Resumen

El CERN (Consejo Europeo de Investigación Nuclear) está construyendo su nuevo acelerador de partículas en la frontera franco-suiza. Actualmente en la fase de instalación, El Large Hadron Collider (LHC), con 26,7 kilómetros de longitud a 100 metros bajo tierra, será el mayor y más potente acelerador de partículas jamás construido.

A su llegada al CERN, cada uno de casi 2000 imanes superconductores que formarán parte del acelerador debe ser verificado, ensamblado y transportado hasta su punto final de instalación. Una estricta metodología se ha implementado para cumplir los objetivos del Planning General de la Instalación. Sin embargo, ninguna metodología concreta ha sido establecida para la instalación de los componentes más particulares del acelerador.

Los Neutral Beam Absorbers son cuatro elementos cuya función principal es absorber el flujo de partículas de alta energía procedentes de los dos principales puntos de colisión del acelerador para proteger los imanes superconductores más próximos a las colisiones.

Este proyecto tiene como objetivo definir las necesidades y las soluciones que aseguren la instalación de los 4 Neutral Beam Abosrbers en el acelerador de acuerdo con las especificaciones técnicas definidas y a tiempo con el planning general del LHC.

En orden cronológico, este proyecto detalla las instrucciones de manutención, diseño de utillaje y conjunto de actividades que deben respetarse incluyendo:

- Estudio de peso y estabilidad frente a seísmos.
- Análisis estructural para la correcta manipulación de los frágiles tubos de vacío de cada uno de los Neutral Beam Absorbers.
- Dimensionado del sistema de fijación y diseño del utillaje que permita el tratamiento de los tubos de vacío.
- Especificación técnica de las necesidades y actividades logísticas que permitan el descenso de los 4 Neutral Beam Absorbers y su transporte por el interior del túnel hasta su punto final de instalación.

La metodología establecida en este proyecto ha sido finalizada y aprobada por el CERN, encontrándose en estos momentos (mayo 2005) en la fase de tratamiento de los tubos de vacío y habiendo culminado con éxito las fases precedentes. Asimismo, cada una de las actividades descritas en este proyecto se está desarrollando cumpliendo escrupulosamente con el Planning General de Instalación.

Contents

1 Glossary

Explanation of the termns used in this document:

- **TAN**: the term TAN is used in this document to denote the Neutral Beam Absorbers that will be installed in the LHC machine. Full details are given in section 5.
- **LCH**: the term LHC stands for Large Hadron Collider, the new particle accelerator under construction at CERN. Full details are given in section 3.2.
- **IP (Interaction Points, Experimental Points)**: Points of the LHC where the two particle bunches traveling in opposite senses collide against each other.
- **Superconducting Magnets (Dipoles, quadropoles)**: Magnets using superconducting technology which are the main components of the LHC machine. An overview of their functions can be found in section 3.3.
- **NEG Coating**: Vacuum Treatment which performs a really good cleaning of the surface of a vacuum chamber. Full details are given in section 8.
- **NEG Coating Lifting Assembly**: denotes the assembly which will support the TANs vacuum chambers during the NEG coating treatment. Full details are given in section 8.
- **Support Jack**: the term support jack is used in this document to denot the pre-aligned permanent jacks installed on the LHC tunnel fllor used to support the different elements of the machine.
- **Transfer**: the term Transfer is used in this document to denote the transversal movement necessary to locate the TAN onto the support jacks in its final installed position.
- **Installation**: the term installation is used in this document to denote the transport of each TAN to its final position and the transfer onto the support jacks.
- **VTI**: the term VTI stands for Vehicle for TANs Installation. Denotes the vehicle and the devices needed to transport and transfer each of the 4 TANs from their initial point onto their support jacks.

2 Introduction

2.1 Origin and Motivation of the Project

The LHC (Large Hadron Collider) is the new particle accelerator which is being built at CERN ("Conseil Européen pour la Recherche Nucléaire"). Finished the Design Phase, the project is now in its Installation Phase. Inside a 26.7 Km circumference tunnel (100 m underground) and with a colliding energy of 14 TeV, the Large Hadron Collider will be seven times more powerful than any other proton accelerator to date. This great challenge will unify the last advances and prototypes in superconductivity, electronics and cryogenic technologies.

Upon arrival at CERN, each one of the nearly 2000 superconducting magnets that will be installed in the LHC machine needs to be assembled, tested and accepted before it can be lowered down to the tunnel. For the good operation of the installation process a strict procedure has been settled in order to achieve the goals of the general planning. Nevertheless, no procedure has been set up for some of the particular components of the LHC machine.

The Neutral Beam Absorbers, hereafter referred as TANs (Neutral Absorber Targets) are four particular elements of the LHC accelerator. Their main function is to absorb the flux of high energy that is produced in the two major experimental points (where the two particle bunches collide against each other) and protect the superconducting components which are close to the collision.

2.2 Aim of the Project

The aim of this Project is to detail the main activities to be followed in order to **test**, **transport** and successfully **install** the 4 Neutral Beam Absorbers at their final positions in the LHC machine.

The most fragile part of the Neutral beam Absorbers is its vacuum chamber. Because this element is complex and really different from the ones inside the normal components of the LHC, a new structure and procedure for the necessary vacuum treatment needs to be designed and implemented.

A verification of the CERN safety standards will also need to be done in order to ensure the safe positioning of the 4 TANs in the beamline of the accelerator.

Finally, due to the reduced dimensions of the already existing tunnel and the complexity of the elements that will be in place, the transport and installation of the Neutral Beam Absorbers are big challenges. Since the 4 TAN have particular characteristics of weight and dimensions, a solution for their descent to the tunnel, the underground transport and installation needs to be found.

2.3 Scope of the Project

The 4 Neutral Beam Absorbers were designed and sub assembled at Berkeley Laboratory (U.S.A). They arrived to CERN with engineering notes about how to assemble them and how to lift and handle the assembly. However, no procedures for their vacuum tests, transport and final installation has been provided.

This project will inherit the technical and design notes given by Berkeley University, and it will detail the procedures to follow from the arrival of the four targets at CERN to their installation in the LHC beamline according to the General Installation Planning. This project will not deal with the TAN's design, their maintainability during their life time and their dismantling and recycling processes.

3 CERN

The creation of an European Laboratory was recommended at a UNESCO meeting in Florence in 1950 and, three years later, a Convention was signed by 12 countries of the "Conseil Européen pour la Recherche Nucléaire". CERN was born as the prototype of a chain of European institution in space, astronomy and molecular biology. This scientific laboratory sites on both sides of the Franco-Swiss border west of Geneva at the foot of the Jura Mountains.

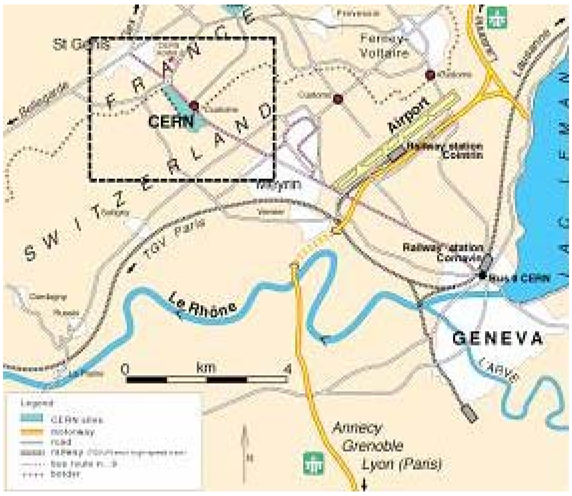


Figure 3.1. CERN's location

CERN is today composed of 20 member States: Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland and the United Kingdom and around 6500 scientists use CERN's facilities [1].

CERN's aim is to provide the European scientific community with the facilities to probe the structure of matter and reach a better understanding of the behavior of the universe, how was it created… only for scientific purpose with no immediate technological or commercial objectives. It has been built and operated the particle accelerators needed as means for such research in a unique centre which allows physicists around Europe to collaborate more fruitfully than if each country maintained an independent program. However, even in the short term this fundamental research, with its stringent demands for accuracy and ultra-fast response, pushes modern technology to the limit.

For high interaction energies, the laboratory has developed several fixed targets and colliding beam machines. The first ones were the Proton Synchrotron (PS) that came into operation in 1959 supplying fixed target experiments with 28 GeV beams of protons, and the Intersecting Storage Rings (ISR) proton-proton collider, which began to act in 1971. The next step was represented by the Super Proton Synchrotron (SPS) which was later made into the proton-antiproton collider (at 450 GeV/beam energy) which started to work in 1981. It led to the discovery of the W and Z particles (the carriers of the weak nuclear force) confirming the elegant theory unifying electromagnetic and weak forces (electroweak theory). This discovery by Carlo Rubbia's team, together with the development of a new technique (stochastic cooling) to control the anti-protons and shape them into an intense beam, by Simon var der Meer, earned them the Nobel Prize for Physics in 1984.

Since 1989, these accelerators have also represented the elements of a chain to pre-accelerate and inject electrons and their antiparticles, positrons, into the Large Electron-Positron collider (LEP), where their energy was increased up to 46 GeV, while bunches containing 10^{11} particles were made travel in opposite direction in the same ring, before the head-on collision of two bunches occurred within a detecting unit. By means of this machine physicists could make a detailed study of Z boson, that were abundantly produced at 92 GeV energy. At 1996, the LEP energy doubled, thanks to superconducting accelerating cavities, reaching 105 GeV per beam.

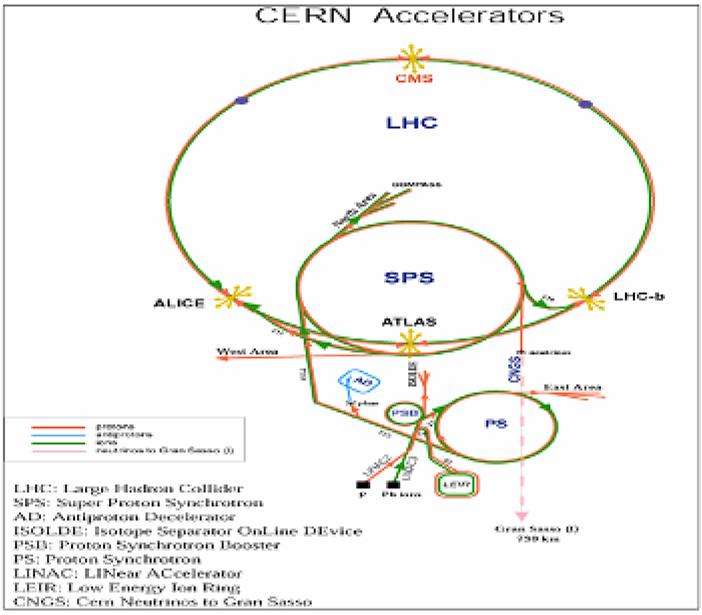


Figure 3.2. The CERN network of interlinked accelerators and colliders

3.1 High Energy Particle Physics Challenges

Particle physicists have found that they can describe the fundamental structure and behavior of matter within a theoretical framework called the Standard Model. This model incorporates all the known particles and forces through which they interact, with the exception of gravity. It is currently the best description we have of the world of quarks and other particles. However, the Standard Model in its present form cannot give answers to some questions: there are still missing pieces and other challenges for future research to solve.

The masses of the particles vary within a wide range of masses. The photon, carrier of the electromagnetic force, and the gluons that carry the strong force, are completely massless, while the conveyors of the weak force, the W and Z particles, each weight as much as 80 to 90 protons or as much as reasonably sized nucleus. The most massive fundamental particle found so far is the top quark. It is twice as heavy as Z particles, and weights about the same as a nucleus of gold. The electron, on the other hand, is approximately 350,000 times lighter than the top quark, and the neutrinos may even have no mass at all.

Why there is such a range of masses is one of the remaining puzzles of particle physics. Indeed, how particles get masses at all is not yet properly understood. In the simplest theories, all particles are massless which is clearly wrong, so something has to be introduced to give them their various weights. In the Standard Model, the particles acquire their masses through a mechanism named after the theorist Peter Higgs. According to the theory, all the matter particles and force carriers interact with another particle, known as the Higgs boson. It is the strength of this interaction that gives rise to what we call mass: the stronger the interaction, the greater the mass. If the theory is correct, the Higgs boson must appear below 1 TeV. Experiments at Tevatron and LEP have not found anything below 110 GeV.

Another open question is the unification of the electroweak and strong forces at very high energies. Experimental data from different laboratories around the globe confirm that within the Standard Model this unification is excluded [2]. When scaling the energy dependent constants of the electroweak and strong interactions to very high energies, the coupling constants do not unify. Grand Unified Theories (GUT) explains the Standard Model as a low energy approximation. At energies in the order of 1016 GeV, the electromagnetic, weak and strong forces unify. One of the GUT theories is the supersymmetry (SUSY) that predicts new particles to be found in the TeV range. Many other GUT theories predict new physics at this energy scale.

These and other questions like the elementarity of quarks and leptons, the search of new quark families and gauge bosons or the origin of matter-antimatter asymmetry in the

Universe, will be addressed by CERN’s next accelerator, the Large Hadron Collider, which is currently under construction.

3.2 The Large Hadron Collider (LHC)

The Large Hadron Collider [3] will collide two counter-rotating proton beams at a centre of mass energy of 14 TeV. This energy is seven times higher than the beam energy of any other proton accelerator to date. In order to achieve an unprecedent luminosity of 1034 *cm*-1*s*-2, it must operate with more than 2800 bunches per beam and a very high intensity. The machine can also be filled by lead ions up to 5.5 TeV/nucleon and therefore allow heavy-ion experiments at energies about thirty times higher than at the Relativistic Heavy Ion Collider (RHIC) at the Brookhaven National Laboratory in New York. Some of the parameters of the new accelerator are listed below:

TOPIC	**VALUE**	**UNITS**
Energy	7	TeV
Injection Energy	0.45	TeV
Dipole Field	8.36	Tesla
Number of dipole magnets	1232	
Number of quadrupole magnets	430	
Number of corrector magnets	8000	
Luminosity	1034	$cm^{-2}s^{-1}$
Coil aperture in arcs	56	mm
Distance between apertures	194	mm
Particles per bunch	1011	
Number of Bunches	2835	

Table 3.1. Summary of the LHC parameters [4]

The primary task of the LHC is to make an initial exploration of the 1 TeV range. The major LHC detectors, ATLAS (*A Toroidal LHC ApparatuS*) and CMS (*Compact Muon Solenoid*) should be able to accomplish this for any Higgs mass in the expected range. To get into the 1 TeV scale the needed beam energy is 7 TeV.

Together with ATLAS and CMS, two other experiments will be fed by the LHC: a dedicated heavy ion detector, ALICE, which will be built to exploit the unique physics potential of nucleus-nucleus interactions at LHC energies, and LHC-B, which will carry out precision measurements of CP-violation and rare decays of B mesons.

The CERN Council approved the LHC in 1994. Civil engineering works for the LHC are almost completed. The series production of the magnets has already half way through and works well. The prototypes String I and II have shown the feasibility of high magnetic field cryomagnets connected in series. Installation of the LHC components into the tunnel started after removal of LEP was completed. Injection into first octant is foreseen for 2006. It is planned to complete the machine installation and to start operation in 2007 [5].

3.3 LHC Layout

The LHC has an eight-fold symmetry with eight arc sections and eight long straight sections. Two counter-rotating proton beams will circulate in separate beam pipes installed in the same magnet (*twin-aperture*). The beams will cross over at the four experiments resulting in an identical path length for each beam.

Each arc consist of 23 identical cells, giving the total length of 2465 m. Cells are formed by six 15 m-dipole magnets and two quadrupole magnets (these dipoles and quadrupoles are called lattice or main magnets). Dipole magnets are used to deflect the beam whereas quadrupole magnets act as lenses to focus the beam. The lattice quadrupole magnets and the corrector magnets of a particular half-cell form a so called short straight section (SSS) and are housed in a common cold mass and cryostat.

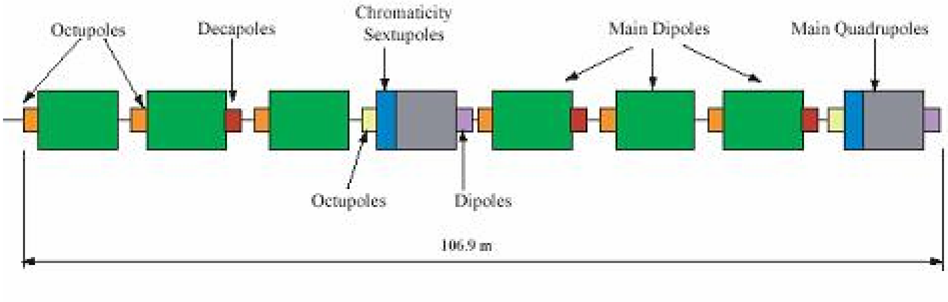


Figure 3.3. LHC cell layout: the six main dipole magnets, two lattice quadrupoles and correctors.

At the beginning and the end of the straight sections a dispersion suppressor cell consisting of four quadrupoles interleaved with four strings of two dipoles each, is in charge of correcting the orbit deviation due to the drift in the energy of the particles. The four long straight sections where the experiments are located, are formed by the dispersion suppressors and the insertion magnets. These last ones quick the separated beams to a common pipe where they are finally focused by the so called inner triplet magnets in order to get very low beams before collisions inside the detectors.

The other insertions are to be used by systems for the machine operation: beam dump, beam cleaning (collimation), RF-cavities (accelerator units) and injection from preaccelerators.

The injector complex includes many accelerators at CERN: linacs, booster, LEAR as an ion accumulator, PS and the SPS. The beams will be injected into the LHC from the SPS at an energy of 450 GeV and accelerated to 7 TeV in about 30 min, and then collide for many hours.

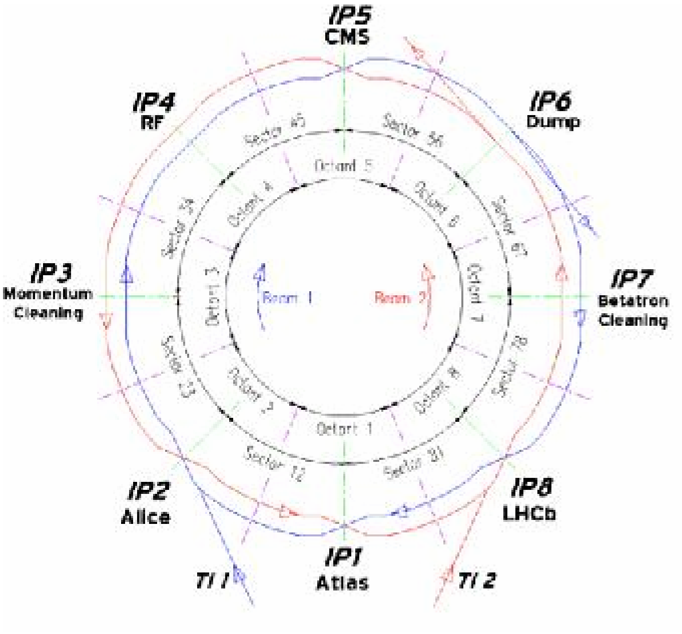


Figure 3.4. LHC layout

4 THE INSTALLATION COORDINATION ACTIVITIES (IC)

The size and the complexity of the LHC project demand a strong coordination of all installation activities. More than 2000 tasks have been identified and about 80.000 tones of materials have to be transported and installed in the tunnel.

The coordination for the installation is carried out by the Installation Coordination (IC) Group which was created for this purpose. The planning, installation and logistics issues and methods are described in the following section.

4.1 Planning

The total time allocated for underground installation is about 5 years, excluding civil engineering. The sequencing of the various installations has been studied in great detail in order to minimize interferences and consequently the amount of time lost [6].

