Success of long term preventive maintenance on telescope subsystems using the example of the VLT Adapter-Rotators at the ESO Paranal Observatory

F. Salgado* , J.Haddad, G.Hudepohl, R.Medina
European Southern Observatory, Paranal, Chile.

ABSTRACT

More than 11 years have passed, since the first of the four Unit Telescopes of the VLT on Cerro Paranal has entered into operations. To keep four such complex telecopes at a high level of availability with only around 3 percent of technical down time does not only depend on a good and robust design and manufacturing process, but long term also on a sound preventive maintenance plan and program.

In this paper the Instrument Adapter-Rotators, twelve of which are installed at the observatory, have been chosen to show how a preventive maintenance plan has been developed, implemented and executed and what the results are.

In the first part the most common problems are shown and some larger interventions are described and listed. It explains the tests that have been developed to follow the status of the systems by measuring key parameters such as position error, motor current, torque and encoders status in order to detect at an early stage any degradation in performance parameters.

Depending on the test results preventive actions can be planned well ahead of serious failures, making optimum use of scheduled technical time periods and consequently reducing loss of observing time.

Finally some statistic charts show how problems have been reduced as a result of the preventive maintenance plan

Keywords: Preventive maintenance, Corrective maintenance, engineering experience, Adapter rotator.

1. INTRODUCTION

The ESO Very Large Telescope consists of an array of four 8-meter Unit Telescopes, each of which has two Nasmyth foci and a Cassegrain focus. Each focus is equipped with an adapter rotator, resulting in 12 units, which forms the mechanical interface between the telescope and the scientific instruments. [1]

The adapter rotators provide several key functions for the operation of the VLT, including field acquisition and guiding, wave front sensing, and instrument rotation.

1.1 Adapter rotator and its subsystems

The following pictures show the adapter rotator in Nasmyth and Cassegrain focus

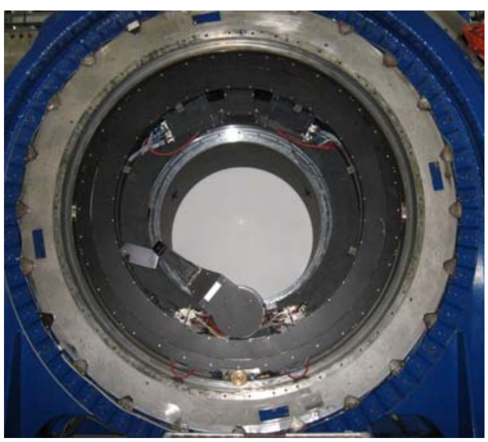

Figure 1. Nasmyth adapter rotator.

The Adapter Rotator includes the following subsystems:

-Rotator: where the scientific instrument is installed, 8 units installed in Nasmyth and 4 in Cassegrain focus..

-Adapter: where the Sensor arm is installed including the aceboxes, counterweight, cablewrap, 8 units in Nasmyth and 4 in Cassegrain focus.

-Sensor arm : Comprises a Turntable, a Supporting Arm, a Focusing Device, a Reference System and an Optical System. Autoguider and Image analysis technical cameras (TCCDs)

Following subsystems are just available in Nasmyth focus, and have been used in side A.

-FNFD (Folded Nasmyth Focus device): Provides the needed tools for Coude beam alignment.

-M4 device: it is a tower used in Nasmyth focus where a mirror bends the light coming from telescope to Coudé focus, for VLTI.

As the telescope field rotates during an observation, the scientific instrument attached to the telescope as well as the Adapter itself must be rotated at the same speed to allow compensation. The angular speed of this field rotation varies according to the position of the observed object in the sky. During observations, the Instrument Rotator (and the instrument attached to it), as well as the Adapter, must rotate at the same speed to compensate for the motion. During this mode of operation the Adapter and Rotator are effectively (although not physically) locked together. During the acquisition phase, however, the Instrument Rotator, the Adapter and the Sensor-Arm can all be moved independently of each another.

1.2 Field Acquisition and Guiding

Before starting an astronomical observation, the telescope control system will point the telescope towards the astronomical object of interest. The Adapter acquisition/guide CCD sensor, located in the Adapter sensor-arm, can be used to view the central part of the telescope field to provide visual identification of the object to be observed. This function is referred to as acquisition.

During the course of the observation the position of the object in the telescope focal plane must be maintained with a high degree of accuracy. To achieve this a reference star close to the object being observed to provide a reference position. The Adapter acquisition/guide sensor continually measures the position of the reference star and any position error detected is passed to the Telescope Control System (TCS) for correction. This function is referred to as guiding.

1.3 Wave front sensing

As the primary mirror of the telescope is relatively thin, the optical quality can be degraded by the changing gravitational flexure during observations as well as by other slow effects such as thermal gradients. In order to allow the correction of these optical errors, a second CCD sensor in the sensor arm measures the shape of the wave front reaching the focal plane. This wave front sensor detects the light of the same reference star used for guiding through an optical system which splits the pupil image of the telescope into an array of sub-images which are imaged separately onto the wave front sensor in a grid pattern of light spots.

