (the grey areas in the overview). Also, some parts are less suitable for the placement of 3DD3 units. The brown rectangles denote the positions of the 3DD3 units that we placed inside the dome. The yellow squares denote the spots on the bows where the 3DD3 units currently look at. The placement of 3DD3 units will be changed in the future. The coloured circles denote the locations of the various wind sensors that were installed.

4. PRESSURE SENSORS

In principle, the wind load on the dome can be calculated from the measured wind field and the geometrical shape of the dome. However, there remain uncertainties in these calculations and moreover, wind load can depend on non-obvious geometrical details. Fast sensitive air-pressure measurements on the outside surface of the dome would be a valuable addition for reliable calculations of the wind load on the dome. We are developing a pressure sensor unit, which can be mounted on the steel bows.

Basic element of the unit is a commercial differential-pressure sensor, which consists of a small piezo-electric membrane, see table 5 for specifications. Fig. 11 shows how the sensor element (P) is built in an elongated aerodynamically shaped house. It consists of a cover that is bolted and sealed with an O-ring to a base plate, which on its turn is bolted to a steel bow of the dome or to another interesting place. The pressure element has two small inlet tubes for air to the two sides of the membrane. One inlet tube is connected with a curved tube, which ends in the open air at the centre of the top surface of the house cover. The second inlet tube ends directly in the closed chamber inside the house. Compared to the air displacement of the membrane, this chamber is large enough to form a constant air-pressure reference against which the fast pressure changes caused by wind gusts at the open air inlet are measured.

Table 5. Specifications for the pressure sensors.

	pressure sensor
sensor element	Honeywell differential microstructure 0 psi to 1 psi
burst pressure	5 psi
response time	8 ms
measuring principle	calibrated and temperature compensated output
unit dimensions (LxWxH)	200mm x 40mm x 30mm

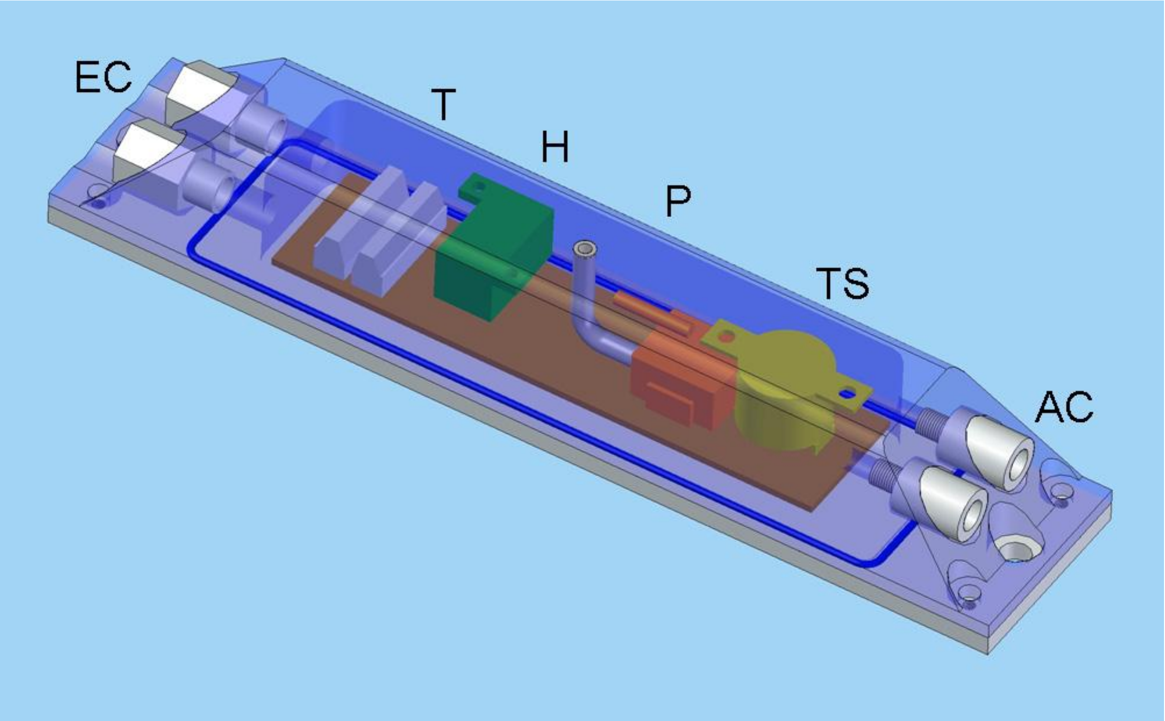

Fig. 11. Design of a pressure sensor unit, which will be placed on the steel bow of the dome.

Several units are planned on a dome bow. Small tubes connect the chambers of the units with each other. The openings at the edges of the units (indicated AC in fig. 11) are used for this connection. Openings not in use are closed with stops. In addition, there are tube connections via the ends of the bows to a central chamber near the floor of the dome. This central chamber has to the outside air an opening, which is protected against wind catch. This system prevents influence of the general air-pressure changes on the measurements.

We did not choose for direct measurements of the air-pressure difference between the outside and inside of the dome with holes through the cloth or bows, because problems would arise when the dome opens and the cloth folds together between the bows. Moreover, such holes are not conducive to the strength: these domes are designed to survive heavy storms on mountaintops, where wind speeds of 68 m/sec are already measured.

Each sensor is electrically wired by means of a terminal block (T). The electrical cables are going through openings (EC) that also have air-closing seals. The openings at the ends of the lids have interchangeable functions: an opening can be used for an air connection (AC) or for an electrical connection (EC). Inside each chamber is a small electric heat element (H) and a temperature switch (TS), which switches the heat element on in case of frost with danger of ice formation at the opening to the outside on the cover of the house. In this way, the pressure sensor will also work during snow and ice periods.

The aim is to place 3-5 pressure sensors per bow. The DOT and GREGOR dome each consist of 5 bows and 15-25 measuring point should be sufficient to map the pressure behaviour of the dome. The data coming from the sensors are handled by a PC104 computer.

5. CONCLUSIONS AND FUTURE WORK

The importance of the search for domes suitable for large new-generation telescopes is significant. Fully retractable domes are attractive because of the option to leave the telescope completely open without obstructions in the near surroundings. This leads to optimal seeing conditions: no large turbulences with wind-gust accelerations around nearby objects and minimal thermal disturbance of the air around the telescope.

The completely and fast-foldable dome construction based on strongly tensioned saddle-shaped cloth is a realistic large-size candidate. It is light weight, fast foldable at strong wind and it does not require costly provisions on building, support tower or foundation when directly placed on the ground.

For the near-future ELTs it will be necessary to be able to predict dome behaviour using accurate simulations for stress, strain, deformations, etc. In this paper and the related paper[3] a first, yet very important, step is made: the development of the required measuring equipment for on-site comprehensive measurements on real domes in different situations, e.g. in heavy storm when closed, the opening and closing in the heaviest wind situations for observations, during observations combined with seeing measurements.

Comparison of these measurements with numerical calculations and simulations will test the value of the existing calculation methods. This will lead to improvements and new developments of these methods, together with an adaptation to the complicate case of a combination of movable steel frame work with tensioned cloth.

At the moment research is being done concerning available FEA software. It is important that the software will be able to perform mechanical analyses, CFD and easy exchange between CAD software and FEA software. We think of two steps in the approach:

1. Commercial software, which for the user appears as a black-box toolbox, but which can give relatively quickly results and can serve well as a first test.
2. Development of modules or code by ourselves, which can handle specific problems and from which we fully understand how it works.

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