4.1.1 Multi-level Planning

- **The Master Schedule** reviews the strategic goals and major milestones of the project. It gives a schematic plan for the different phases of the installation, indicates the main dates and shows the sequence of work in the different sectors of the LHC.

- **The General Co-ordination Schedule** is issued by the planning team of IC and aims to implement and control the flow of installation that is most effective in term of resources and time. It also has to respect the main milestones of the Master Schedule, such as closing of the machine and the end of installation. It is endorsed by the Project Leader.

- **The Detailed Installation Planning** derives from the details of the installation scenario and the knowledge of each individual installation work unit (activities, boundary conditions, resources, etc.). It is maintained with the MS-Project software package, which automatically updates all the chronological relations between the different activities whenever a schedule change or a new task is introduced. It also provides a resource leveling function that is very useful to assess the feasibility of a new scenario.

4.1.2 Installation Phases

The installation of LHC is subdivided into twelve steps occurring at different times in each sector. The installation sequences for the other sections of the machine (extraction, cleaning, etc.) remain to be defined. The installation sequence for the arcs is given below together with a short description of the operations carried-out.

Phase 1: General Services

- Step 1: The marking of the floor and its preparation
    - The theoretical position of the axis of the hack head is marked on the floor together with the name of the cryomagnet.
    - The half-cell boundaries are also marked on the floor.
    - The height of the floor is adjusted
- Step 2: The installation of the general services
    - The positron of the cable trays is modified
    - The AC cables are pulled
    - The position of the lighting is modified
    - The leaky feeder used for communication is installed
- Step 3: The piping work
    - The two demineralised water pipes are installed in the center of the ceiling
    - The helium ring and recovery lines are installed
    - A compressed air line is installed
- Cabling campaign num. 1
    - The power cables
    - The signal cables
    - The optical fibers
    - The connectors

  - The connectors
  - The junction boxes

Phase 2: Cryogenic line

- Step 5: The installation of the QRL
  - The QRL supports
  - The QRL elements (pipe, service and return modules)
  - The helium pipes are welded
  - The vacuum vessel is welded
  - Leak tests
- Step 6: Cabling Campaign num. 2
  - The local cables
  - The connectors
- Step 7: The commissioning of the QRL
  - The connection to the QUI
  - The pump down
  - The cool down
  - The commissioning
  - The warm up

Phase 3: Machine

- Step 8: Installation of the jacks
  - The positioning of the jacks
  - The bolting to the floor
  - The pre-alignment of the jacks

  - Activities left over from the general services phase: e.g. The painting of the optical guidance strip – the signal cables (last campaign)

- Step 9: The transport and the installation of the cryomagnets on the jacks
  - The cryomagnets are lowered via PMI2
  - The transport to the final destination
  - The transfer onto the jacks
  - The pre-alignment of the cryomagnets
- Step 10: The interconnection of the cryomagnets
  - The interconnection of the bus-bars
  - The welding of the beam and helium vessel pipes
  - The connection to the QRL in the jumper
  - The closing of the external bellows
  - The leak test
- Step 11: The installation and the connection of the electronics under the magnets
  - The mounting of the connectors
  - The installation of the crates under the cryomagnets
  - The pre-commissioning

Phase 4: Hardware commissioning

- Step 12; The Hardware commissioning
  - The pump down
  - The pressure tests
  - The insulation tests
  - The cool down
  - The cold commissioning of systems

- The powering of all circuits at nominal current

The installation of the hardware in a sector is expected to be completed in three years. A simplified drawing of the installation planning for the LHC is shown in Figure 4.1

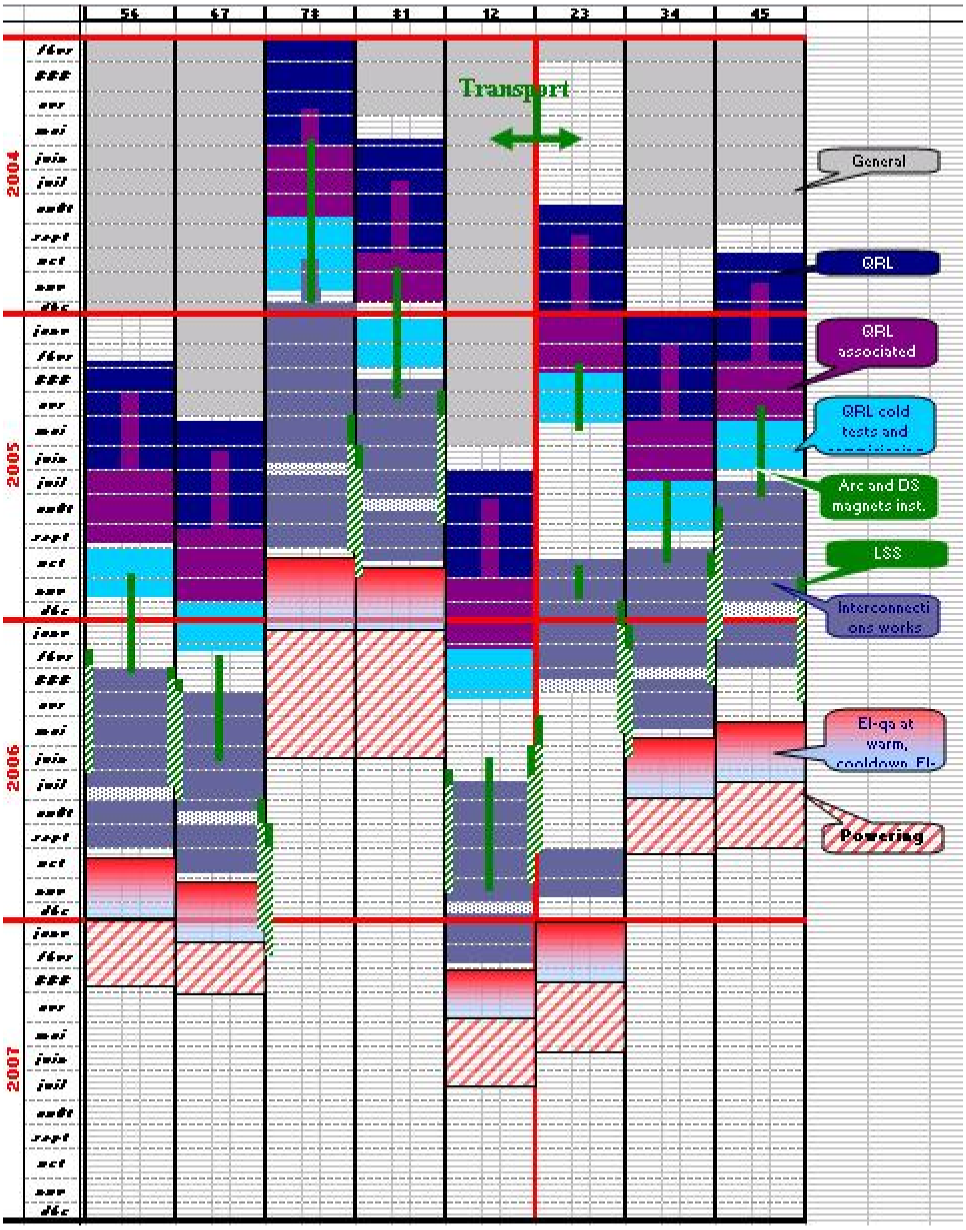


Figure 4.1 The LHC installation simplified planning

4.1.3 Update and Rescheduling

The installation activities have to adapt through continuous feedback from the production sites and from the field. To this end, the detailed installation planning is regularly reviewed. Short Term Planning Meetings, are held every 4 weeks, with the aim of confirming the activities to be carried out over the coming three months. In this forum, early warnings of potential delays may come up. These can include situations such as:

- Interfaces between groups have not been identified,
- The task sequencing is incorrect,
- Components or team are not available,
- Preparation work or integration is not ready,
- The time required for a given task wrongly calculated
- Unexpected technical difficulties are encountered.

It is essential to limit the impact of such problems and rescheduling of activities or redeployment of staff to optimize the usage of resources might be considered. In the decision making process, solutions with no consequences on other work units (co-activity if possible) are initially studied; then, at a second stage, those with no consequences on work units under the responsibility of sub-contractors or vendors, are considered. Rescheduling can be accepted rapidly if the impact is limited to the domain of activity of the project engineers present or represented at the Short Term Planning Meeting and if the dates of the General Coordination Schedule are respected. A revised Detailed Installation Plan, taking into account the current component production and installation contracts as well as the progress of installation is issued periodically.

The direct rescheduling can be a hazardous exercise. Particular care must be taken with the logistics of the supply of the different work sites since activity in a shaft (cabling, piping or installation of cryogenics lines) forbids lowering material through this shaft for the duration of the work. All safety aspects must also be taken into account: safety rules have to be strictly enforced and the procedures must be studied and documented in detail. This is an essential step in the assessment of the feasibility of the new scenario. If it appears that the change cannot be considered locally and that it has implication on the installation of other equipment occurring at different times and locations, the rescheduling must be published and accepted by all parties involved.

Significant rescheduling of the installation, in particular if it concerns a complete phase or even a period, can have major consequences and will certainly involve many parties. To obtain authorization for such a schedule change, a Schedule Change Request is circulated to all the Group Leaders involved in the LHC Project for them to evaluate any eventual implications on the installation of their equipment and on their contracts. Once approved, the document is declared as being a Schedule Change Order by the Project Leader and all the Project Engineers are informed.

4.2 Installation

The machine and service equipment is provided by different groups working closely together during the installation and with a tight coupling of their activities. The planning details the installation scenarios, however the large number of actors and the addition of any unforeseen activities will inevitably lead to interferences. In order to allow rapid reaction and minimise the impact a strict and knowledgeable coordination in the field has to be put in place.

4.2.1 Organization of the Installation of LHC

Due to the number of protagonists both from CERN and from contracting companies, it is important at the beginning of the project to give details about the general organisation of the installation and the decision-making bodies. All the information is gathered in the document “Organisation of the Installation of the LHC and its Experiments” [7]. It describes:

- The specific measures related to the installation: work packages, etc.
- The operational coordination, detailing the role of the group leaders, the TSO (territorial safety officers), the safety coordinators, the site managers, and the operators of transport and handling equipment,
- The working hours and days,
- The access to the sites and to the underground works,
- The barracks and parking on surface,
- The storage issue,
- The handling and transport issues,
- The underground transport of staff to worksites,
- The waste management,

- The utilities, energies and worksite services.

4.2.2 Description of Work Packages

Several protagonists may intervene in the same zone simultaneously leading to a need to check the compatibility of all the activities. This requires an overall view of what needs to be done, which is only possible if the information is coherent across the installation of the whole project. For that very reason, the installation of services and machine components has been broken down in Work Packages which cover a given period of the installation and a specific part of the underground areas.

This means that a punctual delay or a hazard may propagate onto a chain of activities within a given Work Package, thus resulting in additional delays and potential cost over-runs. The role of IC is to limit the impact of such incidents whenever decisions can be taken in the field and to give assistance with minor interventions when this can unblock the situation.

The Work Package documents contribute to the quality assurance process of the LHC project. They are linked with the detailed installation planning. In addition to a summary description of the different tasks to be carried out, these documents give precise information about:

- Human and material resources required, including contact persons,
- Specific logistics needs and means,
- Specific access conditions,
- Installation of surface barracks and storage areas,
- Protective measures to implement if required,
- Field utilities available over the work package time span,
- A Description of the initial environmental conditions if necessary.

The description of an installation Work Package is prepared together with the scheduling process, with the assistance of the Zone Coordinators. It is checked by those involved in the field and approved by the Group Leaders concerned and Heads of Department.

4.2.3 Co-ordination in the Field

Co-ordination in the field [8] requires a very good knowledge of the situation in each worksite and of the possibility of co-activities and of the transport conditions in the underground areas.

The LHC ring and its injection tunnels are subdivided into three main zones as shown in Figure 4.2. Each zone is supervised by a Zone Coordinator who ensures that the installation activities are carried-out as specified in the Work Package description, according to the defined strategy and in conformity to safety rules and regulations of CERN and Hosts States. The aim is to stay aware of the advancement of every work site and to rapidly react to any problems. In order to fulfill this mission, IC provides assistance to installation and carries minor tasks ranging from quick repairs to preparation of masonry, steel structures, electricity, etc. This allows work which is sitting on the borderline of well identified responsibilities (so called orphan activities) to be handled and the unblocking of problematic situations in the field.

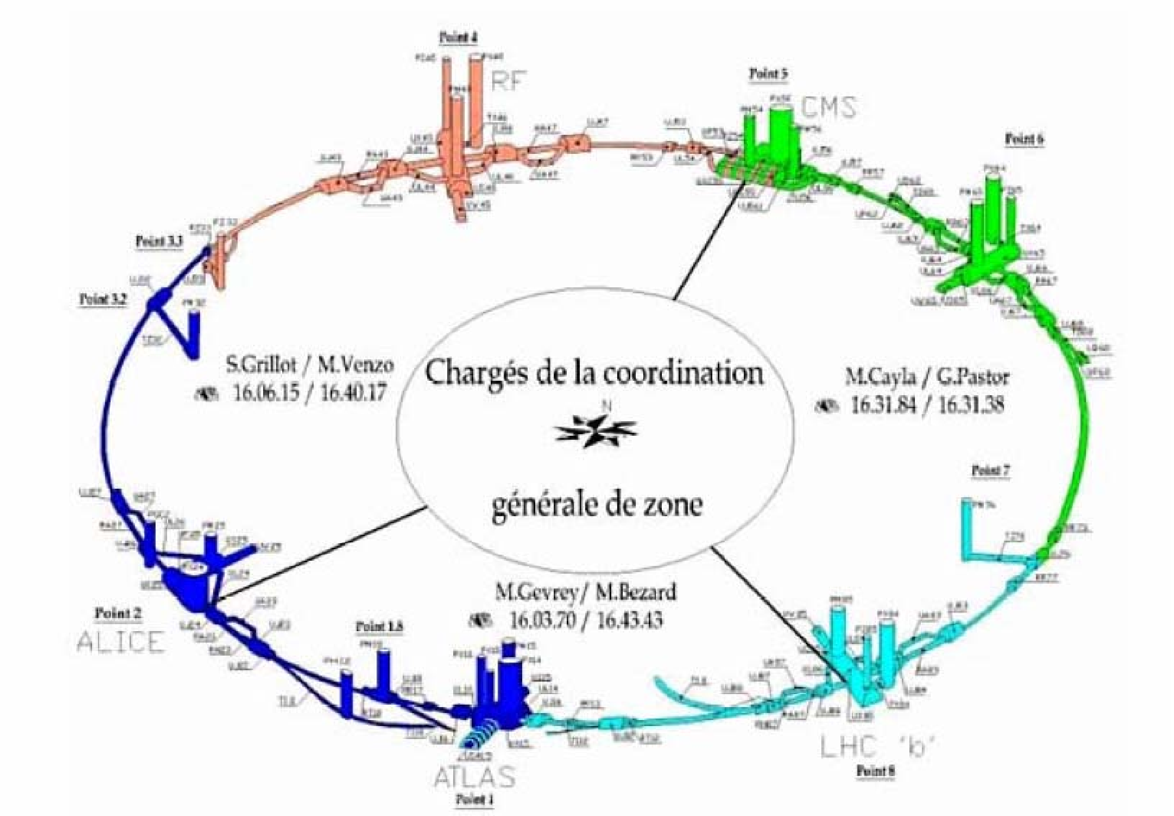


Figure 4.2. LHC installation zones and zone coordinators

4.2.4 Monitoring of Installation Progress

The Zone Coordinators organise weekly meetings in the field with the aim of following the progress of all installation activities, identifying potential problems and proposing corrective measures if necessary. The list of actions is included in the minutes of the meetings. The Work Supervisors of the groups involved, the Site Managers and the Safety Inspector participate to these meetings. Ad-hoc meetings are also organised with the teams involved in specific areas to study the details of a delicate installation scenario.

The Zone Coordinators report to the Installation Follow-up Meeting that takes place every four weeks: this is a forum for the sharing of experience and to check the homogeneity of the installation procedures on the different work sites; it covers the following points:

- The work which has been achieved in the period elapsed since the previous report,
- The problems which have been encountered during that period and the corrective action taken and any repercussions expected on other activities,
- The actual status of the project versus the planning presented in the form of a broken line on the General Co-ordination Schedule.

The advancement of the installation versus the planning is published once a month on the LHC Project home page [9].

4.2.5 Reception of a Work Package and the Treatment of Non-conformities

In addition to the formal hand over meeting with the contractor (organised by the group responsible for the equipment installed), a visit is always organised by IC to identify any non-conformities with respect to the Work Package definition and to ensure that the zone is acceptable for the next installation phase.

In some cases, for example the general services, when a group subcontracts the installation of equipment to another group, who in turn subcontracts this work to an external firm, IC also ensures that the equipment has been installed in conformity with the original technical specification. To this effect, a meeting is organized with the two groups involved in order to identify non-conformities and, if possible, have them resolved before the formal hand over.

Any non-conformities of a Work Package are documented and the Installation Coordination Team follows-up their resolution, according to the LHC quality assurance plan.

4.2.6 Site Management

The general management of all the LHC sites has been placed under the responsibility of the IC group. The mission of the Site Managers consists of assisting all the people working on site. It includes:

- The organisation of repair work when there are technical problems with the infrastructure,

- The daily management of site access conditions assisted by the site guards,
- The management of the so-called shared spaces and facilities.

The site managers are also the territorial safety officers (TSO) for the site and thus have the mandate to make sure that the rules in matters of health, safety and environmental protection are applied. In the framework of LHC installation work, they take care of the correct application of the measures specified in the work package documents. Site managers are present at each of the points 1, 2, 4, 5, 6 and 8 of the LHC and on-call at points 1.8, 3, 7 and I2.

4.2.7 Safety during Installation

During the installation and commissioning, safety is a top priority.

The implementation of the safety rules is both a matter of organisation and a matter of application in the field. The organisation includes all the rules and regulations defined by CERN, but also all those coming from the Host States (France and Switzerland).

The safety coordinators are appointed by the LHC project leader according to French law. They have the mandate to take care of the application of all the measures necessary for safety at all stages of the project. They have complete freedom to send their remarks to all the protagonists of the project. They take care of the application of the French regulations and the associated actions and documentation.

The responsibility in matters of safety is a hierarchical one. Group leaders and their representatives in matters of safety are responsible for the safety of their own equipment, from their conception to their installation in the tunnel.

4.3 Transport Arrangements

The tight schedule and the large quantity of items to be transported require fully integrated logistics on the surface and even more stringent co-ordination underground. The general means of transport and handling of equipment, together with the organisation necessary to bring the equipment to its final destination, are described below. The reliability of all the transport and handling equipment is extremely important as faults, or breakdowns can quickly lead to logistical problems.

4.3.1 Items to be Installed

The quantity and variety of equipment in the LHC is huge. The total weight to be lowered down into the tunnel for the machine is estimated to be about 80’000 tons. This equipment can be categorised as follows:

- Standard equipment for services:

    Electrical equipment such as cable ladders and drums, transformers, distribution boards, etc.

    Piping and miscellaneous equipment for the cooling circuitries, Metallic structures,

- Cryogenic equipment,
- Cryomagnets
- Electrical distribution feed boxes,
- RF equipment,
- Warm magnets,
- Jacks,
- Vacuum chambers and vacuum equipment,
- Power boxes and electronic crates.
- Others…Special elements with no procedure of transport established (TAN, TAS…)

Each category of equipment has specific properties (dimensions, weight and fragility) and has to be treated individually in terms of transport means.