The position of the light spots indicates the shape of the wave front. The light coming from a fibre-optic reference source within the adapter, imaged through the same optics, is used to give the reference positions for the light spots so that systematic optical errors in the measuring system itself can be compensated. The difference vectors between the two grids are analyzed in the Adapter-Rotator control electronics to determine the errors in the shape and position of the telescope mirrors. This information is then passed to the TCS for correction in a similar way as for guiding errors.

*fsalgado@eso.org, phone 56 55 435246; fax 56 55 435001; www.eso.org

2. MOST TYPICAL PROBLEMS FOUND DURING THESE 10 YEARS OF OPERATION

About 700 problems have been reported in those 10 years that can be summarized by the following list:

2.1 Position reading system

The adapter, rotator, turn table and focus devices have Heidenhain encoder systems to read their position, sometimes heads need to be realigned, some electronic boards and heads have been replaced, cleaning of encoders and tapes was needed too, a couple of tapes have been found damaged and one of these was replaced. Since this damage was done by the heads they have been modified to avoid it.

Now cleaning of encoder heads (Heidenhain) and tape is done periodically, meaning a dismounting of the scientific instrument attached to that rotator and the complete opening of the adapter to reach them, in some cases it is done each time a main mirror coating is programmed in other times when an intervention of the instrument is performed giving access to adapter rotator too. Periodical tests are done to determine its status.

Additionally, there is a position detector system in the rotators used to determine how many turns the rotator has done and to set the limits of the range restricted by the range of movement of the instrument attached to it, there is a wheel with some pins that was needed to be modified a bit in several rotators.

2.2 Friction

Friction increasing due to aging of grease inside of the bearing so it is periodically greased where it is possible, in other ones it is done when instrument intervention gives access to this. The worst case was an adapter getting stuck due to some sand found inside. As preventive maintenance activity all of them are periodically tested and compared with healthy measurements.

2.3 Optic fibers

Aging process has been observed in optic fibers since fragility increased through years finding some of them damaged or broken. There are 2 sets of fibers for communication between LCU and aceboxes and 2 reference fibers used for the reference light inside of Sensor arm. Both passing through the Adapter cablewrap so they move each time that the Adapter moves increasing the probability of failures, additionally there is a small arm moving in and out of beam the fiber used to transmit the reference light, so It has been necessary to replace some broken ones. As a preventive action each time that an intervention is done in a scientific instrument the set of fiber is replaced by a new one in the Adapters.

2.4 Electronic components

Replacement of other electronics components have been needed too: like fuses, Adapter and Rotator drives, boards controlling the movement of small linear motors (like MACCON or 4SA boards), Tachometer module, Focus device motor, CPUs and TIM (Time interface module) and the Encoder (IK320) boards.

2.5 Pneumatic brakes

Sometimes there was air leak or limit switch damaged in a brake cylinder. Just few times an electronic valve failed too. Sometimes some cylinders fail and don't release properly so they need to be replaced and the bad one can be recovered.

2.6 Technical CCDs (charge-coupled device)

It was a common problem to find that cameras were not responding, sometimes a replacement of electronic board was needed in the electronic box controlling the camera called ACEBOX, or the CCD head itself. Communication problems have been solved replacing CPU (central processing unit) boards, media converters. Several times a reboot of LCU (local control unit) or recycling power helps too. New generation of TCCD has been developed in close collaboration between people in Paranal and La Silla obsevatories and headquarters in Garching, the replacement process of old units is on going last 3 years, including the replacement of CCD heads, ACEBOX, communication board and CPU in LCU side. A first consequence of this was the availability of spare parts which stock at the moment of first replacement was almost null.

2.7 Software

Lot of problems has been faced in this side and reduction of them has been observed through years by applying intelligent solutions based in the knowledge of system resting in specialized people in Software group but in Electronic and Mechanical groups as well.

3. SOME BIG FORCED INTERVENTIONS

During these 10 years few major problems had appeared but forcing engineers to perform big interventions, main ones are mentioned in the following pages, each time that access to an adapter rotator is needed it includes the dismounting of the scientific instrument attached to the telescope, meaning that it can not be used for observations. It is a very delicate and risky action performed for very specialized people.

3.1 Adapter got stuck [3]

Maybe the most emblematic intervention was this, an Adapter got stuck in UT4 Nasmyth A in August 2004, some sand came from inside of its structure reaching its bearing. The complete unit was dismounted from the telescope and moved to basecamp for several months for complete cleaning and replacement of the bearing cage. First warning was the following torque curve observed there moving it through complete range which was completely different to a normal one (showed in following chart)

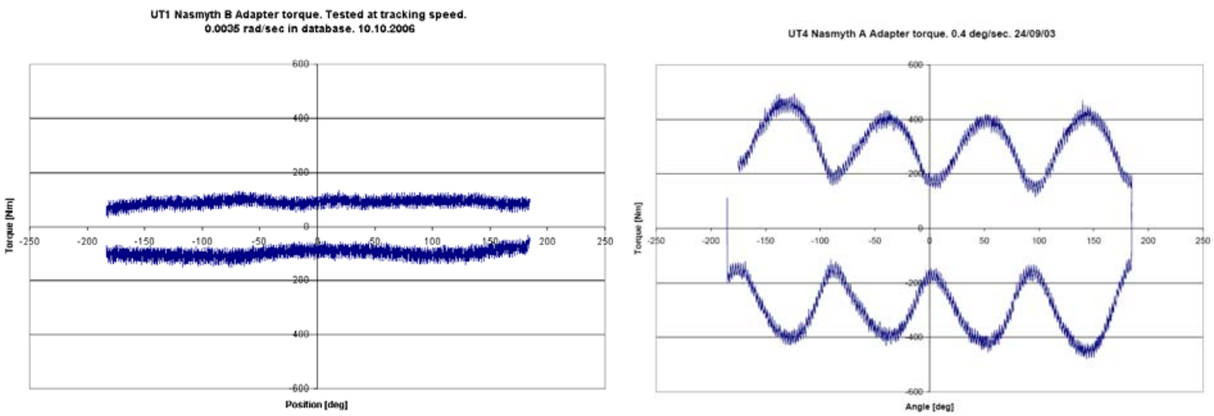

Figure 2. Torque signal versus position for a normal and for a strange Adapter behavior before to get stuck.

After investigation it was found that the sand came from inside of the adapter structure passing through a counterweight. The bearing got stuck and a big intervention was needed, removing the complete Adapter rotator from telescope and moved to base camp where was completely disassembled and cleaned. The following charts show the adapter rotator resting in horizontal position in base camp, the counterweight box with 2 holes where the sand came out, the damaged bearing cage and one of the damaged cylinders too. Unfortunately the cage was not available anymore so the supplier provided an optional one which generated a strange behavior when the Adapter is changing direction.

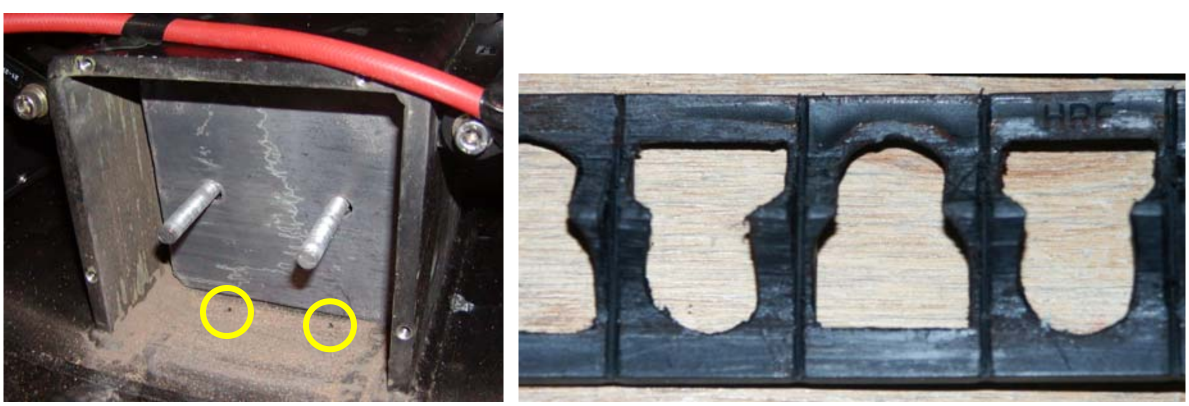

Figure 3. Counterweight box where the sand came from inside of structure through these 2 holes, and the damaged cage are ahowed.

3.2 Encoder tape damaged [4]

The encoder heads originally had a plate in the side that in this case was found a bit rotated enough to start damaging the tape forcing finally to replace it in UT4 Nasmyth B where NACO is mounted, this big intervention was done by people in Paranal following a procedure by Heidenhain. Through following years those plates were removed from all encoder heads in order to avoid a similar damage in other unit.

Figure 4. These pictures show the encoder head and the damaged encoder tape finally replaced.

This was the first time at ESO that a replacement of a big encoder tape is done and the result was successful, this unit is used now in normal operation.

3.3 Cooling leak in a Technical CCD

There was cooling leak in a TCCD in UT3 Nasmyth B in July of 2003, VIMOS was already installed there, the following picture shows the cooling leak holes in the head, from where cooling liquid was flowing inside of Sensor arm, reaching optical components and adapter structure, an encoder head got damaged.