4.3.2 Surface Transport and Handling

Depending on the agreement reached with the supplier, on the requirements of customs formalities or on the assembly processes, equipment will be transported to assembly halls, storage areas or tunnel access points either directly or more usually via the Meyrin and Prévessin laboratory sites. All transport between the different points is carried out using the CERN fleet of vehicles. Of note are the special heavy trailers required for large, heavy and cumbersome loads. Transport over distances of up to 18 km using public roads will be required. Host States regulations apply for public roads, in particular for exceptional loads.

Most standard types of handling equipment are available at CERN including overhead cranes and mobile cranes which can commonly handle objects having a weight of tens of tons.

4.3.3 Access Shafts and Cranes

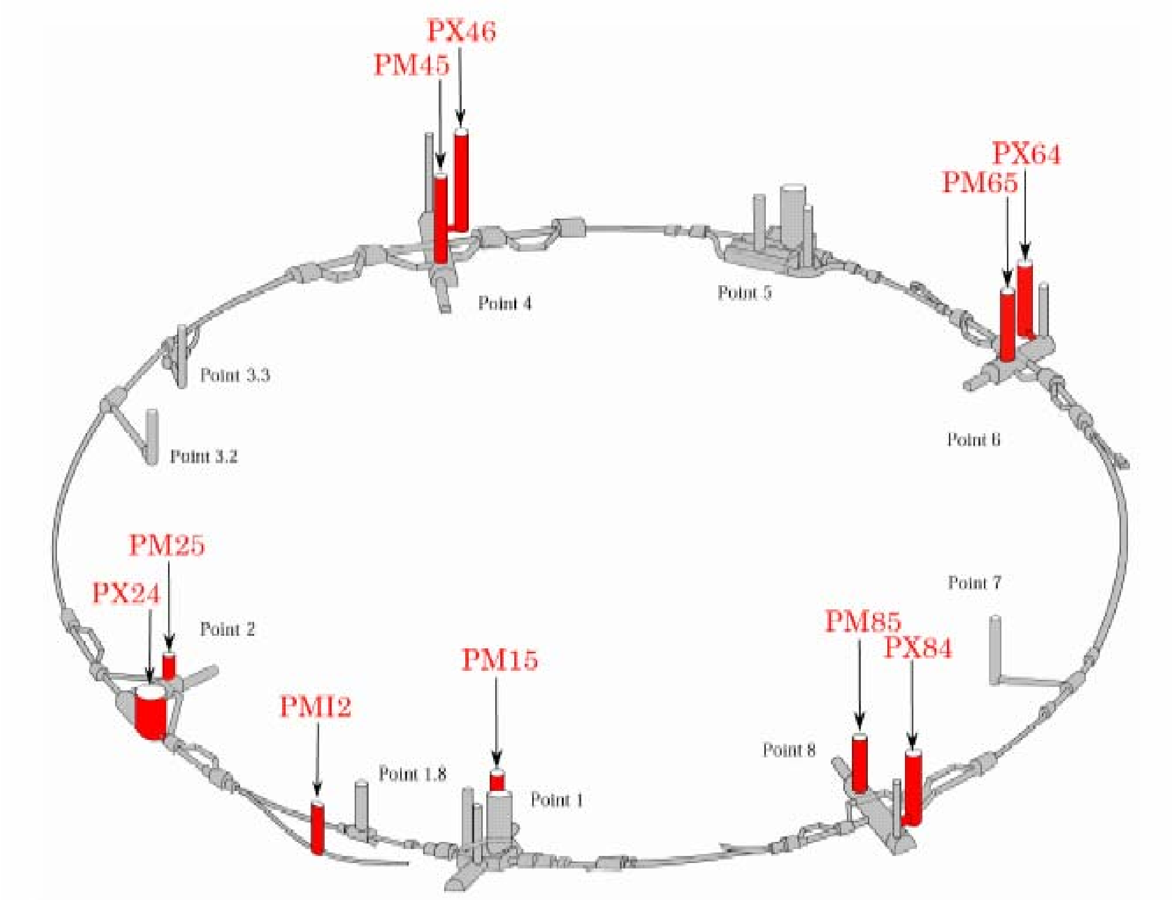


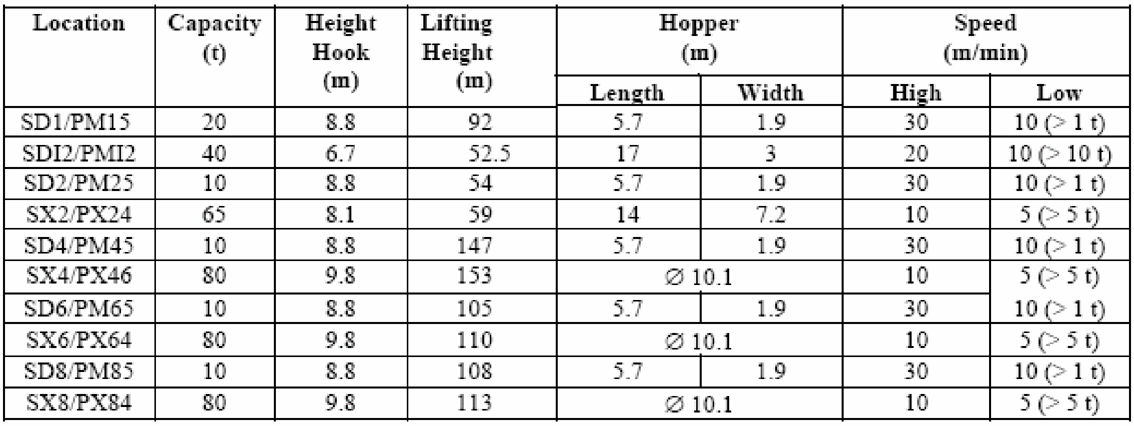
Figure 4.3. The access shafts used for the LHC installation

The access points for the equipment down to the tunnel are eight shafts located all around the machine as shown in Figure 4.3. These shafts have the following particularities:

- Five shafts (PM15, PM25, PM45, PM65, PM85) reach the service caverns. They are equipped with cranes of 10 t capacity or more.
- Two shafts (PX46, PX64) each equipped with an 80 t crane reach the two LEP experimental caverns which are now dedicated to the machine.
- A further shaft (PMI2), equipped with a 40 t crane reaches the TI2 injection tunnel. This allows the larger machine components, like the cryodipoles to be lowered, but the TI2 cross-section is smaller than the main tunnel cross-section, prohibiting transport of high objects.

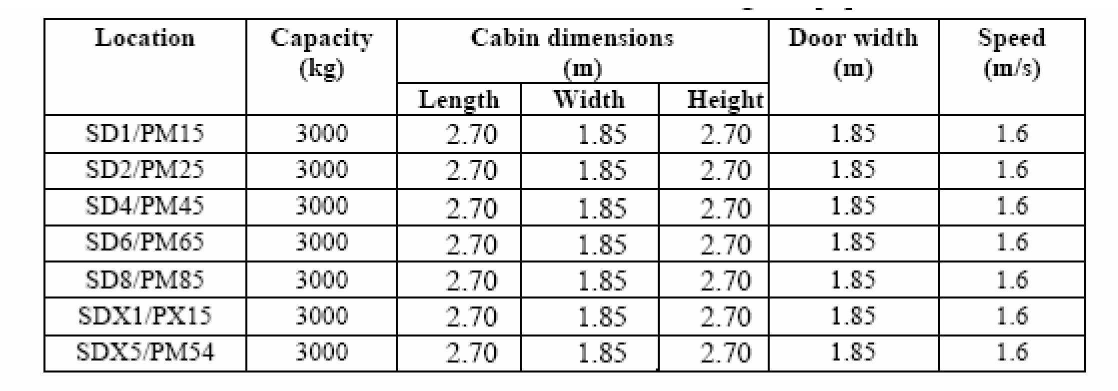
In addition, two shafts (PX24, PX84), can be used occasionally for specific cases (e.g. abnormal dimensions of the equipment, practicality of access) to reach the LHC experimental caverns. The transport arrangement in the shafts described above is summarised in Table 4.1.

Lifts for personnel are available at all access points, except Point I2. These lifts can also be used to take relatively small and mobile equipment down into the tunnel. The capacities of these lifts are given in Table 4.2.



Location	Capacity (t)	Height Hook (m)	Lifting Height (m)	Hopper (m)		Speed (m/min)	
				Length	Width	High	Low
SD1/PM15	20	8.8	92	5.7	1.9	30	10 (> 1 t)
SDI2/PMI2	40	6.7	52.5	17	3	20	10 (> 10 t)
SD2/PM25	10	8.8	54	5.7	1.9	30	10 (> 1 t)
SX2/PX24	65	8.1	59	14	7.2	10	5 (> 5 t)
SD4/PM45	10	8.8	147	5.7	1.9	30	10 (> 1 t)
SX4/PX46	80	9.8	153	∅ 10.1		10	5 (> 5 t)
SD6/PM65	10	8.8	105	5.7	1.9	30	10 (> 1 t)
SX6/PX64	80	9.8	110	∅ 10.1		10	5 (> 5 t)
SD8/PM85	10	8.8	108	5.7	1.9	30	10 (> 1 t)
SX8/PX84	80	9.8	113	∅ 10.1		10	5 (> 5 t)

Table 4.1. Main overhead traveling cranes [10]



Location	Capacity (kg)	Cabin dimensions (m)			Door width (m)	Speed (m/s)
		Length	Width	Height		
SD1/PM15	3000	2.70	1.85	2.70	1.85	1.6
SD2/PM25	3000	2.70	1.85	2.70	1.85	1.6
SD4/PM45	3000	2.70	1.85	2.70	1.85	1.6
SD6/PM65	3000	2.70	1.85	2.70	1.85	1.6
SD8/PM85	3000	2.70	1.85	2.70	1.85	1.6
SDX1/PX15	3000	2.70	1.85	2.70	1.85	1.6
SDX5/PM54	3000	2.70	1.85	2.70	1.85	1.6

Table 4.2. Main lifts to be used for lowering of equipment [11]

4.3.4 Underground Transport and Handling

The efficiency with which equipment and personnel can be transported underground has a major influence on the installation planning. The length and narrowness of the tunnel strongly influence the rate of transport of the equipment. The floor width, initially around 2.5 meters, will narrow down to 1.35 meters when the machine is installed. Crossing of vehicles transporting equipment becomes impossible over lengths of 3 km. (See Figure 4.4).

During the first phase of the installation, the general services, tractors and trailers, developed for underground use, are the standard means of transport. For the cryogenic line, trailers provided by the contractor are pulled by the same tractors. However, for the last phase, the equipment and methods used to transport each piece of machine equipment should be specifically selected. In particular, the warm magnets will be transported with the so-called buggies: the automatically guided vehicles developed for the injection tunnel magnet installation [12].

Figure 4.4 . An SSS trailer passing by an "installed" cryodipole

4.3.5 Organisation of Transport Operations

All the constraints already mentioned lead to strictly organised logistics. Most of the information is stored in a database, extracted partly from the reference database [13], a documented pre-warning is requested months in advance and all the transport requests are issued via an electronic procedure. This allows definition of handling methods and preparation of associated tools. On the surface, standard CERN transport procedures are used, but underground a transport schedule linked in real-time with the co-ordination schedule is issued. For this, all oversized and/or heavy components are transported by IC.

5 LHC NEUTRAL BEAM ABSORBERS (TAN)

The Neutral Beam Absorbers (TAN) are required to absorb the flux of forward high energy neutral particles that are produced at the high luminosity Interaction Point 1 and 5 of the LHC, thereby preventing these particles from quenching the twin aperture superconducting beam separation dipoles and localizing the induced activation to the absorber.

5.1 TAN Description

The TAN is a 30 Tonne absorber that is assembled from 8 subassemblies. Each subassembly is 5 Tonne or less in weight.

Figure 5.1 The Neutral Beam Absorber (TAN) shielding

The inner assembly of the TAN is the Absorber Box. The copper vacuum beam tube is at the center of the Absorber box and is surrounded by a copper clamshell and then a steel box. The OFHC vacuum beam tube has a large tube facing the IP which transitions smoothly to two tubes going away from the IP (Interaction Point).

Five steel assemblies surround the Absorber Box: the Lower Base Plate, Upper Base Plate, Cryo Side Shielding, Aisle Side Shielding and the Upper Shielding.

On the IP end of the TAN there are two marble subassemblies, the Cryo Side Marble and the Aisle Side Marble, to reduce the tunnel radiation exposure.

The TAN absorbs 315 W at ultimate luminosity (10^{34} $cm^{-2}sec^{-1}$) and is cooled by the ambient tunnel air.

The configuration and dimensions of the TAN are shown in Figure 5.2 and Figure 5.3.

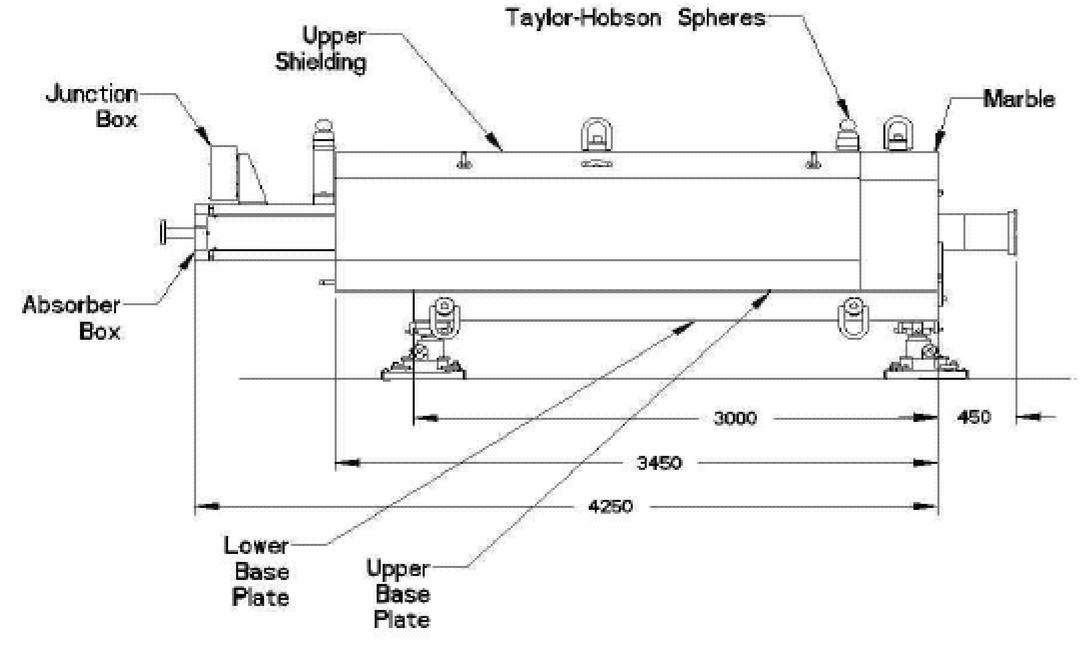


Figure 5.2. TAN Elevation View (dimensions in mm)

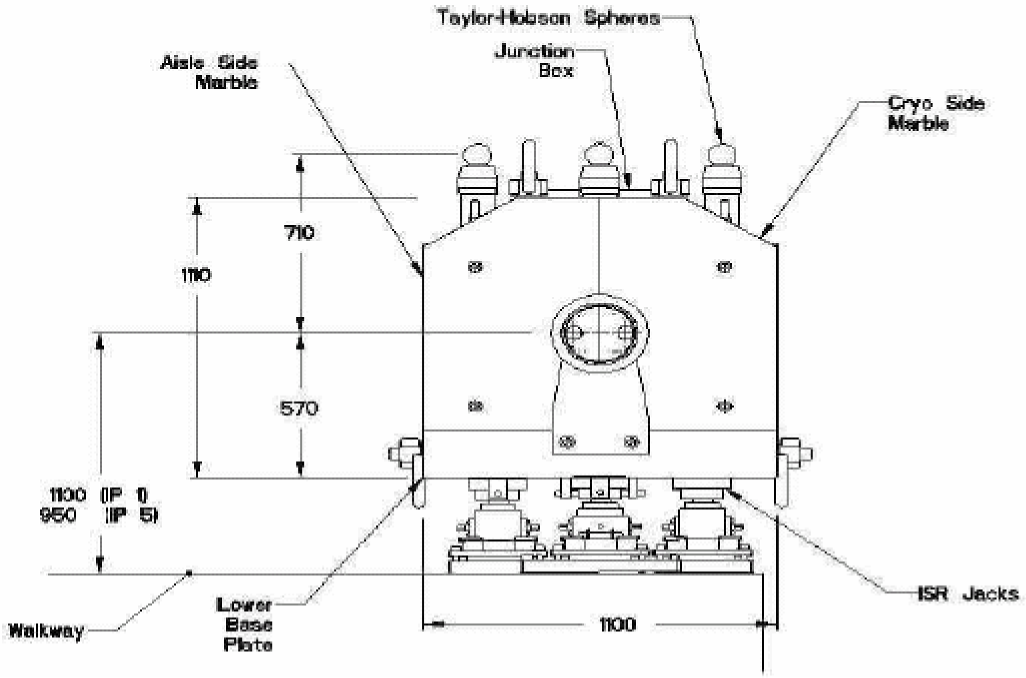


Figure 5.3. TAN End View - IP Side (dimensions in mm)

5.2 Functional Overview

At design luminosity 10^{34} $cm^{-2}sec^{-1}$, approximately 1KW of inelastic collision products leaves the high luminosity IPs 1 and 5 in each direction [14][15]. Special purpose absorbers are needed to protect superconducting magnets from this radiation to prevent them from quenching [16]. The function of the TAN is to absorb the neutral particles leaving the IPs, primarily neutrons and photons, that pass through the aperture of the quadrupole triplet.

The TAN is located between the two beam separation dipoles D1 and D2 and contains the transition from two beams in a common beam tube at the IR to two beams in separate tubes in the arcs. There are two TANs per IR1 and IR5. At the design luminosity of 10^{34} $cm^{-2}sec^{-1}$, each TAN absorbs 210 W. The TAN must reduce the maximum instantaneous power density transmitted to the conductor of twin aperture superconducting magnets to less than 0.4 W/Kg to protect them from quenching.

5.3 Technical Requirements and Design Parameters

In order to prevent quenching the maximum allowed radiation deposited power in LHC superconducting magnets is normally taken to be 1.2 W/Kg. The TAN is specified to transmit a maximum 0.4 W/Kg into the coils of the superconducting dipole D2 at design luminosity 10^{34} $cm^{-2}sec^{-1}$. Even at ultimate luminosity $2.5x10^{34}$ $cm^{-2}sec^{-1}$ the specified power density would be 1.0 W/Kg and less than the maximum allowed 1.2 W/Kg.