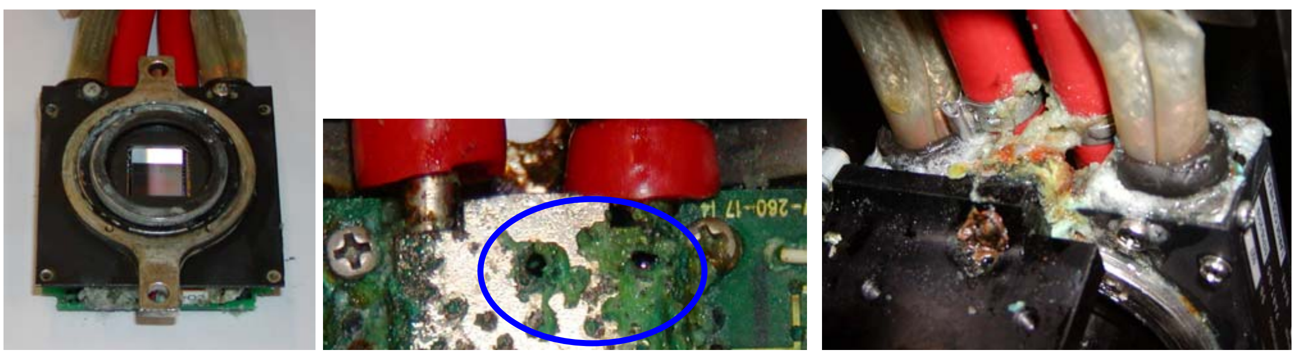

Figure 5. These pictures show the damaged TCCD

Figure 6. These pictures show some optical components and the damaged encoder head.

It was a clear signal that a replacement of TCCDs was needed.

3.4 Fibers broken

There is a reference star generated in a source located in LCU side and transmitted by a fiber to the Sensor arm, passing through the Adapter cablewrap. It rests in a small arm that moves in and out of beam, this fiber is getting older and replacement has been needed in several of them. This light is used as reference to calibrate and test Image Analysis system and Autoguider too. In some cases that failure forced to get access to the system leaving an instrument out of service during some days.

Figure 7 Replacement of a fiber in a Sensor arm.

This was modified to provide a better adjustment.

There is another set of fibers used for communication between Autoguider and Image Analysis aceboxes and LCU, several of them have been damaged by aging and replacement was done too. As soon as there is an option to get access to an Adapter the old sets are replaced by new ones. The replacement of old TCCDs implies that these fibers are not used anymore and just a pair is needed.

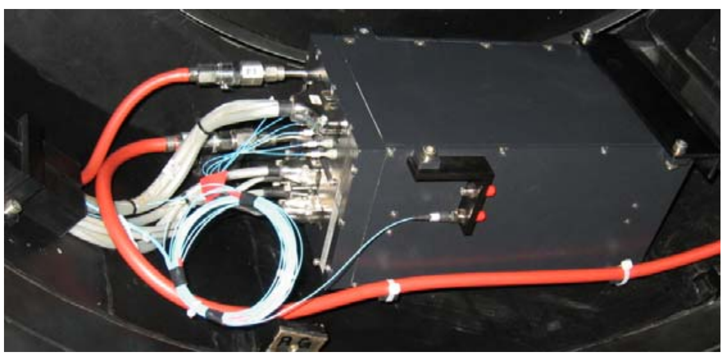

Figure 8 Acebox and optical fibers connected

The ACE-Box for technical CCD for I/A and A/G are connected to the LCU using fiber for control and data acquisition. The fiber for that application was selected more than 10 year ago, when there was few alternatives, it is not an standard cable, it is home made, too fragile, not confident difficult to replace, and is difficult to maintain, today there are new more confident technologies to use in that application, like the new MTP connector and the Mini Core Cable , both offers up to 12 times the density of standard connectors, providing significant space, ease to replaced and cost savings.

The MTP connector, is a multifiber connector that contains up to twelve optical fibers, within a single ferrule.

4. PREVENTIVE MAINTENANCE

A key aspect of reduction of number of problems has been the procedures implemented to keep systems under monitoring to avoid big failures and interventions like the ones previously mentioned. A first consequence of this preventive maintenance is a reaction in advance when any special job is needed so a proper coordination take place in close contact with Science operations department in order to reduce the operational loses. Any intervention to get access to an adapter rotator means the dismounting of the scientific instrument attached to this, so it is needed to look for the best period to leave it out of service reducing the impacts on scientific observations. As it is always a delicate job Maintenance, Mechanical and Instrumentation groups are included in the coordination process, in order to reduce the risk and costs of resources to be used too. Those preventive actions can be summarized as it follows:

4.1 Measurements of torque

Torque measurements in Sensor arm, Adapters and Rotators are periodically done in all of them, comparing the results with a set of reference data taken at the beginning of operations of VLT. A software script was developed to test them in full range recording these signals and then an analysis of variations is done comparing with those healthy measurements of same unit, warnings, alarms and a ticket in Action Remedy software is generated if any further action is needed.

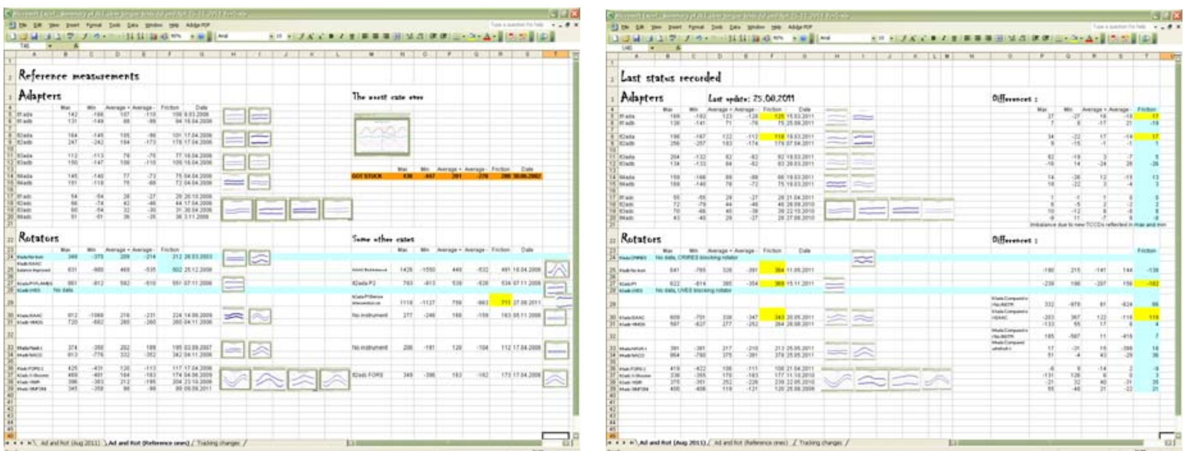

Figure 9 Torque measurements for all adapters and rotators, a healthy measurement and last status recorded to be compared.

The following chart shows a case [2], where the effect of having a damaged support wheel could be reflected in the torque measured in Rotator, it shows a noisy torque, some of bigger peaks coinciding with junctions points in the wheel and second one for the improved situation.

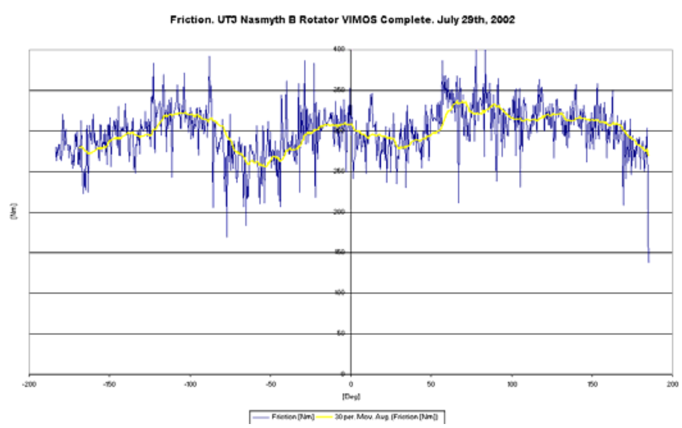

Figure 10 Torque measured while Rotator is moved in whole range with a damaged supporting wheel in VIMOS

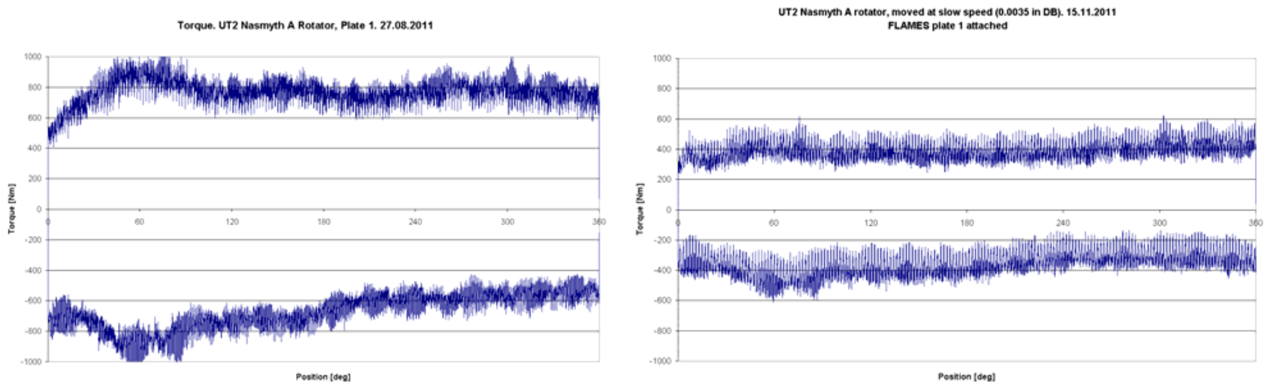

Figure 11 Example of reduction of friction after an intervention in UT2 Nasmyth A rotator, FLAMES, left chart shows an average of 800 Nm reduced to half the value in the right side, by greasing and improvement of brake system.

4.2 Greasing

Bearings are greased periodically and when torque tests show that it is specially needed for example due to an increasing of friction.

4.3 Checking brake system

Some times the increasing of the friction is due to a bad behavior of one or two pneumatic brake cylinders (of 24 in Nasmyth) or 20 in Cassegrain) in the rotator. These cylinders are checked periodically. Some modifications have been needed in the brake disk too.