Following below you can see a summary of the main requirements and parameters of the TAN [17]:

5.3.1 Functional Requirements ($10^{34}CM^{-2}SEC^{-1}$)

Absorbed collision power at $L=10^{34}$ $cm^{-2}sec^{-1}$	210 W
24 hr average absorber collision power	126 W
Maximum transmitted beam power density to superconducting coils of D2	0.4 W/kg

5.3.2 Lattice Requirements

Distance from the IP to the TAN front flange	140.0 m
TAN flange to flange length	4.9 m
Distance from IP to back of the transition from one tube to two tubes	141.2 m
Beam tube horizontal separation, (s=±141.2 m)	160.0 mm
Beam tube horizontal separation, (s=±144.9 m)	160.0 mm

5.3.3 Tunnel Requirements

TAN locations	RI13 & RI17 for IR1 (ATLAS) R53 & R57 for IR5 (CMS)
Tunnel cross-sections	Shown on Figure 5.4 and Figure 5.5 on page 40
Nominal beam height from floor	1100 mm at IR1 950 mm at IR5

Nominal longitudinal tunnel slope	+1.23 % at IR1 -1.24 % at IR5
Nominal transverse tunnel slope	0 % at IR1 0 % at IR5
Longitudinal TAN slope	+1.23 % at IR1 -1.24 % at IR5
Transverse TAN slope	+0.73% at IP1 -0.73% at IP5
Maximum TAN width	1150 mm
Maximum TAN height Nominal	550 mm radius from the two-beam centerline
Tunnel floor loading	<0.5 MPa
TAN horizontal earthquake loading	0.15 g
TAN vertical earthquake loading	0.11 g
TAN support and adjustment	3 - 15 Tonne ISR magnet jacks
TAN support arrangement	Symmetric about the two-beam centerline
Tunnel crane limit for installation/removal	5 Metric Tonne

5.3.4 Vacuum Requirements

Beam tube material	Oxygen free high purity copper (OFHC) and Oxygen free with Silver (OFS)
Copper alloy options for the beam tube (Copper Development Assoc. Alloy numbers)	C10100 through C10800
Flange types	CERN ConFlat, 316LN stainless steel (rear) Helicoflex Quick Disconnect System Class 300 (front)

Flange modifications	OFHC ring explosion bonded to SS flange to attach copper beam tube
Copper surface preparation	LBNL Engr. Spec. M735
Stainless steel surface preparation	LBNL Engr. Note M7024
Fabrication methods	Electron beam welding
Vacuum qualification leak rate	7.5 X 10^{-11} Torr-l/sec in a 50% helium atmosphere for 2 minutes
Vacuum qualification base pressure	5 X 10^{-10} Torr
CERN vacuum processing	Glow discharge, NEG Coating at CERN
Maximum beam tube operating temperature (@$2.5\times10^{34}cm^{-2}s^{-1}$)	85C
In-situ beam tube bakeout temperature	200C
Minimum time to reach bakeout temperature	24 hrs

5.3.5 Vacuum Design Parameters

Beam tube facing IP (2 beams in one tube)	
Inner radius	106.0 mm
Mechanical tolerance (radius)	±2.1 mm
Transition section	
Inner radii	106.0 to 26.0 mm
Mechanical tolerance (radius)	Entrance/middle/exit ±1.9/±4.9/±1.4 mm
Beam tube away from the IP (2 beams in two tubes)	
Inner radius	26.0 mm

Mechanical tolerance (radius)	±1.1 mm
Vacuum chamber to alignment fiducial tolerance	± 0.6 mm

5.3.6 Absorber Design Parameters

Inner absorber material	ETP Copper (C11000)
Outer shielding material	Steel (G10200)
Front shielding material	Marble
Number of detector slots	1
Absorber width	1100 mm
Inner absorber length	3500 mm
Total weight (8 assemblies,<5 Tonne ea.)	<30 Tonne
Supports range of motion	±10 mm horiz. and vert.
Absorber cooling	Ambient air

5.3.7 Alignment Requirements

Survey line of sight	Horizontally 380 mm toward the aisle and vertically 400 mm above the two-beam centerline
Fiducial locations	Two at the end of the TAN facing away from the IP One at the end of the TAN facing toward the IP
Fiducial type	88.9 mm dia. Taylor – Hobson Sphere

5.4 TAN layouts in the tunnel

End-view layouts of the TAN located in the IR1 and IR5 tunnel regions of the LHC are shown in Figure 5.4 and Figure 5.5.

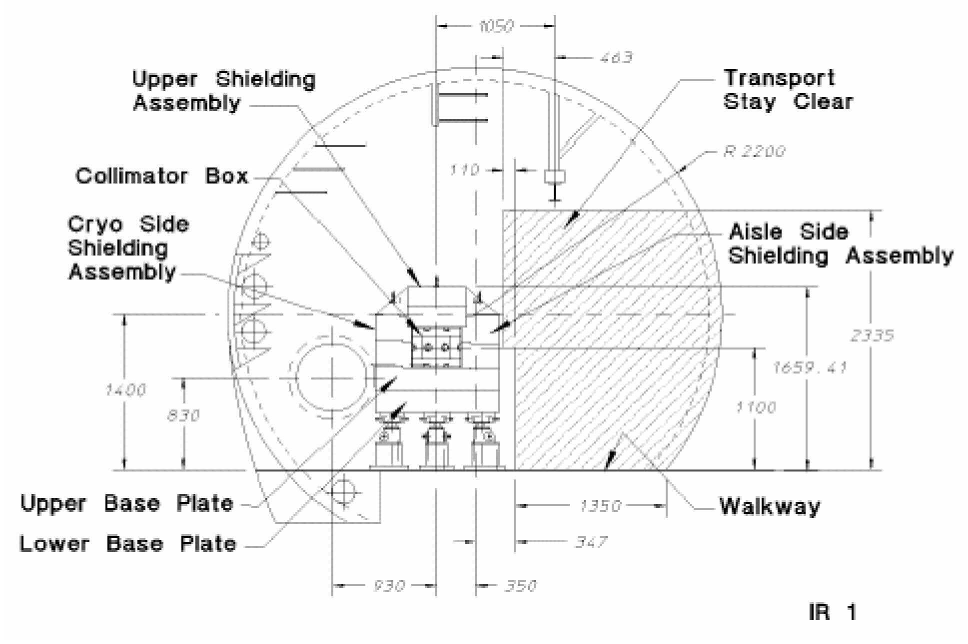


Figure 5.4. TAN shown in the IR5 region (dimensions in mm)

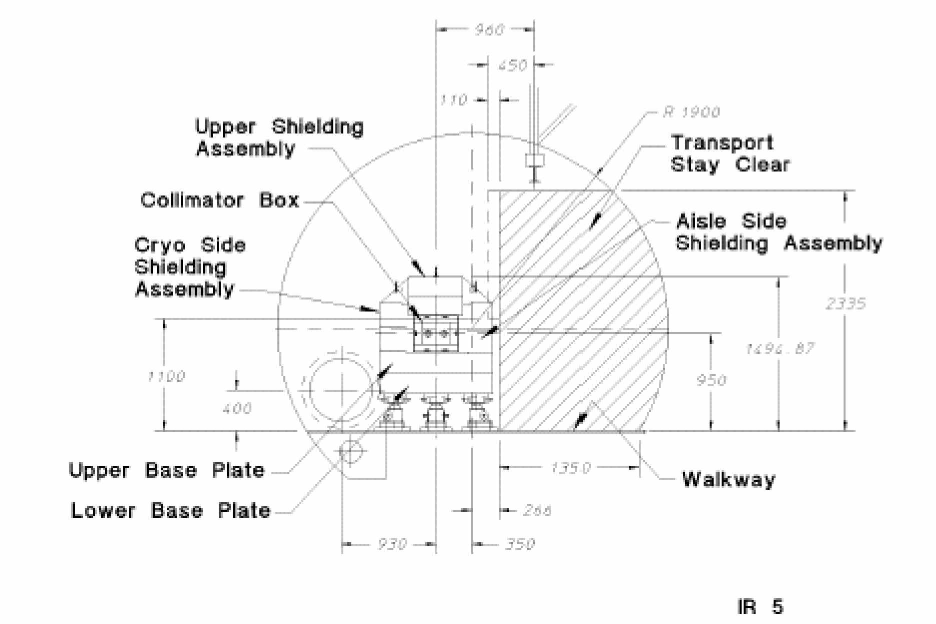


Figure 5.5. TAN shown in the IR1 tunnel region (dimensions in mm)

6 TAN Component Weights and Seismic Stability. The Jack Positioning

The TAN is assembled from eight subassemblies, each weighting less than 5 Tonne. Total TAN weight is almost 30 Tonne. The location of the three support jacks will depend on CERN's seismic safety standard and the space required to maneuver when installing the TAN in the tunnel.

6.1 TAN Component Weights and Longitudinal Center of Gravity

No	Component	Material	Specific Gravity	Nominal Size (mm)	Volume (dm^3)	Mass (Kg)	Center of Gravity from A (mm)	Moment about A (Kgmm)
1	Lower Base	Steel	7,85	190x1100x3000	627	4 922	1 350	6 644 633
2	Upper Base	Steel	7,85	190x1100x3000	627	4 922	1 800	8 859 510
3	Absorber Box	Copper	8,89	246x300x3500	258	2 297	2 350	11 337 219
		Steel	7,85	2x62x444x3800	209	1 643	2 200	
		Steel	7,85	2x72x246x3800	135	1 057	2 200	
4	Aisle Side	Steel	7,85	545x323x3000	528	4 146	1 800	7 462 124
5	Cryo Side	Steel	7,85	545x323x3000	528	4 146	1 800	7 462 124
6	Upper Shielding	Steel	7,85	305x185x3000	169	4 988	1 800	8 979 262
				350x444x3000	466			
7	Aisle Side Marble	Marble	3,11	920x550x450	228	708	75	53 111
8	Cryo Side	Marble	3,11	920x550x451	228	708	75	53 111
	Total					**29 537**		**50 851 093**

Figure 6.1. TAN Component Weights and Longitudinal Center of Gravity

$$\bar{z} = \frac{m_A}{W_T} = \frac{50{,}60 \cdot 10^6}{29536} = 1713\,mm$$

6.2 Vertical Center of Gravity

No	Component	Mass (Kg)	Center of Gravity from Floor (mm)	Moment about A (Kgmm)
1	Lower Base Plate	4 922	625	3 076 219
2	Upper Base Plate	4 922	815	4 011 389
3	Absorber Box	4 997	1 100	5 496 700
4	Aisle Side	4 146	1 183	4 904 273
5	Cryo Side	4 146	1 183	4 904 273
6	Upper Shielding	4 988	1 479	7 377 252
7	Aisle Side Marble	708	1 085	768 180
8	Cryo Side Marble	708	1 065	754 020
	Total	**29 536**		**31 292 307**

Table 6.1. TAN Component Weights and Vertical Center of Gravity (IR1)

$$\bar{y} = \frac{m_{FLOOR}}{W_T} = \frac{31{,}29 \cdot 10^6}{29536} = 1060\,mm$$

6.3 Jacks Positioning on TAN’s Base

In order to find the best position where the TAN will be placed, I have performed a mechanical analysis that is detailed in the Appendix A.

This analysis has been performed taking into account CERN seismic safety standard which requires that a device withstand 0,11 g vertical and 0,15 g horizontal acceleration without overturning.

All of the three jack’s spacing proposed by Berkley Laboratory fulfil the CERN safety standards. The configuration shown in Figure 6.2 has been chosen since is the one that combines a good stability of the load with a enough spacing between rear jacks for better manouvring when the transfer onto the jacks will be done.

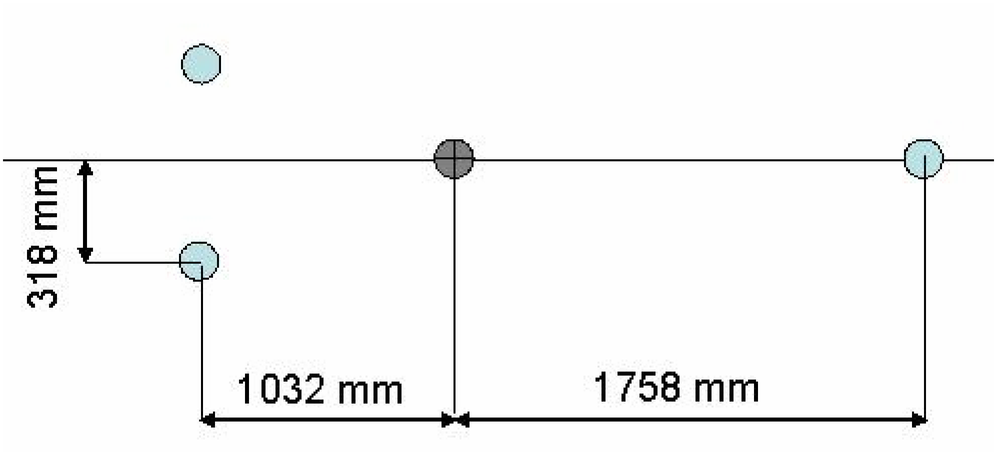


Figure 6.2. Sketch of the final position of jacks on TAN's base (top view)

6.4 TAN Jack Locations in the Tunnel

The 4 TAN's will be located 140 m. at each side of the experiences IP1 and IP5 (Atlas and CMS Detectors).

In order to ensure the exact position of the TANs the jack locations will be marked on the tunnel floor prior to TAN's installation. They will be:

Jack No	Longitudinal Position from IP (Y) (mm)	Transverse Position from the Two-Beam Centerline (X) (mm)
1	± 140 560 ± 2	0,0 ± 2
2	± 143 350 ± 2	± 318 ± 2
3	± 143 350 ± 2	± 318 ± 2

Table 6.2. TAN Jack location in the LHC tunnel

6.5 TAN Jack Floor Plates

The two floor plates have been dimensioned to stand the loads taken by each of the three support jacks (Calculations are shown at the end of the Appendix A).

Jack 1 will rest on a plate: 500 mm x 475 mm

Jacks 2 & 3 will rest on a plate: 950 mm x 475 mm

Floor Plate No	Jacks on Plate	Floor Plate size (mm^2)	Load on Plate (Tonne)	Unit tunnel loading (MPa)
1	1	500 x 475	10, 93	0, 45
2	2 & 3	950 x 475	18, 61	0, 40

Table 6.3. TAN Jack Floor Plates Dimensioning

In the next picture we can see the a virtual image of the already assembled TAN sitting on the three support jacks and the two floor plates:

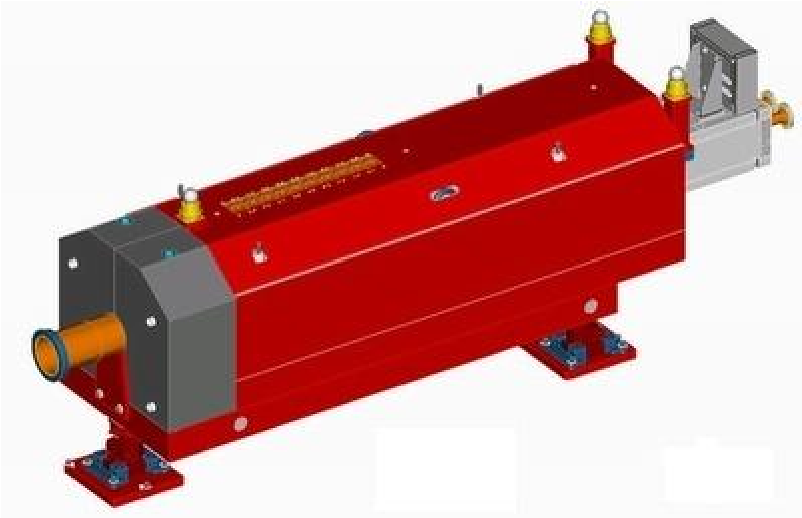


Figure 6.3. Virtual image of the assembled TAN

7 The TAN’s Vacuum Chamber

The TAN’s Vacuum chamber is a welded copper assembly constructed of two long, small diameter tubes welded to a much larger diameter tube/transition section. The critical welds at the joint between the sections as well as the long tubes themselves could be damaged easily by bad handling. Overstressing any of the critical areas could compromise the vacuum integrity and performance of the Vacuum Chamber [18].

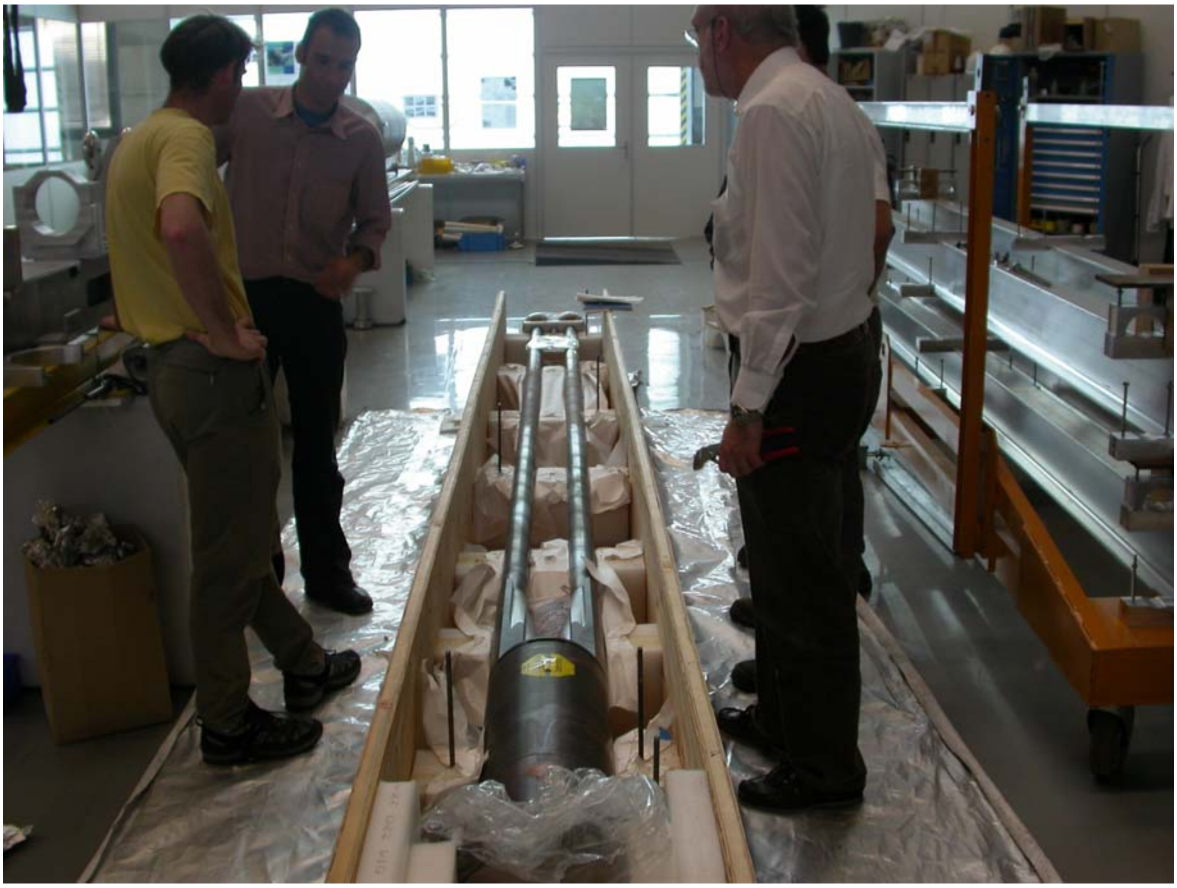


Figure 7.1. Picture of a TAN's Vacuum Chamber in its shipping case

7.1 Analysis of the horizontal handling of the TAN’s Vacuum Chamber

7.1.1 Introduction

In order to ensure that the critical areas of the Vacuum Chambers are not overstressed during testing and assembling a horizontal analysis using two support points has been performed. (See Appendix B for the complete calculus procedure):