4.4 Monitoring encoders

Heidenhain Encoder signals are measured periodically too using electronic tools provided by supplier, so if any deviation is detected it can be solved before it gets out of service. People have been trained to read those signals and get conclusions before to open it, it is possible to know in advance if there is an alignment needed or just cleaning of tape and heads.

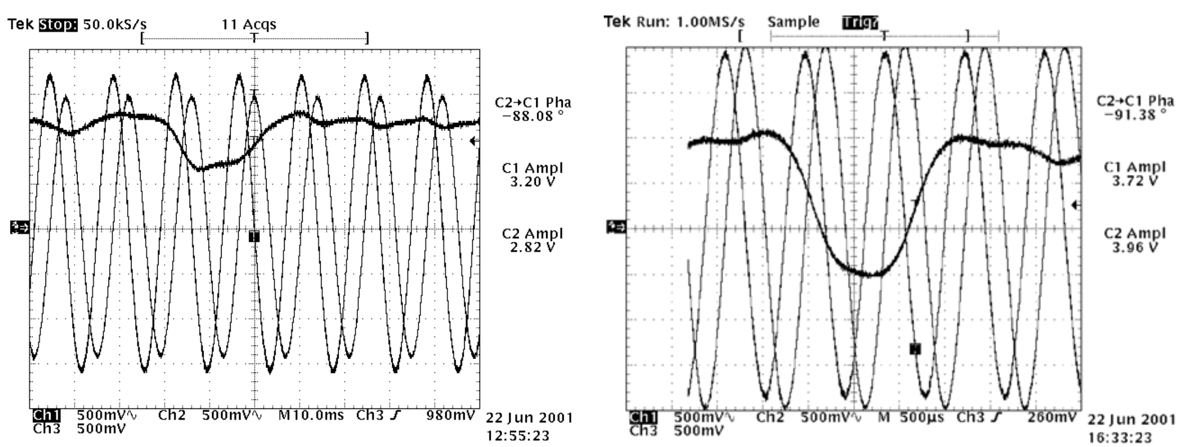

Figure 12 Example of bad (left) and good (right) status of an encoder head obtained by maintenance devices.

4.5 Inspections

Periodical inspections are performed by Maintenance department.

4.6 Replacing fibers

Each time that there is access to an Adapter Rotator the old set of fibers is replaced by a newer one to avoid that the aging process forced to a an unexpected intervention.

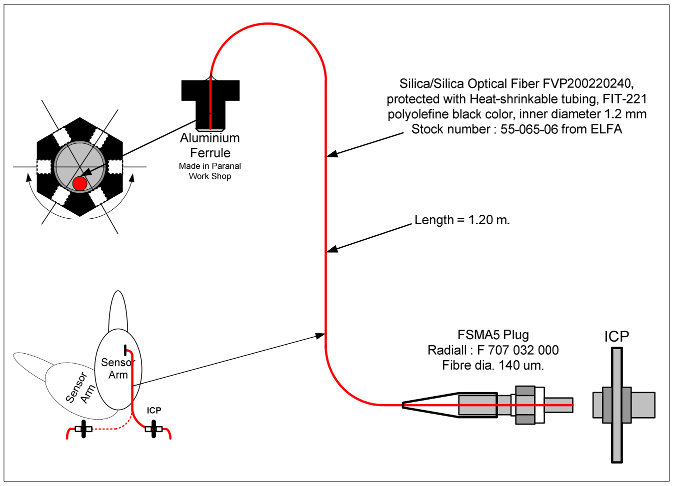

Figure 13 Reference light source Fibre, type B1 (Sensor Arm to ICP) spare manufacture

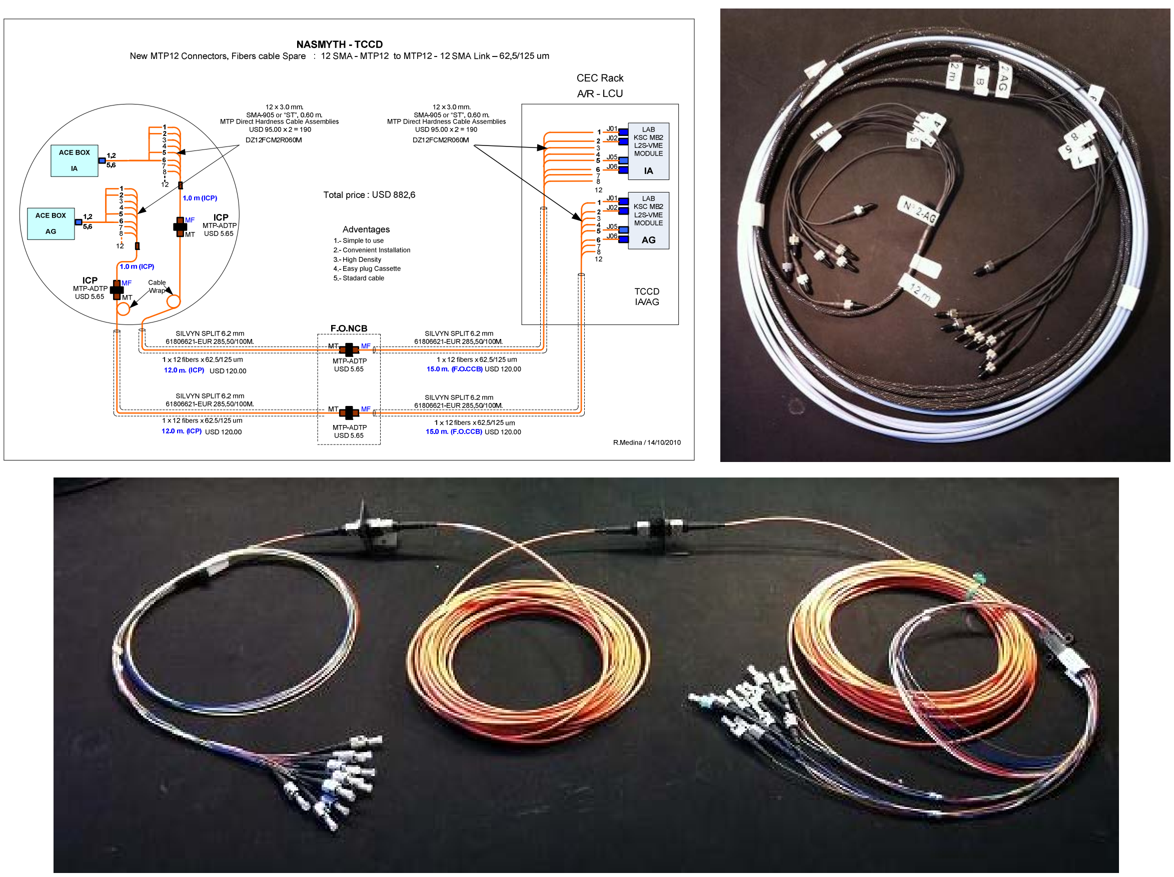

Figure 14 Old fibers were first replaced for new technology ones.

5. IMPROVING THINGS THINKING ON MAINTENANCE

Some improvements have been done thinking to improve and facilitate the maintenance activities, for example lifter machine used to remove the Cassegrain adapter rotator is now motorized and moved by a pusher instead of a group of people

A tend is mounted inside of the telescope each time that an intervention on adapter rotator is done during Main mirror coating to avoid that dust could reach it.

An additional junction box was installed inside of the main mirror cell to give a better access to disconnect Casseegrain adapter rotators when it is dismounted for interventions like it is done each time that a coating of main mirror is on going. Before it was done disconnecting directly from LCU which access to is very complicated.

Figure 15 New junction boxes were installed inside of the M1 cell to avoid getting access to LCU, that was difficult and slow, an important reduction of time dismounting the Cassegrain adapter rotator was achieved thanks to this improvement.

6. OBSOLESCENCE, LOOKING FOR ALTERNATIVES FOR OLD DEVICES

Old systems are starting to fail like the TCCD showed previously, so it has been needed to look for alternatives, The replacement of old units for newer ones like it happened with technical CCDs where a big project resulted in the development of a new version of Head and associated electronic devices which are since a couple of years used to replace the oldest ones.

Another example of this is the adapter rotator drives (ETEL DSA2) which are customized models feeding 2 phase motors and they are not available in the market and the supplier is not manufacturing them. Stock of spare parts available in Paranal is just 2 units for 24 units installed, creating a risky situation, so if a big failure occurs then there is a probability to be forced to leave an adapter rotator out of service meaning that a scientific instrument could not observe the sky. So an effort has been done to prevent this, looking for a direct replacement of the drive, but until now no plug and play device has been found increasing complexity of the project, new technologies for new project of ESO: ELT (Extremely large telescope), could open a door to get a new design for the system.

7. SOME STATISTICS OF PROBLEMS

There is Action Remedy software used to register problems in the observatory and to keep control of a data base resulting in a treasure of information very useful to face problems in the future, some statistics can be done from this data and the following chart shows the evolution of quantity of problems per year. A reduction of this number has been achieved thanks to the advance solving problems and improving maintenance procedures.

The script to test torque in adapters and rotators and other preventive actions started to be implemented in 2004, next charts show a jump on that year, when number of problems decreased.