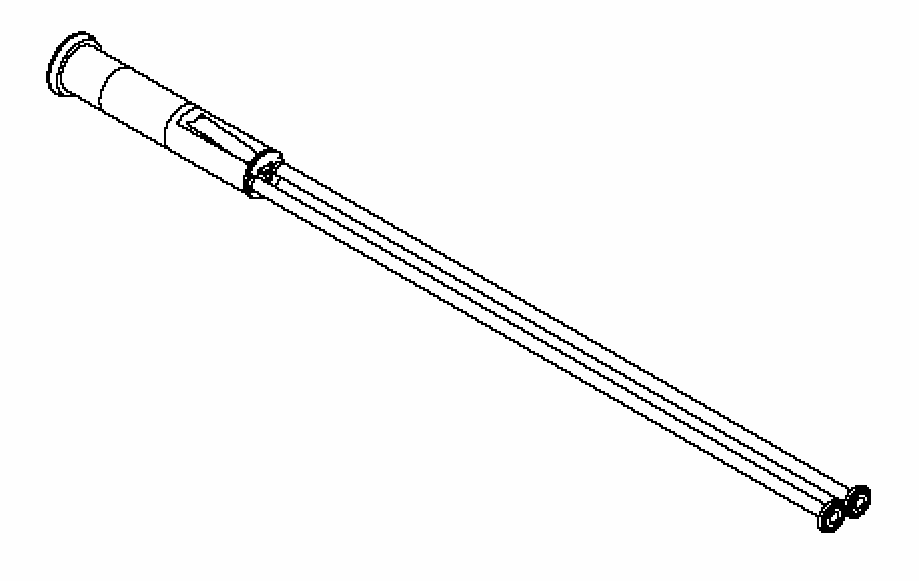
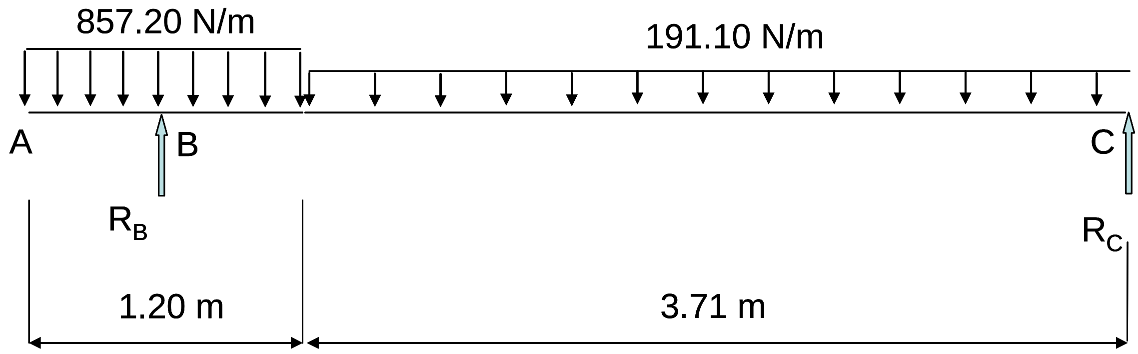


Figure 7.2. 3D view of the TAN Vacuum Chamber

Three different models have been studied:

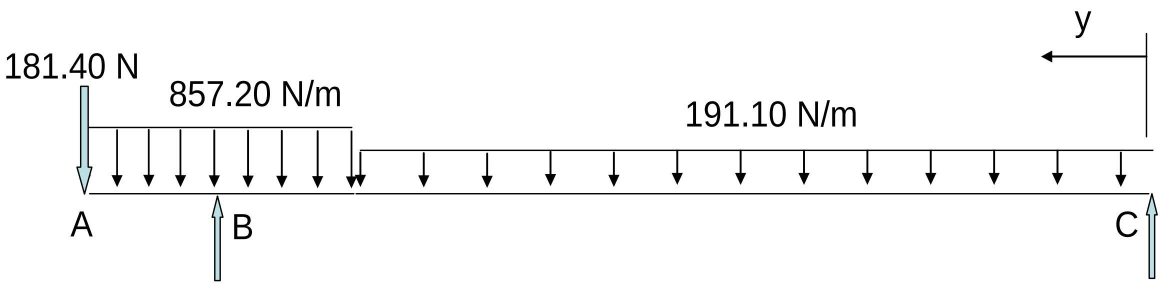
- **The first model**

Consisting of the two sections of the Vacuum chamber with two support points (one at the c.g. of the large end the other one at the extremity of the twin beamtube):



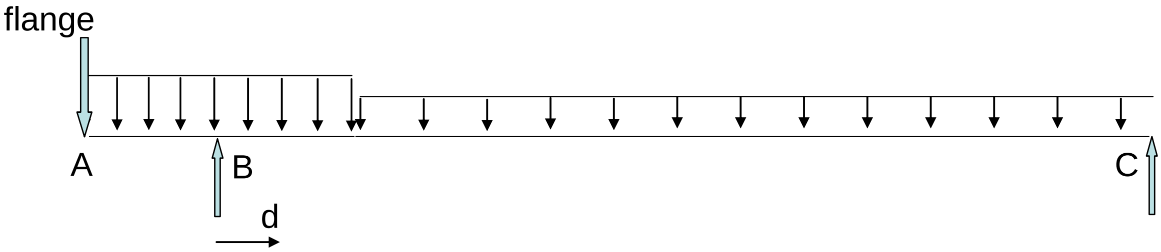
- **The second model**

Including the action of the flange adapter (181.4 N) at the left end of the large end section:



- **The general model**

In order to study all the possible positions of the support point B depending on the reactions, bending moments and stresses that would appear.



7.1.2 Tables, plots and results

The Table 7.1 shows the values of the Maximal Bending Moment, Maximal Stress and the reactions for different positions of the support B:

d [m]	M_{MAX} [N m]	σ_{max} [N/cm^2]	R_c [N]	R_B [N]
-0,60	840,08	3 129,01	566,64	1 352,07
-0,50	758,80	2 826,26	538,53	1 380,18
-0,40	678,47	2 527,06	509,23	1 409,48
-0,30	599,44	2 232,71	478,65	1 440,06
-0,20	522,13	1 944,76	446,72	1 471,99
-0,10	447,02	1 665,00	413,34	1 505,37
0,00	374,67	1 395,50	378,42	1 540,29
0,10	305,72	1 138,70	341,83	1 576,88
0,20	240,94	897,43	303,46	1 615,25
0,30	181,22	674,99	263,18	1 655,53
0,40	127,60	475,28	220,84	1 697,87
0,50	81,30	302,81	176,28	1 742,43
0,60	43,75	162,95	129,31	1 789,40

Table 7.1. Values of the Maximal Bending Moment, stresses and reactions in function of the position of the support point B

Plotting the relation $M_{MAX}(d)$ (Figure 7.3) we see that the maximal bending moment decreases as we move the support point B inboard:

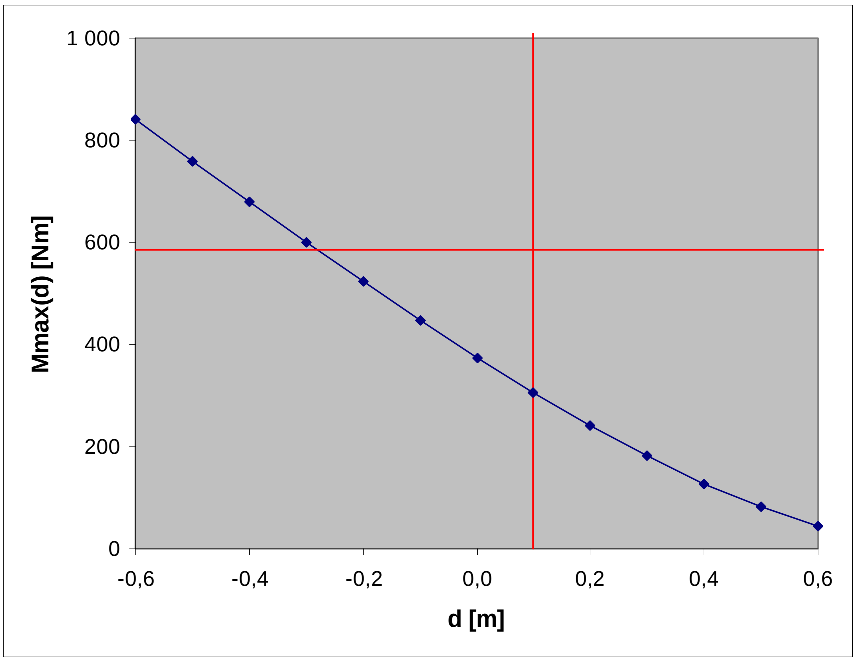


Figure 7.3. Relation between the Maximal Bending Moment and the position of R_B

From distances d=0.10 to d=0.6 the large end part enters in its transition segment. In this transition segment, where a special particle detector will be placed, we are not allowed to set a support (delimitated by the vertical red line x = 0.10).

The horizontal red line, y = 585.29, delimitates the maximal allowable bending moment for the vacuum chamber.

In the next plot (Figure 7.4) we can also see the relation between the stress induced by the maximal bending moment and the different positions of the support point B:

The horizontal red line, y = 2180, delimitates the maximal allowable tensile stress for the vacuum chamber.

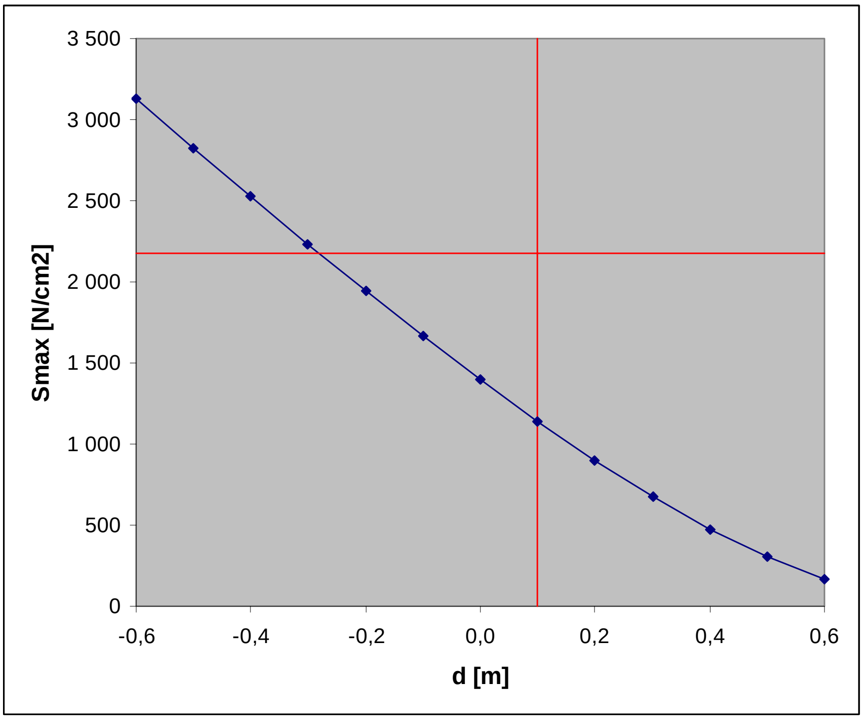


Figure 7.4. Relation between the Maximal Tensile Stress on the chamber and the position of the support point B

As we could imagine and we can see in Table 7.2 and in Figure 7.5 the incidence of the reactions on the support points B and C does not compromise the structure since the tangential stresses are so low:

d [m]	R_c [N]	σ_B (2T/A) (N)	R_B [N]	σ_C (2T/A) (N)
-0,10	413,34	40,78	1 505,37	98,36
0,00	378,42	37,34	1 540,29	100,64
0,10	341,83	33,73	1 576,88	103,03
0,20	303,46	29,94	1 615,25	105,54
0,30	263,18	25,97	1 655,53	108,17
0,40	220,84	21,79	1 697,87	110,94
0,50	176,28	17,39	1 742,43	113,85
0,60	129,31	12,76	1 789,40	116,92

Table 7.2. Values of the tangential stresses induced by the reactions on the support points

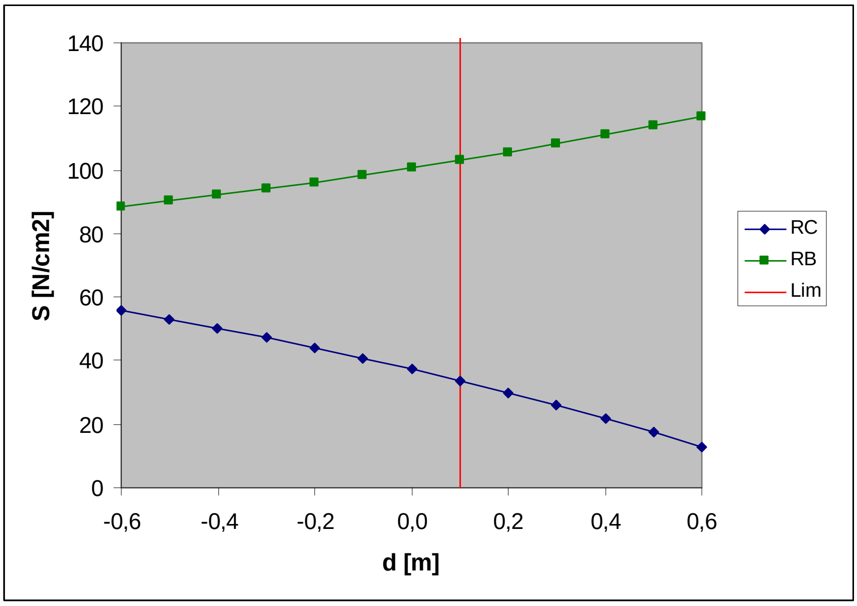


Figure 7.5. Tangential stresses at the support points related to the position of the support B

Choosing the support B to be situated 0.65 meters from the left end of the Vacuum Chamber (d=0.05) will induce low and acceptable stresses to the structure and will give a enough tolerance (± 50 mm) for the handling team. The values of the reactions, maximal moment and stresses will be:

d [m]	M_{MAX} [N m]	σ_{max} [N/cm^2]	R_c [N]	σ_B [N]	R_B [N]	σ_C [N]
0,05	339,72	1 265,35	360,34	35,55	1 558,37	101,82

Table 7.3. Values of reactions, max moments and stresses for the final position of support B

7.2 General lifting and moving instructions

7.2.1 Support/Lift Point Locations

Support B: situated 650 mm. from the left end of the Vacuum Chamber (tolerance ± 50 mm)

Support C: situated at the right end of the Vacuum Chamber (a little inboard ± 50 mm)

7.2.2 Crane maneuvering

The crane hook shall be positioned directly over the center of mass of the load.

Good care needs to be taken when moving the Vacuum Chamber since accelerations greater than 1.35g [24] could overstress the critical areas.

7.2.3 Danger of overturning

In a horizontal position, there will be no danger of overturning of the chamber when choosing the support point B between d = - 0.6 and d = 0.3. With the support point B situated 0.65 m. from the left end (d = 0.05) there should not be any problems of stability. Nevertheless, the large end will always be raised slightly before the twin beamtubes end, and the twin beamtubes end will always be lowered before the large end, to assure the load's stability.

Figure 7.6. Lifting of the Tan's Chambers following the instructions stablished above

8 The Non Evaporable Getters Film Coating

8.1 Introduction

In order to achieve a stable beam and to increase the life time of the LHC it is really important to perform a good cleaning of the inner surface of the vacuum chambers. The search for an effective solution to the problem, lead, at the end of 1995, to the start of the development of Non Evaporable Getters (NEG) thin film coatings at CERN. Coating the whole inner surface of a vacuum chamber, after dissolving the NEG oxide layer by heating (activation) transforms it from a source of gas into a pump providing very high pumping speed per unit length [19].

The TiZrV ternary allow was chosen over a broad range of compositions for its low activation temperature (180 °C). This low temperature allows best quality film coatings to be produced by sputtering from low cost cathodes made of intertwisted wires of the constituent elements (stainless steel, copper and aluminium) [20].

Because of its favourable characteristics, TiZrV will be extensively applied in the LHC warm sections and in the experiments ATLAS, ALICE and CMS.

8.2 Application of the TiZrV NEG coated films to the LHC

The beam vacuum system interposed between the cryogenic modules of the LHC, called long straight sections (LSS), will operate at room temperature. In order to achieve the optimal operating conditions, most of its components will be coated with TiZrV films. It is the case for the 700 LSS drift space chambers, designated here as LSS standard, and the 285 warm magnet chambers (MQW, MCBW, MBW, MSI, MSD and MBWMD), designated as LSS non-standard.

Some additional chambers (about 50) for the experimental areas of ATLAS, CMS and ALICE will also be coated. These chambers present a wide range of lengths and cross sections, and are made of stainless steel, aluminum alloy and beryllium brazed to stainless steel sleeves. The LSS non-standard chambers also present a wide spread of lengths (from 1 m to 5 m), with circular and elliptical cross sections, and are made of copper, mumetal or stainless steel.

The 4 TANs will operate at room temperature. Therefore their vacuum chambers will also be coated with TiZrV films. After this operation the chambers will be sealed, filled with dry nitrogen at 1, 2 atm. and stored.

8.3 Coating facilities

For series production, a new coating facility with three coating units was created. One unit is dedicated to the coating of the LSS non standard and experimental chambers, and the other two to the LSS standard chambers. Each unit consists on a vacuum pumping system, a manifold, a base support and a vertical solenoid (see Figure 8.1).

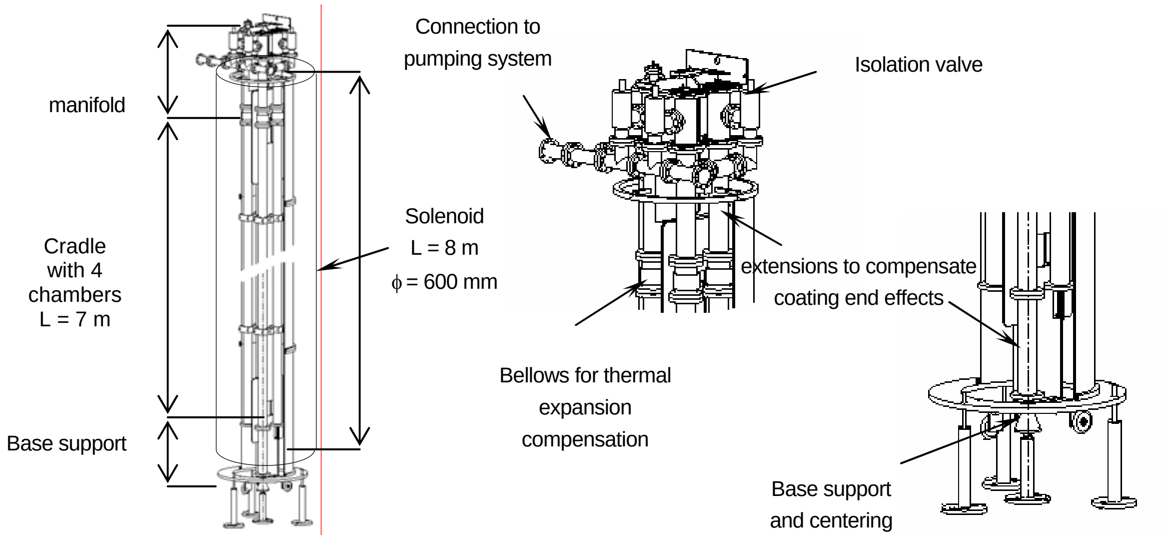


Figure 8.1. Coating set-up for the standard LSS vacuum chambers

Four chambers to be coated are assembled on a cradle. The vacuum pumping system, driven by a rotary-turbomolecular pumping station, is equipped with a discharge gas injection line (Kr as discharge gas), a dry air venting injection line, a pumping by-pass, two cold cathode gauges, and a residual gas analyzer (RGA). An electropneumatic gate valve isolates the system in case of power failure, keeping it under vacuum [21].

A manifold, supported by a stainless steel structure, allows the pumping of the chambers and provides a rigid mechanical connection to the cradle. Each chamber can be isolated from the rest of the system by a valve. The supports and electrical feedthroughs for the cathodes are located on top of the manifold and are fed by four 1.5 kW DC plasma power supplies (one per cathode). At the other extremity of the cradle, a mechanical support allows the centering of the assembly inside the solenoid. The solenoid is 8 m long, has a 600 mm internal diameter and provides a magnetic field of 150 Gauss.

Figure 8.2.The two solenoid units. The right one with four LSS chambers being coated

A 16 m long assembling bench allows the horizontal insertion of the cathodes in the chambers. The whole structure can then be lifted up with a crane and inserted into the solenoid, installed inside a 6.3 m deep pit. The vacuum pumping system is installed on a platform located at the top of the solenoid and is connected to the manifold by a bellows.

Figure 8.3. 4 LSS chambers waiting on the assembling bench to be coated

All the coating parameters, (pressures, residual gas analysis, currents and voltages), are computer monitored, giving a real time view of the global process to the operator.

8.4 The coating procedure

To obtain a 2 μm thick film in one working day, a deposition rate of 0.2 μmh^{-1} has been chosen; it is obtained by imposing a cathode current of 1.5 A and a voltage of -500 V at a pressure of about 5×10^{-3} Torr and a magnetic field of 150 Gauss. The chambers are baked over night at 200 ^{o}C and maintained at 100 ^{o}C during coating. Pressures on the low 10^{-8} Torr are attained at this stage. Each coating unit is able to coat four chambers in 2 working days and the operation of two coating units in parallel allows a maximal production rate of four chambers per working day.

A coating cycle requires a day to mount four chambers and pump down, and one day for coating. Then the chambers are vented with dry air, dismounted, pumped with an independent turbomolecular pumping station, filled with dry nitrogen and stored. In parallel, four new chambers are installed and a new cycle is started.

9 The NEG Coating Lifting Assembly

9.1 Introduction

As it has been introduced in Section 8.3, it already exists a coating procedure for the 700 LSS standard vacuum chambers. With the aim of coating at a rate of 20 chambers/week a structure was developed to allow four chambers at a time to be lifted up with a crane and inserted into the coating solenoid. This structure sits on a 16 m long assembling bench which allows the horizontal insertion of the cathodes in the chambers:

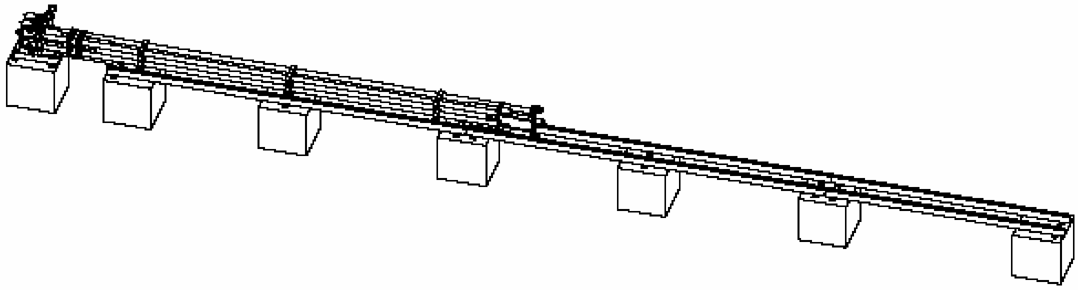


Figure 9.1. LSS NEG Coating horizontal Assembly

Figure 9.2. Picture of four LSS Chambers ready to be coated

For the non standard vacuum chambers no particular procedure has been implemented for their NEG coating. Due to the special dimensions and fragility of the TAN's vacuum chambers another structure was needed to be designed.

9.2 The NEG Coating of the TAN Vacuum Chambers

Unlike the coating of the standard LSS chambers, four cathodes will be used to the coat each one of the TAN vacuum chambers. Two will be placed in the large end (due to its big diameter) and the other two in each one of the twin tubes. They will penetrate the chamber through the bottom and top extensions. From the top extension, a manifold will allow the pumping of the chamber down to 10^{-8} Torr.

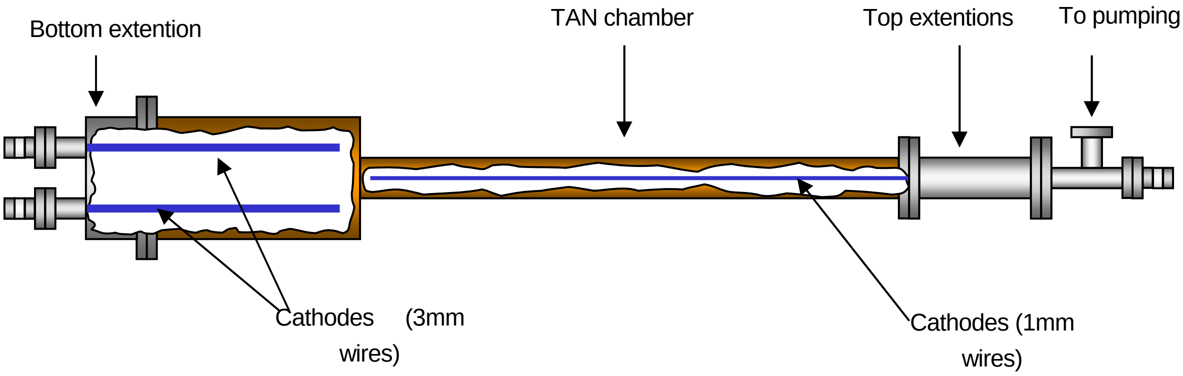


Figure 9.3. Sketch of the coating material for the TAN Vacuum Chambers

9.3 The NEG Coating lifting assembly

In order to insert the chamber into the vertical solenoid, hold it during the coating and prevent it from damaging, a new assembly will be needed. This lifting assembly will need a bottom support which will stand the chamber in vertical position and will center the chamber att the base of the solenoid. It will also need support for the chamber when in horizontal position and a connection to the crane that will lift the whole structure and introduce it into the solenoid.

This structure will be compatible with the 16 m long assembling bench from which it will be lifted. The next figure shows a sketch of the assembly holding the chamber and the extensions.

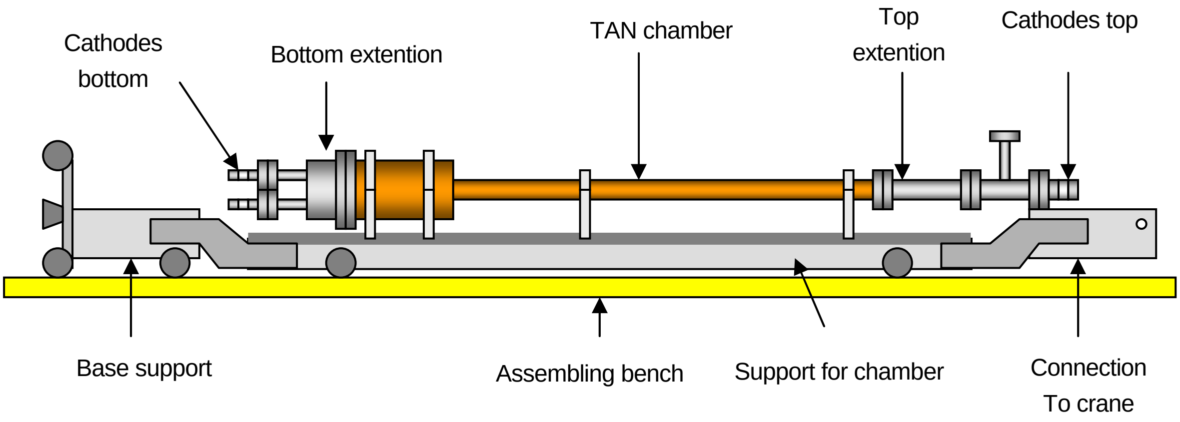


Figure 9.4. Sketch of the NEG Coating Lifting Assembly for the support of the Chambers

9.3.1 Parameters considered for the design of the NEG Coating Lifting Assembly

The design of the lifting assembly must be compatible with the 16 m long assembling bench used to coat the LSS standard vacuum chambers. It must also assure that the TAN vacuum chamber does not overstress.

The parameters considered for the design of the NEG Coating Assembly have been the following:

- **The profile of the beam support**: the main purpose of the support is to stand the flexion due to the weight of the chamber. Considering a general section subjected to pure flexion Mz, we know that the maximal normal stresses will be in the upper and lower fibers [26] :

$$\sigma_{x\max} = \frac{M_z}{I_z} \cdot \frac{h}{2} \tag{9.1}$$

Being the geometrical concept ‘Resistance Moment’:

$$W_z = \frac{I_z}{\frac{h}{2}} \tag{9.2}$$

The expression 9.1 becomes:

$$\sigma x_{\max} = \frac{M_z}{W_z} \tag{9.3}$$

The best section for the profile will be the one with the higher resistance moment Wz.

The geometrical performance of a section is defined by the relation between the inertia moment of the section and the ideal inertia moment of a section of the same area with all the material concentrated at the maximal distance from the neutral axis [27].

From the regular section that we can find in the industry the best selection is an I profile.

- **The Beam Support's material**: the use of a magnetic material for the main beam support is not allowed since the assembly will rest with the chamber inside the solenoid which provides a magnetic field up to 300 Gauss.

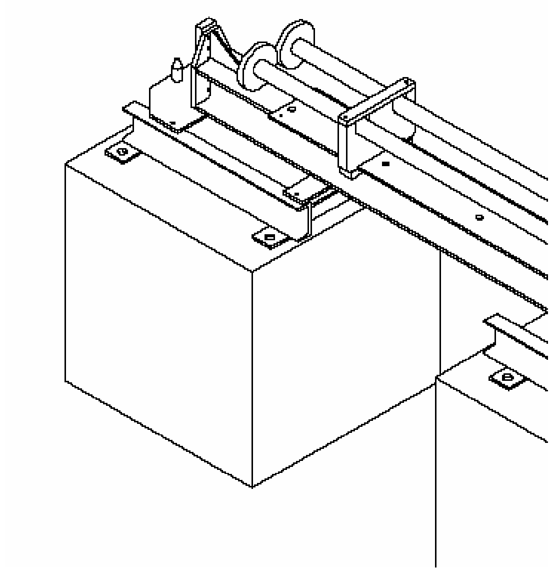
  The choice would be between a non magnetic stainless steal and aluminum.

  The aluminum is the non magnetic material that is used the most at CERN. Particularly aluminum beams are used to coat the standard LSS vacuum chambers. Since its performance inside the solenoid has already been tested and the cost of it would be lower, the aluminum will be the main structural component of the assembly.

- **The height of the Beam Support Section**: The higher the section the best that it will resist the flexion. This parameter is mainly determined by the configuration of the assembling bench and the diameter of the solenoid.

  The extreme of the assembling bench, where the crane fits the hook connected to the lifting assembly, has a configuration that cannot be removed and(figure adsf) that does not permit spaces for a beam higher than 150 mm.

Figure 9.5. Detail of the extremity of the assembling bench



The solenoid has a theoretical diameter of 600 mm. However measuring the irregularities on the real solenoid, I could not consider the practical diameter bigger than 595 mm.

- **The length of the Beam Support**: The length of the beam support is mainly determined by the depth of the solenoid and the length of the extensions that will go on the extremities of the vacuum chamber.

  The solenoid is 8 meters depth. The manifold (for pumping) connected to the upper extension of the vacuum chamber has to come out the solenoid. Including the hook to connect the crane and the base centering support that will be attached to each of the extremities of the structure, the assembly should measure between 8.5 and 9 meters long.

Several configurations of I aluminum beams have been tested in terms of stress and deformation. Assuming a maximal deformation of 10 mm on the beam support there is an existent beam at CERN which compiles perfectly (less than 3 mm of deformation with the chamber charge on it).

The diameter of the solenoid would leave enough space to fit the already existent beam but in one local point, at the extremity of the large end part, where the helicoflex flange is situated. The flange (80 mm long) sticks out from the vacuum chamber 40 mm. Since this conflict is only 80 mm long, a local cut of the beam has been considered:

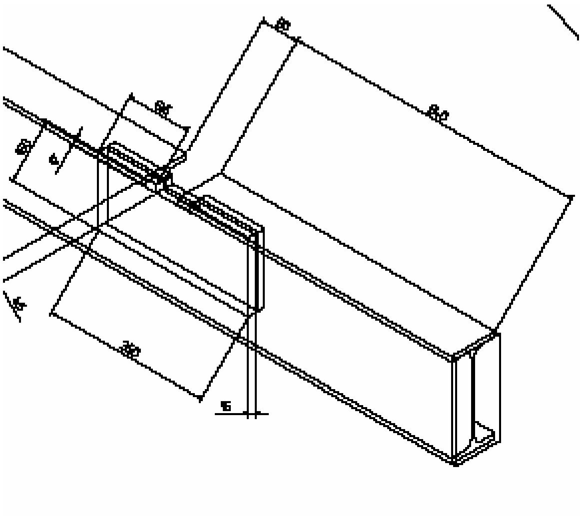


Figure 9.6. Local cut of the main Beam extremity

This configuration will allow using the existing beam. This beam is 6.5 meters long. At the end of it another beam (150 mm x 150 mm) could be attached by an adaptor piece in order to save the conflict with the assembling bench.

This two beams are from Alcan Allega Industries (www.allega.ch), type Anticorodal 112 and have the next specifications:

Number	h (mm)	b (mm)	Length (mm)	I_z (cm^4)	W_z (cm^3)
31528-12	215.9	101.6	6500	3010.6	278.0
31691-11	150.0	150.0	6000	1960.10	261.3

Table 9.1. Specifications of the two selected beams

The Beam 31691 would be cut to 1900 mm

Several Finite Element simulations have been carried out in order to determinate:

The position of the cut and the vacuum chamber supports on the top of the structure

- The dimension and types of support plates in order to give more rigidity to the whole assembly

Some of the simulation models and results can be seen in the Appendix D

9.4 The definitive NEG Coating Lifting Asssembly

The NEG Coating Lifting Assembly is 8780 mm long from end to end. It is mainly composed of the two aluminum beams explained above unified by an adaptor piece. Support plates in aluminium (10 mm thick) are distributed on the top of the beams in order to better place the tooling that will support the vacuum chamber and to give more rigidity to the structure. The first beam (216 mm x 102 mm), which is locally cutted on the right end also incorporates lateral plates (10 mm thick) to rigidify the structure.

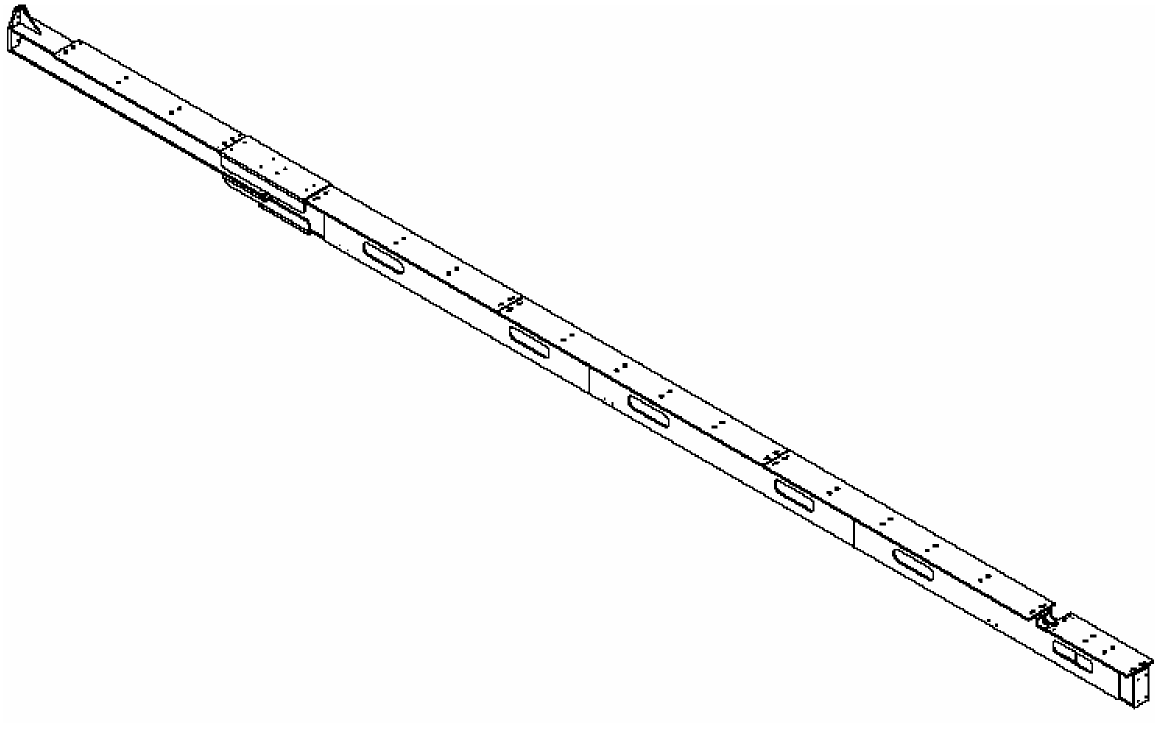


Figure 9.7. The two beams unified with support plates

In the next picture we can see an explosion of Figure 9.7. Here we can better identificate:

- the longer beam locally cutted on the right extremity
- the shorter beam which will connect to the crane
- the adaptor piece to unify the two beams
- The 5 upper support plates
- The six lateral plates welded to the longer beam

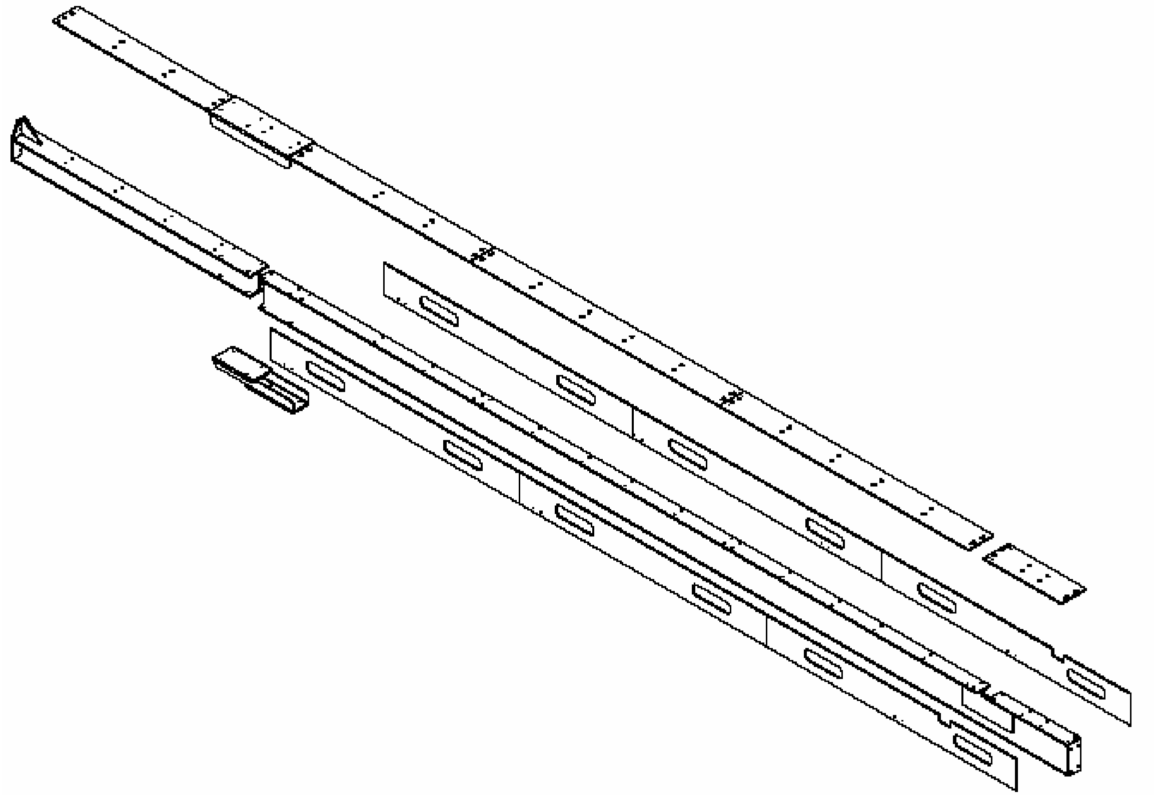


Figure 9.8. Explosion of the main structural part of the lifting assembly

Two clamping flanges will support the vacuum chamber in horizontal position. One situated in the c.g. of the large end part of the chamber and the other one on the c.g. of the twin beamtube end part.