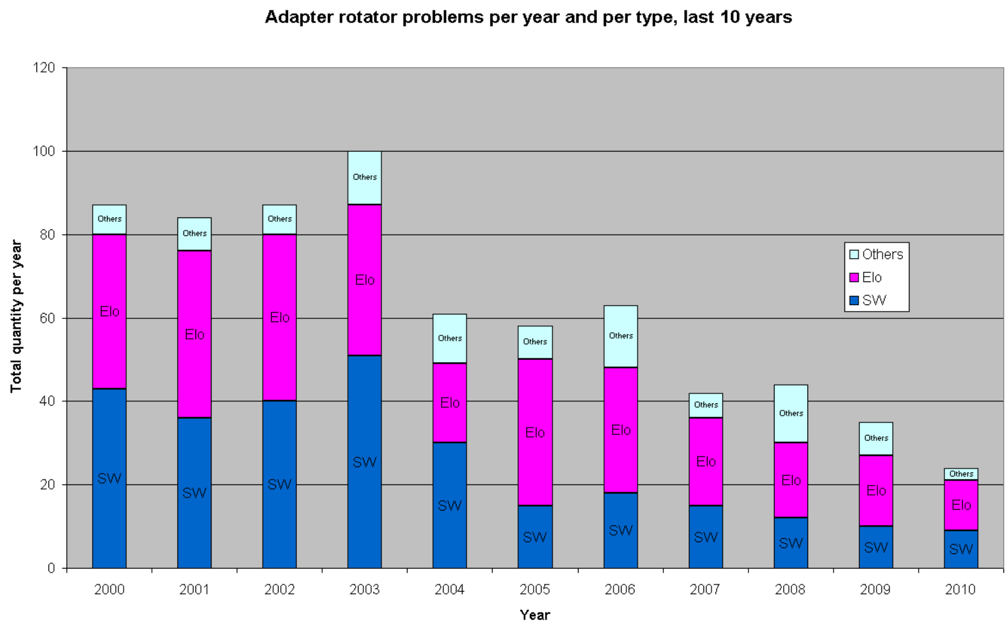

Figure 16. This chart shows the evolution of problems during last 10 years classified by type of problem as electronics, software or others including optical, mechanical,etc. Elo means electronics, SW means software and Others include optical, mechanical, etc.

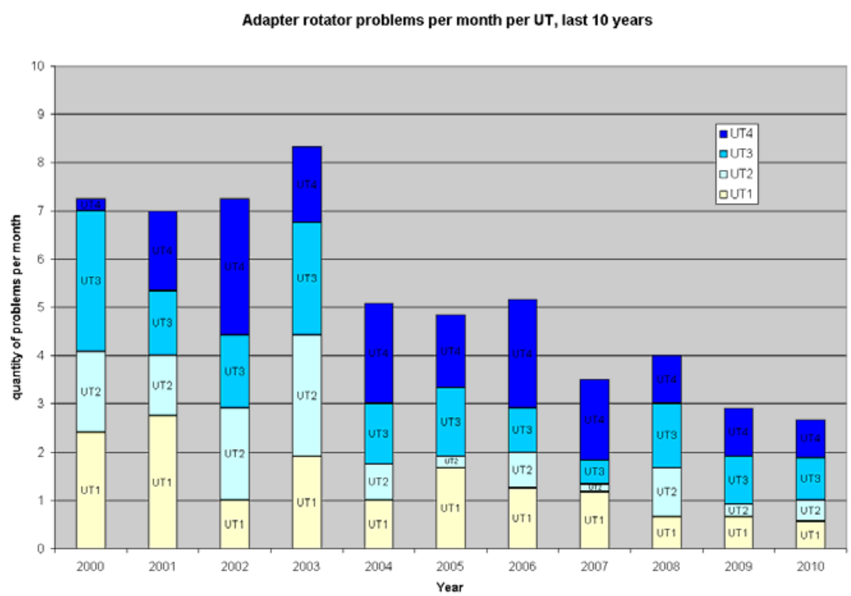

Figure 17. This chart shows the evolution of problems during last 10 years too but classified by telescope, where UT means unit telescope.

No more big forced interventions have been needed since those preventive actions have been implemented.

8. SOME FINAL COMMENTS

Well knowledge of adapter rotator and its subsystems, flowing through Electronic, Software and Mechanical groups where specialists with a system engineering overview have taken care of this, has been a key aspect to fix complex problems and keep them working until now, reducing the rate of failures through last 10 years resulting in smooth operation. One way to get and keep that knowledge is to provide good trainings to people in charge of systems and keep information flowing between them. Action Remedy software is a very important tool in this aspect providing a data base of all the problems in the observatory, including all specific data related with them. That is a treasure of information and has been very important to let people to reach a good level of knowledge of the system.

As a consequence of that cumulated knowledge some preventive maintenance has been implemented. In this way it is possible to reduce the occurrence of emergencies letting Engineers to coordinate interventions in a better way, avoiding strong damage and keeping systems working as it is foreseen for longer periods, reducing the costs related with resources needed and loses of operational time. Coordinating these activities with all people involved including Instrumentation group, Maintenance and Science operations Departments. This clearly has been one of the main reasons why the number of problems related with adapter rotators has been decreasing through years.

It is highly recommendable to take into account the preventive and corrective Maintenance of systems during the design process, in order to provide good access to the different parts as far as it is possible, to greasing points, bolts, patch panels to connect and disconnect cables when dismounting of system is needed, in order to let the people in charge to keep it working for a long time. It should include as well all the tools needed to perform this.

At the moment of definition of stocks of spare parts it is highly recommendable to consider real rates of failure and real periods of useful life of the systems to face in a proper way the aging and obsolescence of systems. Getting alternative spare units to replace the original ones results in complex projects where 100% of compatibility should be fulfilled.Even when this process already started some years ago it is still an important challenge for the future.

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