One clamping flange situated on the right end of the structure will support the weight of the chamber when in vertical position inside the solenoid. Another clamping flange is situated on the left end to prevent the chamber from moving.

The rest of the tooling will able the connection to the crane, the centering of the load inside the solenoid and the running on the assembling bench. The approved plans for all the NEG Coating tooling can be found in the Appendix F.

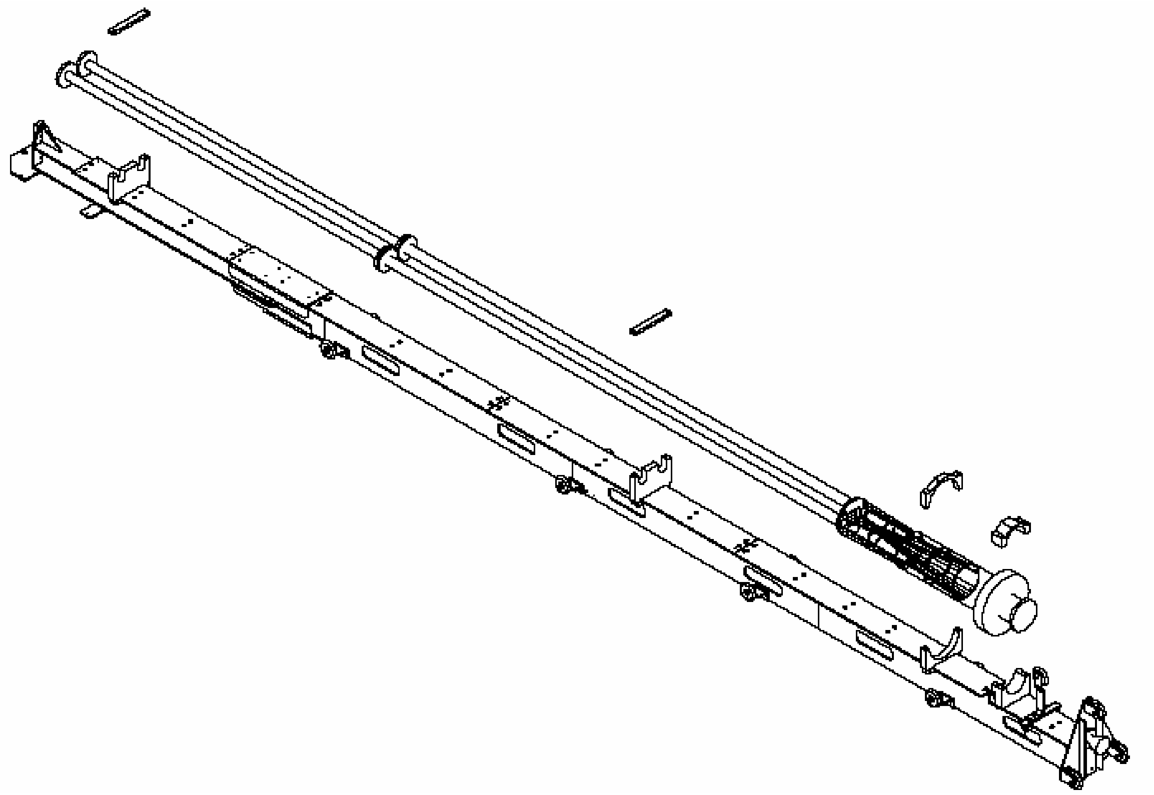


Figure 9.9. Explosion of the whole Lifting Assembly with the TAN Vacuum Chamber

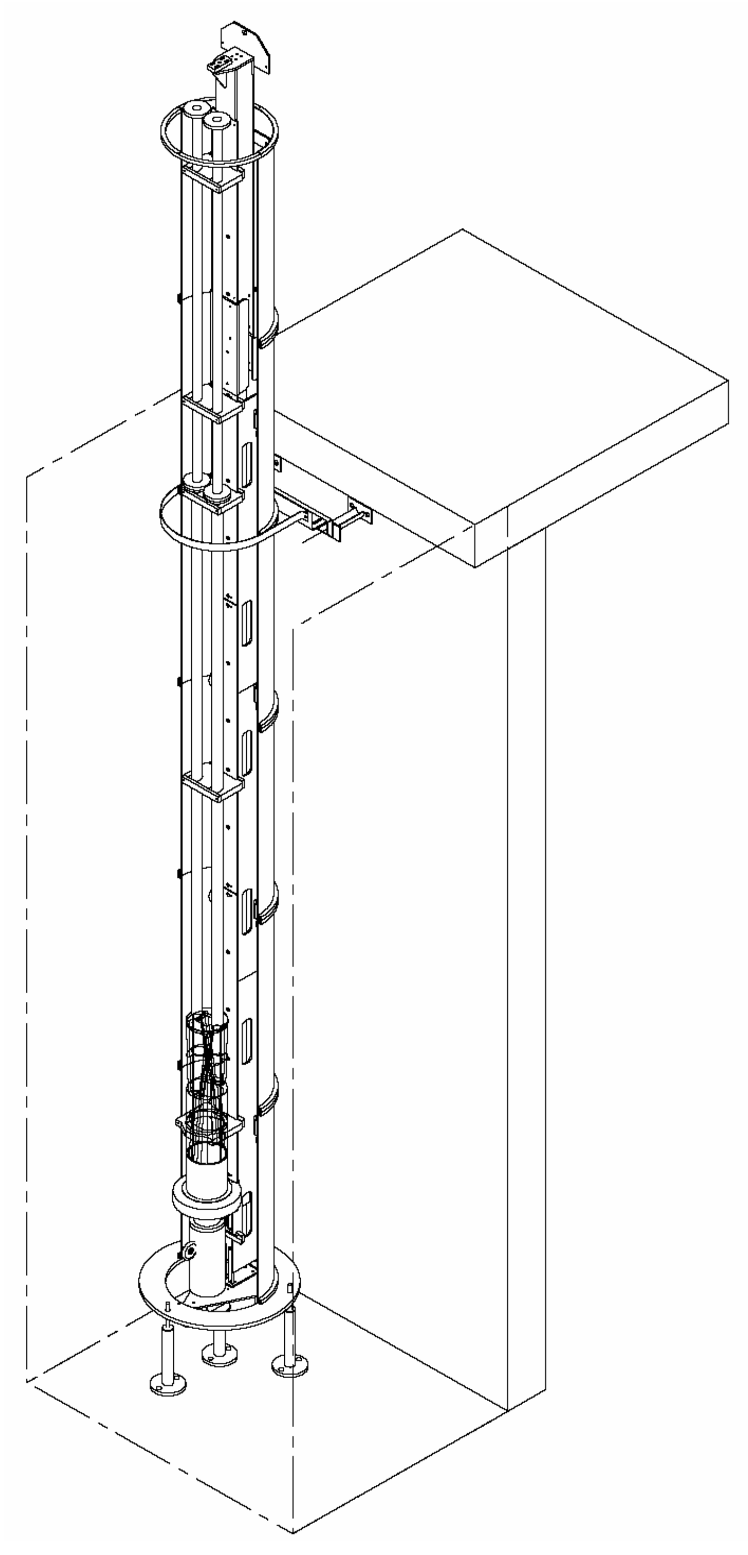


Figure 9.10. Vertical configuration of the Lifting Assembly with the Chamber

9.5 Results and Figures of the Simulations and Tests of the definitive Lifting Assembly

As it can be seen in the Appendix D, several models have been simulated in order to assure that the lifting assembly would compile with the constraints of deformation and stress. Ansys 8.1 and Ansys Workbench have been used as simulation tools in order to select the best configuration.

9.5.1 Finite Elements Simulation with Ansys 8.1

Following below are shown the plots and results corresponding to the definitive model of the Lifting Assembly:

A horizontal analysis has been carried out considering the worst moment (higher equivalent stresses and deformations) when the crane starts to pull up the assembly. In that instant there will only be two supports: the crane hook and the two rear wheals.

The Environment is formed by:

- Two fixed supports on both extremities of the assembly.
- Two vertical forces, 1100 N and 900 N, representing the weight of the Vacuum Chamber one on each of the two clamping flange supports.
- One vertical surface force of 2000 N, representing the weights of the rest of the tooling not modeled in Ansys, all over the upper support plate.
- The Standard Earth Gravity.

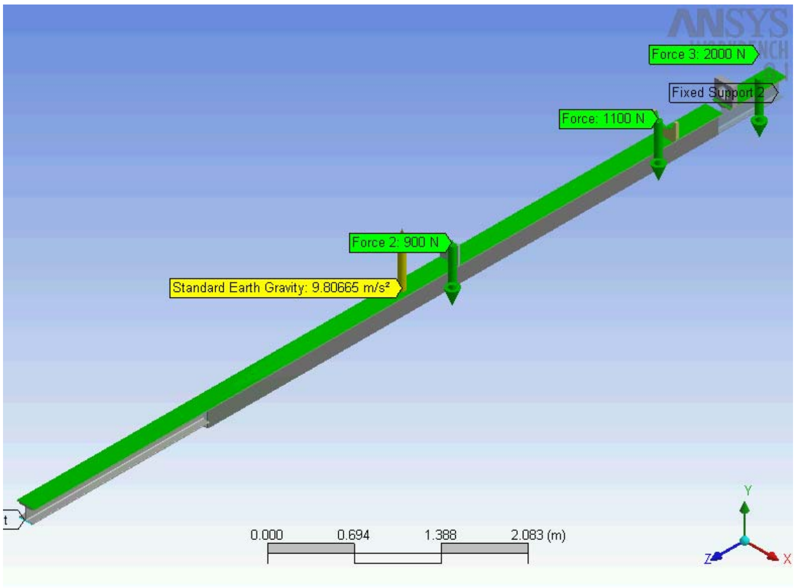


Figure 9.11. Environment of the definitive Assembly Model

With a Mesh of 24142 nodes and 10683 elements:

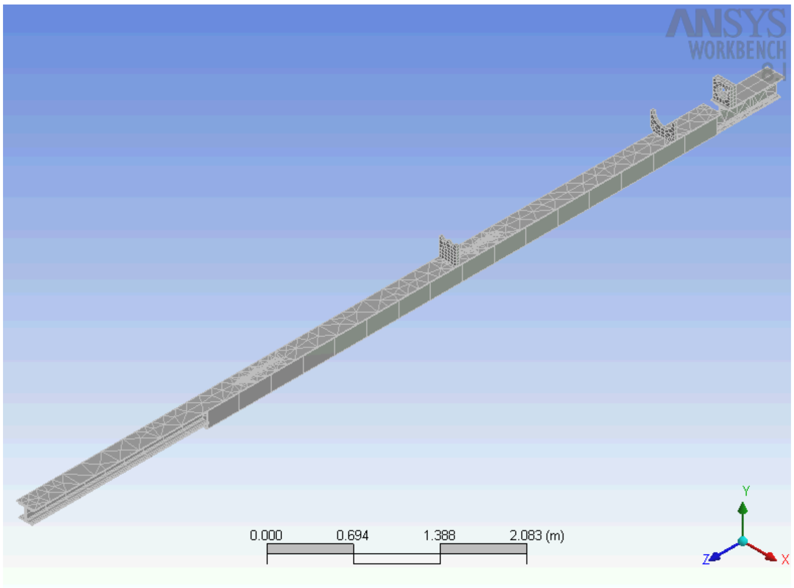


Figure 9.12. Mesh of the definitive Assembly Model

We can see in the next figures how the stress transmitted to the Vacuum Chamber is acceptable and does not exceed the Maximum allowable stress:

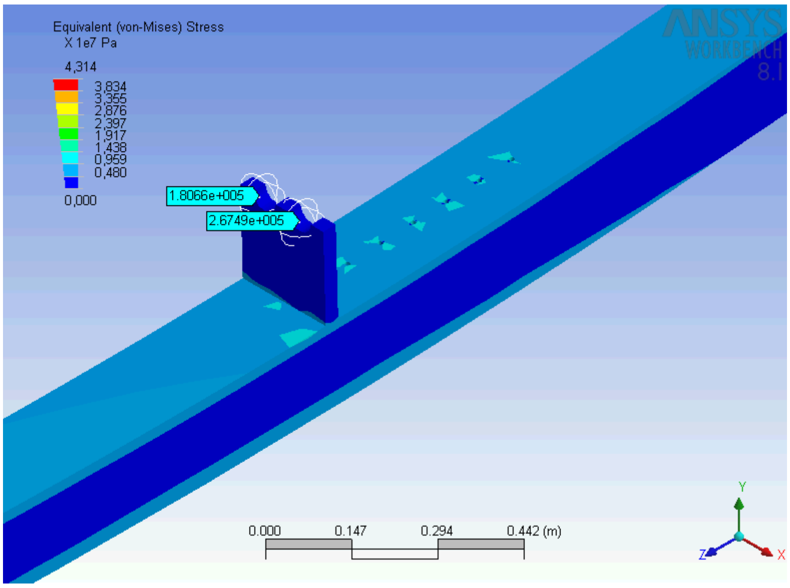


Figure 9.13. Equivalent Stress on the twin beam tube support

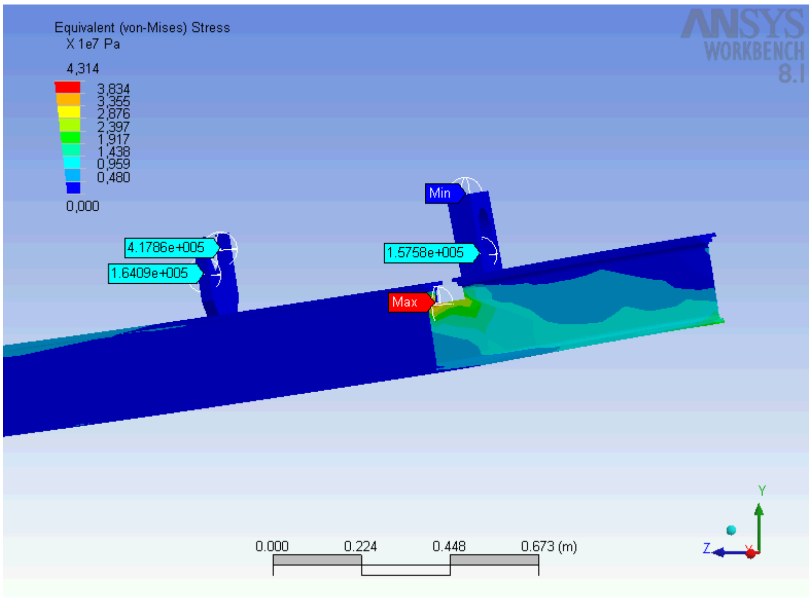


Figure 9.14. Equivalent Stress on the large end support

The deformations of the Assembly are also acceptable (less than 1 cm in the central part):

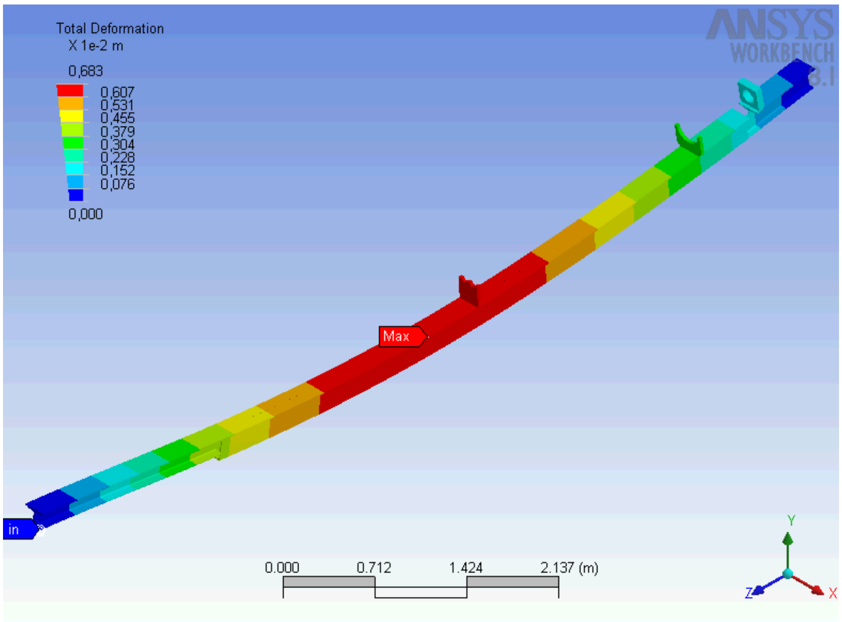


Figure 9.15. Total deformation of the whole Assembly

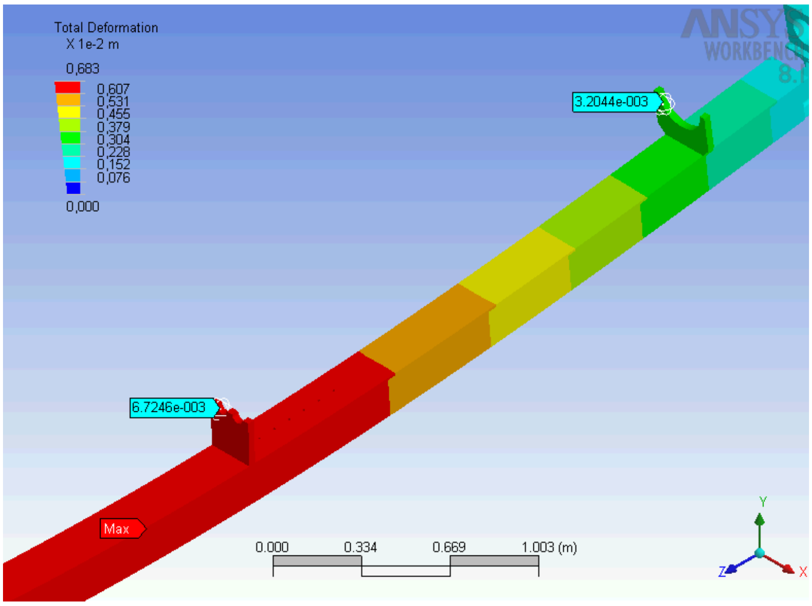


Figure 9.16. Deformations on the supports of the Chamber

A vertical analysis has also been carried out to assure the stresses and deformations of the assembly when lifted by the crane and inside the solenoid.

As we could predict, lower stresses (maximum of 10 MPa) and deformations (maximum of less than 1 mm) apply on the assembly in this configuration.

9.5.2 Test of the real NEG Coating Lifting Assembly with simulate charges

Once the final virtual model and plans where approved and the lifting assembly was constructed and assembled, a test with simulate charges was made to assure the performance of the structure and contrast the results with the virtual model.

The two support points representing the rear wheels and the hook of the crane where simulated by three cylindrical supports. The weight of the TAN vacuum chamber was simulated by putting 8 lead blocks, of 11.5 Kg each, on the place of the twin beamtube clamping flange and 10 blocks on the place of the large end clamping flange. In addition 5 other blocks have been distributed along the assembly to represent the NEG coating tooling (extensions of the vacuum chamber):

Figure 9.17. Test of the Lifting Assembly with simulated charges

Two dial gauges were set up underneath the upper support plates, underneath the clamping flange loads to measure the deformation of the assembly:

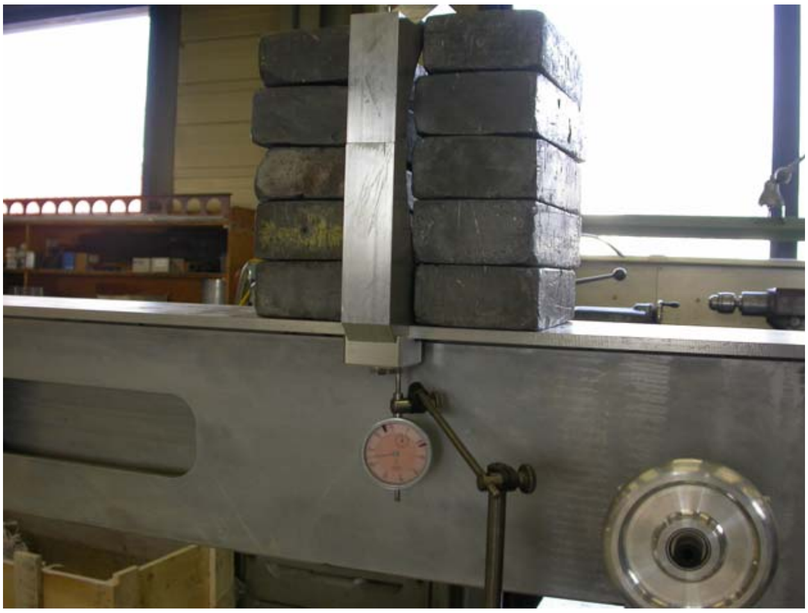


Figure 9.18. Dial gauge underneath the large end support

Figure 9.19. Dial Gauge underneath the beamtube support

Several tests have been performed (letting the assembly stretch between each one of them) obtaining deformations of:

$\delta_{\text{beamtube}} = 0.304 \times 10^{-2}$ m

$\delta_{\text{large end}} = 0.607 \times 10^{-2}$ m

Results that we can consider quite close to the ones obtained in the finite elements simulation.

9.5.3 Test of the real NEG Coating Lifting Assembly with the TAN Vacuum Chamber

Prior to the first real coating, one of the TAN vacuum chambers was brought to the NEG Coating hall for a final test with the real load.

For this final test, all the instructions regarding the secure lifting and handling of the chamber were followed. Two dial gauges were set up in the same spot of the simulated charges test:

Figure 9.20. Test of the Lifting Assembly with the TAN chamber

The same two dial gauges were set up underneath the upper support plates, underneath the clamping flange loads to measure the deformation of the assembly:

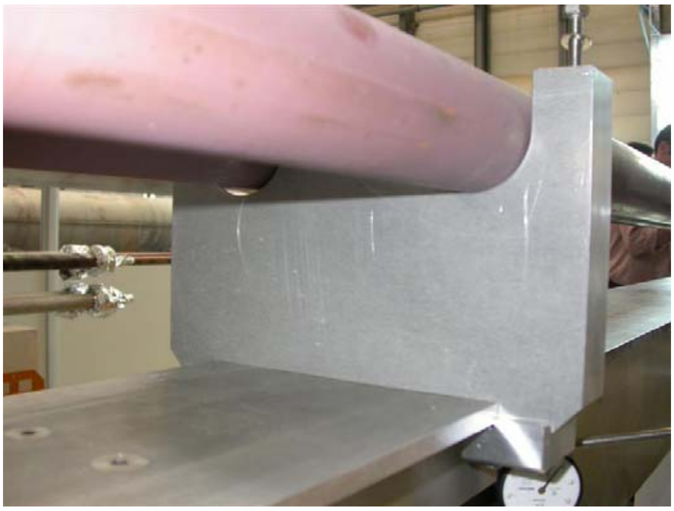


Figure 9.21. Dial gauge underneath the beamtube support

Figure 9.22. Dial gauge underneath the large end support

In this test we have obtained deformations of:

$\delta_{beamtube} = 0.360 \times 10^{-2}$ m

$\delta_{large\ end} = 0.620 \times 10^{-2}$ m

These results can also consider quite close to the ones obtained in the finite elements simulation and in the simulated charged test.

As it can be seen in the next pictures, the test was completed with the lifting of the chamber and the introduction of it into the magnetic solenoid. The test finished without any problem and was considered a success.

Figure 9.23. Lifting of the assembly with the crane

Figure 9.24. Lifting Assembly in vertical position

Figure 9.25. Introduction of the Assembly into the solenoid

Figure 9.26. Setting of the Lifting Assembly back to its inicial position

10 TANs Transport and Handling: From the Surface to the Underground Shafts

The 4 TANs will be installed in the Interaction regions IR1 and IR5. The parameters of these two regions are indicated below in Table 10.1 [25]

Parameter	Interaction Region IR1	Interaction Region IR5
Tunnel radius (mm)	2 200	1 900
Maximum TAN Available Width (mm)	1 150	1 150
TAN Width (mm)	1 100	1 100
TAN transverse Tunnel Position to Tunnel Centerline (mm)	- 350	- 350
TAN Height above Floor (mm)	1640	1490
Nominal Beam Height from Tunnel Floor (mm)	1100	950
Nominal Longitudinal Tunnel Floor Slope (%)	+ 1, 236	- 1, 236
Nominal Transverse Tunnel Floor Slope (%)	0, 0	0, 0
Longitudinal TAN Slope (%)	+ 1, 236	- 1, 236
Transverse TAN Slope (%)	+ 0, 73	- 0, 73

Table 10.1. Parameters of (RI13 & RI17 and R53 & R57 Tunnel Regions

The reduced dimensions of the LHC tunnel (RI13 & RI17 for IR1 and R53 & R57 for IR5) make impossible the assembly of the TANs at their installation point. Therefore the 4 TANs will have to be assembled on surface and then lowered and transported to the IRs. This situation introduces a new challenge due to the fact that the whole assembly (5 m long and 30 Tonne) can not be lowered down by all the access shafts making the tunnel transport longer and more complicated.

The nearest access shaft to the interaction region IR1 with a crane capable of lowering the TANs is the PX24. To get to IR5 the nearest access shaft is the PX64 (See Figure 10.1). From the bottom of the access shafts until the interaction regions IR1 and IR5 the assembled TANs will have to be transported on the underground.

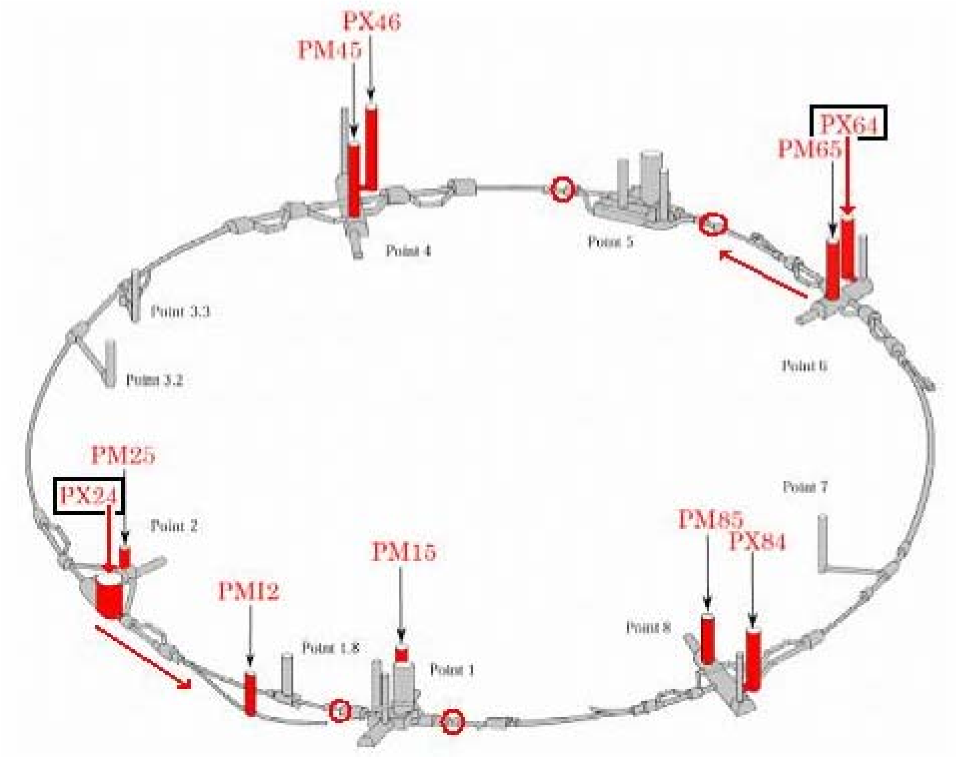


Figure 10.1. Access shafts used for lowering down the 4 TANs

The parameters of the cranes at PX24 and PX64 are listed below:

Location	Capacity (t)	Height Hook (m)	Lifting Height (m)	Hopper (m)		Speed (m/min)	
				Length	Width	High	Low
PX24	65	8,1	59	14	7,2	10	5
PX64	80	9,8	110	∅ 10,1		10	5

Table 10.2 . Overhead travelling cranes used to lower down the 4 TANs

During handling and transport, the four TAN Absorber crates will be subject to both shock and vibratory accelerations. The following requirements include appropriate factors of safety:

- Maximum vertical shock acceleration transmitted to the TAN crates: ± 25.0 g.
- Maximum horizontal shock acceleration transmitted to the TAN crates: ± 25.0 g.
- The specified limits are the net maximum allowable accelerations measured on the equipment during transport. The shipping crates must be isolated from the actual external shipping accelerations, which could be considerably higher.

In order to notice if the maximum vertical and horizontal accelerations are exceeded during transport shock clocks will be attached to each one of the assembled TANs.

11 The Underground Transport: From the Access Shaft to the Installation Point (The VTI)

Once the TANs are lowered down by the two access shafts PX24 and PX64 they will have to be transported to their installation position at the IR1 and IR5. The total underground transport distance for each of the TANs will be:

TAN No	Underground Start Location	Distance to IP1 (m)	Installation Location	Distance to IP1 (m)	Transport Distance (m)
1	PX24	3 309	RI13 (IR1)	-140	3 449
2	PX24	3 309	RI17 (IR1)	140	3 169
3	PX64	16 684	R53 (IR5)	13 189	3 495
4	PX64	16 684	R57 (IR5)	13 469	3 215

Table 11.1. Total Underground Transport Distance for each TAN

In order to bring every assembled TAN along the tunnel until its final position new equipment will be needed. This equipment for transportation of the TAN targets (hereinafter referred to as "VTI") will have to fulfill several specifications that will be detailed below.

11.1The VTI: a Vehicle for TANs Installation in the LHC Tunnel

11.1.1 General Description of the VTI main functions

The four targets TAN will be lowered down by CERN transport and handling team. On the base of the shaft, the VTI will be loaded with the TAN. The VTI will then be required to:

- **Transport each TAN from the base of the shaft to its final installation location.** The distance to be covered will be approximately 3.3 Km. Due to the space restrictions in the tunnel, the transport will be done in an uninterrupted process and in the shortest time possible in order to not interfere with other transports and works done in the tunnel (see Appendix C).

- **Transfer the TAN from the VTI onto the support jacks.** Either directly with the VTI by transversal moves, or lifting the TAN with hydraulic or mechanical mobile jacks, disposing the VTI in the perpendicular direction, and then transferring it on top of the support jacks (see Appendix C).
- **Be stored ready to be used in case of need of intervention in any of the four TANs during the LHC lifetime.**
- **Transport of each TAN from its location to the nearest shaft once their life time (around 25 years) is over.** The distance to be covered will be exactly the same as in the first transport. Since the TANs will be radioactive in the moment of its removal, the VTI should incorporate a remote control system.

Note that the VTI will be used rarely (10 to 15 times) and for long distances (≈3 Km).

11.1.2 Environmental conditions: the LEP Tunnel

The VTI will operate exclusively in the LEP tunnel and will not be exposed to outdoor conditions.

- Ambient temperatures in the LEP tunnel will be greater than 18°C.
- Rates of relative humidity are in the range 50% - 65%.

Therefore, the design of the VTI will not have to deal with extreme temperatures or wet environments.

Nevertheless, as it can not be guaranteed that the floor of the tunnel will be completely clean during the transport, the mechanism must include a protection against eventual metallic pieces and dust.

Figure 11.1. View of a section of the LHC tunnel at point 6

11.1.3 Distances, slopes and change of slope

The main LHC ring tunnel has a transverse cross section diameter of 3800 mm.

The LHC main ring tunnel is not horizontal. The tunnel lies on a plane inclined at **1.44%** to the horizontal with its low point in the area of Point 8 and high point in the area of Point 4.

There are some abrupt local changes of slope of maximum 1%, with the worst case for the total local slope of 2.39% near Point 6. Changes of slope are always a minimum of 15 m apart.

The VTI shall be capable of operating on a smooth wet concrete surface with a slope up to **2.5%** and **1%** in the longitudinal and the transversal direction of the tunnel respectively, as well as under all tunnel floor conditions including abrupt change of slope.

11.1.4 Floor characteristics

The tunnel floor is made of concrete and it is slightly cracked. Details of the concrete are given below:

- Maximum load/m^2: 200 kN.
- Maximum concentrated load: 10N/ mm^2.
- Maximum crack width: 8 mm.
- Maximum step height: 8 mm.
- Maximum local undulation amplitude: 10 mm (within one-meter range) and 20 mm (within five-meter range)

Even though the floor is mostly flat (≈ 95%) in the trajectory of the TAN, the vehicle must be able to pass through uneven parts like the ones shown at Figure 11.2.

Figure 11.2. Uneven part of the floor of the LHC tunnel at point 6

11.1.5 Power Supply

Power supply points, i.e. CE type wall outlets 400 V, 63 A, will be made available by CERN approximately every about 110 m along the tunnel. These plugs are protected using 300 mA differential circuit breakers. Only electricity cubicles, with a protection conforming to European norms (30 mA differential circuit breakers) can be plugged into these outlets.

11.2General design and operational requirements of the VTI

11.2.1 Standards

The VTI shall be built in conformity with CERN Safety Code D1. D1 calls for compliance with European Standards (see Appendix C for the applicable documents).

11.2.2 Dimension limits of the VTI

Once the accelerator components are already installed, the transport zone of the tunnel is really reduced. Therefore **the VTI shall not be wider than 1200 mm (all equipment included) and shall not be taller than 400 mm underneath the load.** Consider that the TAN height of the support plate + jacks is 380 mm and the vertical stroke of the jacks is ±20 mm. So in order to transfer and place the TAN onto the jacks, the TAN should go between 360 and 400 mm above the floor.

11.2.3 Motorisation

Vehicles with thermic engine are not allowed in the LHC machine tunnel. The experience of other installations in the LEP tunnel, and the availability of power supplies all along the tunnel make of the electrical motorisation the best choice. In this case the vehicle supply could be considered with battery, cable or both.

The VTI could be one single motorised unit, a combination of tractor–trailer or two single motorised units (with one capable to maneuver and change directions).

11.2.4 Protection devices

The VTI shall be equipped with overload protection devices, to prevent damage to the equipment in the event of any movement or drive being stalled due to overload or obstruction.

Motors and drives shall not overheat when used for extensive periods. Note that the VTI will have to cover a distance of over 3 Km non stop. Therefore oil cooling system should be considered to avoid overheating of the motor.

11.2.5 Mass of the VTI

In order to allow handling and transport of the VTI in the LHC tunnel the mass of it shall be limited to a maximum of 2 Tonne.

11.2.6 Operating speed of the VTI

The minimum speed of the VTI loaded with the TAN shall be 3 m/ min.

11.2.7 Noise

The noise level generated by the VTI shall be less than 65 dB(A) at 1 m/s.

11.2.8 Protection against corrosion

Paint finishes shall be applied to prevent corrosion for the lifetime of the VTI, paint shall be smooth and well attached and mechanically strong to allow cleaning. Surfaces that are bolted together shall be painted or otherwise protected before assembly. Two-component paint shall be used. For the unpainted parts, a surface treatment shall be applied.

11.2.9 Maintainability

The VTI design shall be such as to require a minimum of special tools, test equipment, etc. to perform calibration, adjustment, fault identification and repair.

The VTI design shall ensure that oil does not drip onto the area below the VTI.

Periodic maintenance requirements during storage shall be minimised.

11.2.10 Life time

The VTI design life shall be 25 years. The designs shall be based on lifetime calculations considering the main functions exposed in section 11.1.1.

11.3Electrical Design

11.3.1 Making of electrical components

All the operating components, like push-buttons, selectors, pilot lamps, end stops, distributors, etc. and their connections shall be marked in a durable manner.

11.4Breakdown recovery

Due to the reduced space in the tunnel and the parallel operations of transport of magnets, a VTI failure would be critical. For this reason the following requirements shall apply in order to reduce the time taken to recover from a breakdown.

- The VTI maintainability manual shall include a breakdown diagnosis chapter that permits to identify the root cause of any breakdown.
- The VTI design shall allow repair by replacement of faulty components.

11.5Summary of the technical requirements of the VIT

Therefore the VTI will have to achieve the following main specifications:

- Have a loading capacity of **350 kN**.
- Not be wider than 1200 mm. and not be taller than 400 mm. underneath the load.
- Be capable to operate loaded for 3.3 Km on an uninterrupted way.
- Be capable to stop, start and break when loaded on both ways in slopes up to 2.5% and to go on uneven floors.
- Be capable to manoeuvre to avoid eventual obstacles.
- Be capable to transfer the load onto the support jacks (by itself or with any other equipment.
- Have a system to centre and secure the load from turning over and sliding.
- Incorporate a remote control system.
- Incorporate a safety blockade system in case of absence of personnel.

The Standards and Documents applicable for the design and fabrication of the VTI as well as Sketches of a possible transfer onto the support jacks are enclosed in the Appendix C.

Conclusions

This project has described the procedures in order to successfully install the 4 Neutral Beam Absorbers in the LHC Machine according to the Detailed Installation Planning.

- The final position of the TAN´s jacks has been chosen to comply with CERN safety standards of Seismic Stability, and to let enough space for the VTI on the final transfer of the TAN.

- The lifting and handling instructions for the Vacuum Chambers have been defined to ensure that any of the critical areas of the chambers are not overstressed during maneuvering with the cranes. Several tests have been performed following these instructions and they have been a success.

- The new NEG Coating Lifting Assembly has been designed to allow the safe vacuum treatment of each one of the TANs vacuum chambers.

  This lifting assembly has been designed to be compatible with the already existing elements used for the standard coatings and with other possible types of chambers. It has been virtually simulated with Ansys, tested with simulated charges and with the real vacuum chambers obtaining acceptable results of stresses and deformation.

  Up to date (May 2005), already two chambers have been NEG coated successfully.

- The definition of the logistic activities to be followed in order to safely lower the 4 TANs down to the tunnel and transport them to their final position has been approved by the CERN and introduced in the Detailed Installation Planning.

- The Technical Specification describing the needs for the safe underground transport of the TAN´s (weighting 30 Tones each) from the access shaft to the final installation positions has also been approved by CERN.

  Up to date, a firm is developing a vehicle strictly following the Technical Specification and with the close supervision of CERN.

Work to be done

Actually (may 2005) the project of TANs installation is in the vacuum treatment phase. Two chambers have already been coated and the previous phases have been successfully completed.

Once the Vehicle for TAN´s Installation (VTI) is already at CERN, tests will have to be developed to ensure the safe transportation of the TANs in the underground tunnel. It will be also necessary to determine the exact amount of time and human resources needed for this underground transportation in order to write a Work Package and ensure the compatibility of all the possible activities in the same zones of the tunnel.

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